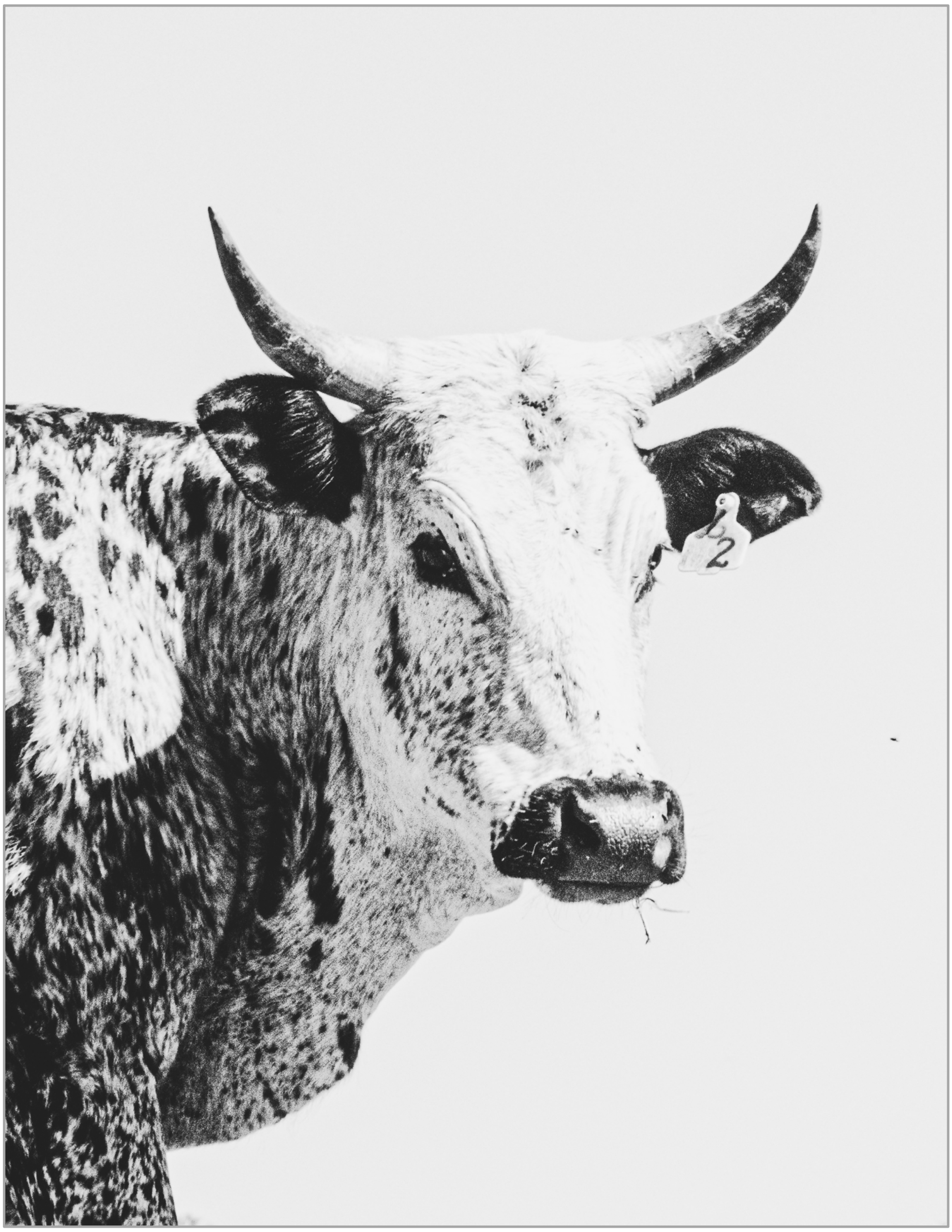
Thinking differently about clinical skills training:

The bovine pregnancy diagnosis via transrectal palpation showcase



Annett Annandale

Thinking differently about clinical skills training: *The bovine pregnancy diagnosis via transrectal palpation showcase*

Annett Annandale, 2020

Thesis – Universiteit Utrecht

ISBN: 978-94-640-2361-9

Thinking differently about clinical skills training:

The bovine pregnancy diagnosis via transrectal palpation showcase

Anders denken over het trainen van klinische vaardigheden:

Drachtigheidsdiagnostiek door middel van rectale palpatie bij runderen als voorbeeld

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Utrecht
op gezag van de rector magnificus, prof. dr. Henk Kummeling,
ingevolge het besluit van het college voor promoties in het openbaar te verdedigen
op maandag 6 juli 2020 in des avonds te 6.00 uur

door

Annett Annandale

geboren op 30 april 1980
te Beckendorf-Neindorf, Duitsland

Promotor: Prof WDJ Kremer

Copromotoren: Dr HGJ Bok

Prof DE Holm

To Henry,

Finn and Oliver

"Education is for improving the lives of others and for leaving your community and world better than you found it." Marian Wright Edelman

Contents

Chapter 1
Introduction

Introduction

Veterinary education has changed over the past years with a worldwide shift from mainly knowledge-based to competency-based veterinary courses,[1-8] and follows a similar trend seen in medical education.[9, 10] Veterinary teaching institutions are required to produce highly skilled entry-level graduates with advanced skills,[11, 12] while maintaining accreditation requirements and aligning veterinary programs with priorities at national levels.[3, 4, 11, 13, 14] Increased expectations of what veterinary graduates should be capable of achieving does not only include theoretical knowledge and professional attitudes but also acquisition of clinical skills.[1, 2, 3, 4, 11] The emphasis on clinical hands-on skills is highlighted by Day One Competency and Year One Skills lists published by veterinary governing bodies. Traditionally, clinical skills training was based on an apprenticeship model which had first been described in medical education by Halsted over 100 years ago.[15, 16] Apprenticeship learning is a common characteristic of training programs for complex professional skills,[17] and involves the 'see one, do one' approach under expert supervision.[18] In addition to clerkships where medical and veterinary medical students spend considerable time in clinical rotations, group training methods and training by procedure-oriented or skills-oriented methods have been described.[19-21] Historically, surgical skills training was accomplished through live animal, cadaver and terminal surgeries.[20-23] More recently, skills acquisition opportunities are limited by welfare and ethical concerns around the use of live animals for training purposes, large student cohort sizes, budget constraints and difficulty sourcing cadaver materials.[6, 11, 24-34] Apart from these challenges, gaps between traditional approaches to training and the demands of teaching and learning in the modern workplace have been identified,[11] and include the unpredictable variability in workload, inconsistent longitudinal exposure to a given trainee and time constraints of clinicians.[35] Striving towards a humane veterinary education is not a new notion. The concept of the '3 Rs': Replacement, Refinement and Reduction was first published by Russel and Burch in 1959 and related to animal use in fundamental and applied research.[36] It has since become an accepted ethical principle applied to animal-based science including veterinary research and education.[19, 22, 37, 38] The drive towards competency based and strongly skills oriented veterinary education while meeting societal demands towards high ethical standards led to the development of veterinary simulators, models and skills laboratories.[11, 24-26, 28] Skills laboratories provide a safe and lower stress environment where clinical skills and student-centered learning can be fostered without harming animals, and repeated practice opportunities can be provided.[11, 24-26, 28, 39, 40] A wide range of small and large animal veterinary simulators and models of varying fidelity levels have been developed and implemented into veterinary training programs.[20-23, 41-46]

Bovine transrectal palpation and pregnancy diagnosis

Bovine pregnancy diagnosis (PD) by transrectal palpation (TRP) is widely used in veterinary practice and is of economic importance.[47-56] It is also one of the most frequently performed procedures in bovine practice,[57] and therefore an important competency for veterinary graduates.[58]

Bovine PD via TRP is performed according to a well-defined method.[59-61] In brief, palpation of the female reproductive tract is done through the rectal wall in order to determine positive and supportive signs of pregnancy as well as gestational age. Pregnancy diagnosis via TRP has first been described in the early 1800s and is the oldest described direct method for bovine PD.[51, 59, 62] Depending on skill level of the examiner PD via TRP can be done reliably from as early as day 30 to 35 of pregnancy and thereafter until term.[59, 63-66] Rectal palpation can detect the positive signs as well as supporting signs of pregnancy. The four positive palpable signs of pregnancy are fetal membrane slip, amniotic vesicle which had first been described by Wisnicky and Cassidy in 1948, placentomes and fetus.[51, 59-61, 63, 64] Supporting signs of pregnancy suggest a pregnancy but can have other causes.[59] These supporting signs are asymmetry of the uterine horns, resilience and fluctuance of the uterine wall, fixation of the cervix, ovarian changes (‘Corpus luteum of pregnancy’) and hypertrophy of the middle uterine artery (‘Fremitus’).[60, 67] While other indirect methods to determine pregnancy status and reproductive ultrasonography have become established methods to perform bovine PDs,[51, 59, 60, 66, 68-72] TRP is still seen as a skill of utmost importance and a prerequisite to optimal ultrasonography use.[52, 56, 60]

Bovine transrectal palpation and pregnancy diagnosis training

Bovine TRP and PD training is challenging since it requires extensive exposure to TRP in live cows to ensure competency.[41, 73-75] Conventionally, bovine TRP and PD training at our institution consisted of theory lectures on reproductive anatomy and physiology, the bovine oestrous cycle and bovine pregnancy. It was followed by hands-on practical sessions for reproductive tract abattoir organ inspection and palpation, non-pregnant live cow palpations and PD via TRP on live cows at a University farm. Students would palpate one to two live cows in the first non-pregnant live cow palpation session and between 5-10 cows during the PD training session on the farm. The same approach of abattoir organ exposure followed by live cow palpations has been described for other training institutions.[76] Further training strategies include the use of cows at abattoirs prior to slaughter,[75] student exposure to bovine TRP and PD during Extramural Studies (EMS),[41, 77] or during ambulatory clinic rotations.[75] Disadvantages of EMS palpation experience mentioned were potentially minimal preparatory training and difficulties to ensure equal palpation exposure for all students.[77] While there are not many publications available evaluating students' TRP and PD performance after training and how many palpations are actually required to ensure competence,[73-75] veterinarians often refer to the anecdotal 'magic 10000', the number of rectal palpations assumed to be necessary to ensure palpation competence. The origin of this number is unknown but indicates the perceived amount of practice necessary to confidently perform bovine PDs. It is possible that it is a link to Ericsson's concept of deliberate practice where a practice time of at least 10000 hours is stipulated to lead to expert status in a specific skill.[78] Looking at students' TRP skills it had been reported that 200 live cow palpations were insufficient to establish TRP competence.[73] The Australian Veterinary Association previously recommended that a minimum of 2000 cows should be palpated before an individual is considered eligible to take their competency examination.[76, 79] Limited resources, increasing student numbers, availability of teaching animals and welfare issues reduce training opportunities on live animals in general,[24] and thus influence PD training for veterinary students at teaching institutions.[41, 73-75, 77] Furthermore, it seems difficult for students to get additional bovine PD and TRP exposure outside the veterinary course.[75] Compared to many other skills TRP and PD training is further complicated due to the nature of the procedure whereby demonstration of the technique by an instructor and observation of a trainee palpating a live cow is not possible as execution of the procedure cannot be seen.[41, 73, 76, 77]

George described a 'Simple Five-Step Method for Teaching Clinical Skills' which aims at optimising psychomotor skills teaching in an organised way leading to a satisfactory learning experience for the student.[80] Step 1 of this method is called 'overview' which leads to conceptualisation and motivation to learn the skill. It entails the cognitive apprehension of the skill, why and when it is done, and which equipment is needed. Step 2 is a silent demonstration of the skill by the instructor to help the trainee visualise the procedure in its entirety. During step 3 the instructor repeats the demonstration while explaining the procedure in detail. Step 4 is verbalisation of the procedure by the trainee who explains all steps to demonstrate understanding of the skill before performing it. The trainee then practices the skill under supervision and with feedback of the instructor in step 5. Once the trainee is able to perform the procedure continuous practice is advised until the required level of competence is achieved.[80] This method places great emphasis on feedback, repetition and positive reinforcement and is supported by publications in human and veterinary medical education.[25, 26, 28, 46, 81, 82] It is also in line with the concept of deliberate practice where continuous constructive feedback in conjunction with repetitive performance of skills lead to continuous skills improvement.[78] Applying this 5 step method to bovine TRP and PD is impaired by the fact that steps 2, 3 and 5 cannot be followed during live animal palpations. Finding ways to overcome this difficulty could prove beneficial to student TRP and PD training.

In an attempt to overcome some of the TRP and PD training restrictions investigations into the use of a Computer Assisted Learning (CAL) tool,[76] the use of slaughterhouse animals,[75] and the effect of assigning or choosing cows on training outcome have been done.[74] Norman *et al*. found that while implementation of the TRP CAL tool did not result in a reduction of live cow palpations needed it led to more efficient animal use due to better prepared students. It was concluded that the CAL tool has the potential to support and enhance student learning.[76] Lopes *et al*. reported that the use of slaughterhouse animals for TRP classes is an appropriate method to overcome a shortage of palpation opportunities at teaching institutions.[75] French *et al*. compared student improvement in TRP skills when assigned to the same cows for palpations versus choosing cows at random. While it was hypothesised that students assigned the same cow would be more accurate at palpation, it was shown that this was not the case. However, it was concluded that having students identify specific reproductive landmarks such as the cervix and uterine horns with quantitative size measurements and choosing cows that are easy to handle have a positive effect on student training.[74] A variety of rectal examination simulators are commercially available. Fibre glass cow backends with silicone reproductive organs are represented by the Veterinary Simulator Industries' bovine theriogenology model (https://vetsimulators.com/, Calgary, Canada) and by Minitube's 'Henryetta' model (https://www.minitube.com/, Tiefenbach, Germany). The Breed'n Betsy® rectal examination simulators (http://www.breednbetsy.com.au/, Victoria, Australia) are models consisting of a steel frame with silicone artificial cow perineum at the height similar to that of a cow and an artificial pelvis. A latex artificial rectum and female reproductive organs are attached to the frame with spring-loaded clamps for easy removal and replacement (Figure 1).[73] These three rectal examination simulators allow trainees to palpate silicone reproductive tracts resembling non-pregnant and pregnant cows at different stages of pregnancy, and ovaries with a variety of structures. Trainees can go through the entire procedure and movements of bovine TRP while the instructor can visualise what the trainee is doing and give feedback. While a pneumorectum can be mimicked to an extent, the absence of rectal peristalsis, anal sphincter tone, and other internal organs such as a bladder and rumen make locating of the reproductive tract easier than in the live animal and the simulator experience may not impart the real feeling of palpating a live cow.[75] In addition to these medium fidelity models, the Haptic Cow (Virtalis Ltd, Cheshire, UK, https://www.virtalis.com/haptic-cow/) is a high fidelity computer based teaching tool that was developed using haptic technology.[77] A fibreglass model of the rear half of a cow houses the PHANToM haptic device (SensAble Technologies, Massie and Salisbury 1994). A user interacts with the device by placing his or her finger in a thimble at the end of a mechanical arm. The device then allows a user to move freely in a three-dimensional environment (Figure 1). The PHANToM produces forces to restrict the user's motion creating the illusion of a physical object.[41, 77] The student receives touch feedback from the haptic device while palpating virtual objects resembling a variety of physiological and pathological reproductive conditions as well as pregnancy stages. The instructor can visualize the student's actions on a screen and give training and guidance.[41, 77] Costs associated with the acquisition of rectal examination simulators is a significant financial investment regardless of simulator type and numbers of simulators needed to ensure efficient practical training sessions for trainees and instructors. Other factors influencing the type of simulator to be purchased are labour, time and cost constraints affecting simulator set up, maintenance and repair which would be more intense for some of the simulators compared to others. While fairly independent trainee practice is possible for medium fidelity models, the Haptic Cow invariably requires an instructor and only enables small group teaching. However, despite some limitations, implementation of bovine rectal examination simulators into veterinary teaching programmes, offers remarkable additional training opportunities to live cow training, and may help reduce the requirement of live animal training. Several studies have evaluated rectal examination simulators,[41, 42, 73, 83-85] and concluded that training on simulators was superior to theoretical instruction only for locating the uterus and cervix,[84] while additional simulator training after live cow palpations significantly improved students' performance.[41] Bossaert *et al*., using the Breed'n Betsy® (BB) simulator and live cows, showed students trained on live cows were more skilled evaluating the uterus and ovaries in non-pregnant cows while there was no difference between the two training groups in recognizing pregnant cows by TRP.[73] Live cow training in conjunction with simulator training was advised to optimise learning outcomes.[41, 73, 84]

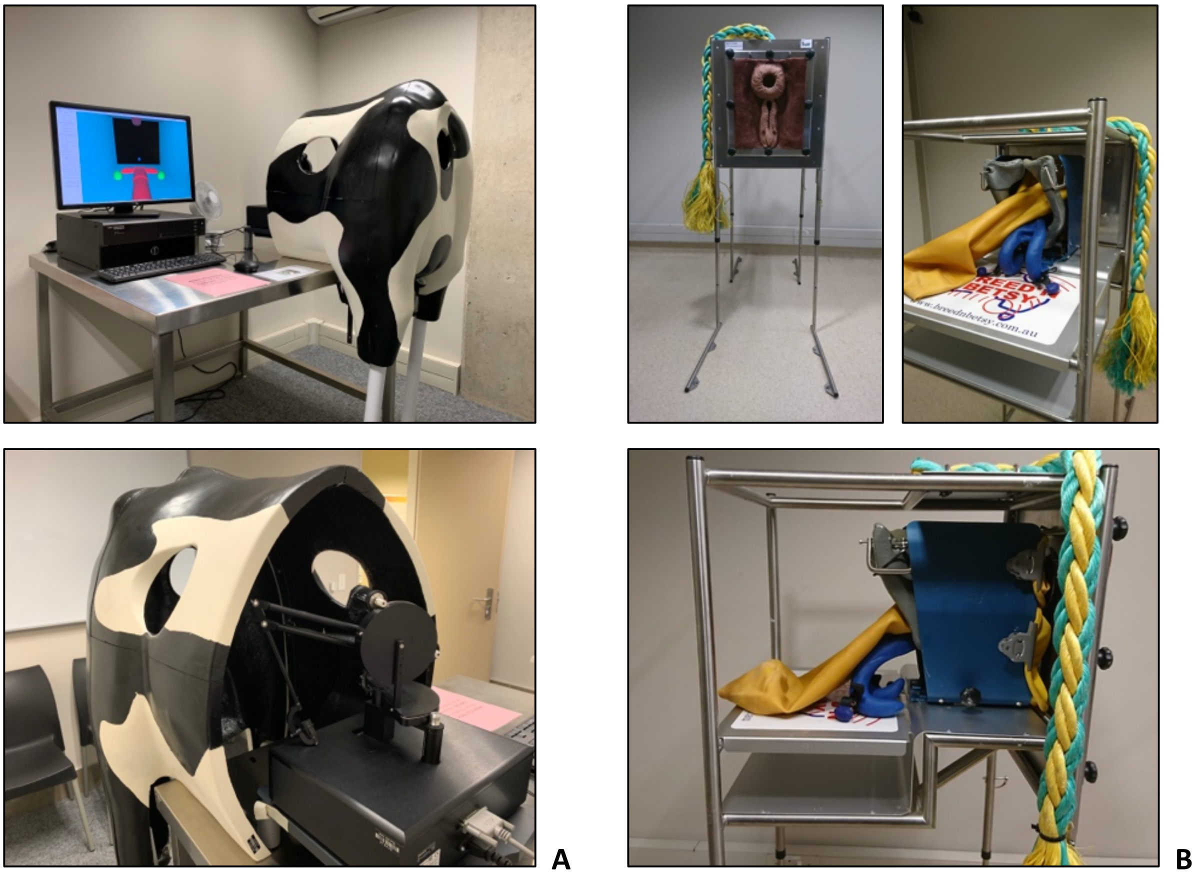


Figure 1 Rectal examination simulator set-up for the Haptic Cow (A) and Breed'n Betsy® (B)

Summary of problem definitions and research questions

The overall aim of this project is to investigate alternative and improved undergraduate veterinary training methods for bovine TRP and PD skills. The study aims at identifying approaches and teaching interventions that lead to optimised live animal training opportunities and that might decrease the number of palpations needed to become competent or in other words to 'fast-track' the TRP skill learning process. The data gathered will be used to develop and implement research-based innovative teaching ideas, including optimised simulator training, in-training assessment methods, additional training opportunities linked to or not directly linked to the TRP skill itself, the use of technology to improve skills training and added benefits achieved by some of these innovations. It will be demonstrated how training innovations can be combined with traditional training. The investigations into bovine PD via TRP skills will be an example for clinical skills training in general. It is hoped that thinking differently about clinical skills training for bovine TRP and PD might lead to an alternative approach to traditional skills training in general that has the potential to overcome some of the training constraints at teaching institutions.

While bovine TRP and PD student training has been identified as challenging,[41, 73-76] there is limited research available on student performance in bovine TRP and PD. Studies involved small student cohorts, and TRP skills evaluation was based on different assessment criteria for each study.[73-75] Management thinker Peter Drucker is often quoted as saying that 'If *You Can't Measure* It, *You Can't* Improve It'. It means that *you can't* know whether or not *you* are successful unless success *is* defined and tracked. Applied to this PhD study it is necessary to be able to measure training outcomes for TRP and PD to evaluate the success of training interventions. This leads to the first research question:

> *How can students' TRP and PD skills be reliably assessed and what is students' TRP and PD accuracy after training?*

These questions will be answered in Chapter 2 and 3 of the dissertation.

Secondly, recent developments in student training within veterinary education have shown that simulator training is an alternative approach to live animal training.[11, 24, 25, 28] While simulations are increasingly attractive as a parallel to clinical experience, it is crucially important that simulations be validated to meet the expected training outcomes.[6] Several studies evaluated the use and implementation of rectal examination simulators in veterinary training programs.[41, 42, 73, 83-85] There are however, no large scale rectal examination simulator studies validating the effectiveness of simulator training compared to live animal training which leads to the second research question:

Is rectal examination simulator training as good as live cow training, and could this be an effective approach to compensate for a shortage of live animal training opportunities?

This question will be addressed in Chapter 2.

Thirdly, some studies have evaluated the effect of upbringing location, gender and previous pet ownership on career choice of veterinary students.[86-90] Two of the key demographics shown to be positively correlated to a career in mixed or food animal practice are an upbringing in a small centre or rural area and being male.[86, 88, 89] Experience working on a farm,[89] and other agricultural exposure was positively associated with a preference for food animal employment.[90] It is hypothesised that some of the factors that have been shown to have an influence on career choice, might also influence students' performance in bovine PD. The authors are not aware of publications linking factors that influence an interest in mixed or food animal practice to core skills like bovine PD via TRP. There is furthermore no data available regarding 'Learner Trait Ability' for bovine TRP and PD skills. 'Learner Trait Ability' is defined as an inability to perform a task due to lack of strength, fine motor skills or fine motor coordination,[80] and an investigation into possible factors that are physically necessary to perform the skill might help to develop an optimised training approach. This leads to the third research question:

Are there specific predictors and student level variables that affect students' TRP and PD skills? And if so, can these predictors and student level variables be used to adjust training approaches or implement new teaching innovations to improve TRP and PD training?

These predictors and student level variables will be looked at in Chapters 2, 4 and 5.

Investigations into surgical skills training have shown that a part-task or skills-oriented training approach initially focusing on fundamental surgical skills such as tissue, instrument and suture handling, different suture patterns, ligation techniques and haemostasis before advancing to whole-task training such as performing ovariohysterectomies (OVHs), is recommended and results in better training outcomes compared to procedure-oriented training.[19, 23, 46, 91] Part-task training prior to whole-task training allows trainees to combine all the psychomotor skills with the procedural and theoretical knowledge necessary to successfully perform an entire procedure, such as an OVH. Student training using the skills-oriented approach furthermore resulted in greater student competence when handling other surgical procedures they had never been exposed to as compared to students trained using the procedure-oriented OVH approach.[91] The assumption that bovine TRP and PD training can be broken down into part-tasks, predictors and student level variables to find a skills-oriented training approach, leads to the final research question:

How can the findings of Chapters 2-5 be used to develop a skills-oriented training program that combines training innovations with traditional training to optimise bovine TRP and PD training outcomes?

This will be discussed in Chapters 6 and 7.

Thesis outline

In order to be able to evaluate training interventions, training outcomes have to be reliably measured. Therefore, in Chapter 2 we report on a study describing an approach to measure students' PD accuracy on live cows, while Chapter 3 describes a TRP Objective Structured Clinical Examination (OSCE) which is tested for validity and reliability. The study described in Chapter 3 further evaluated if students' TRP OSCE scores are predictors for students' future PD accuracy. The same study also resulted in the development of the 'Mini Cow Palpation Box'. The study described in Chapter 2 additionally evaluated the effectiveness of rectal simulator training compared to live animal training, and furthermore investigated factors influencing students' PD accuracy. The TRP and PD assessment methods described in Chapters 2 and 3 were further implemented and validated in the studies described in Chapters 4 and 6. Chapter 4 reports on a study based on the unusual physical activity involved in bovine TRPs and the 'Learner Trait Ability' hypothesis and investigated the effects of arm muscle strength, grip strength, proprioception and an exercise programme on students' PD accuracy. Results from this study led to the investigation presented in Chapter 5 where an EMG study took the results of the previous study a step further and led to the development of the 'Bovine PD Improvement Exercise Program'. Chapter 6 describes a study based on the findings of the studies outlined in Chapters 2, 3 and 4, and investigates the effect of a one-week intense training programme on final-year veterinary students' PD accuracy. Chapter 7 discusses the results described in the previous chapters, highlights the teaching innovations and strategies that originated from the studies and provided a comparison with the literature. In addition to reflecting on the implications for a new approach to teaching bovine TRP and PD skills, we conclude by describing strengths and limitations, and implications for further research based on this thesis. Because all studies have been published separately in peer-reviewed, international journals, there is inevitably some repetition across chapters.

Research context

The studies described in this thesis were conducted at the Faculty of Veterinary Science, University of Pretoria in South Africa. The University of Pretoria's six-year Bachelor of Veterinary Science (BVSc) programme includes nine semesters of didactic pre-clinical training and three semesters of clinical work-integrated learning during the last 18 months of study. At the time we conducted our studies (2014-2018), availability of student cohorts from seventh to 12th semester provided us with opportunities to investigate teaching strategies with students in their didactic pre-clinical training as well as students in their clinical work-integrated training. Being able to evaluate fourth-, fifth- and final-year student cohorts enabled us to not only investigate different teaching approaches but also to optimise time frames as to when teaching innovations and interventions are best executed. We were very fortunate having been able to collaborate with physiotherapists, biokineticists, Information Technology (IT) staff, and the University of Pretoria's MakerSpace.

References

1. Bok HGJ, Jaarsma DADC, Teunissen PW, Van der Vleuten CPM, Van Beukelen P. Development and validation of a competency framework for veterinarians. *Journal of Veterinary Medical Education* 38(3):262-9, 2011.
2. Bok HGJ, Teunissen PW, Boerboom TBB, Rhind SM, Baillie S, Tegzes J, Annandale H, Matthew S, Torgersen A, Hecker KG, Härdi-Landerer CM, Gomez-Lucia E, Ahmad B, Muijtjens AMM, Jaarsma DADC, Van der Vleuten CPM, Van Beukelen P. International survey of veterinarians to assess the importance of competencies in professional practice and education. *Journal of the American Veterinary Medical Association* 245(8):906-13, 2014.
3. May SA, Silva-Fletcher A. Scaffolded active learning: Nine Pedagogical Principles for Building a Modern Veterinary curriculum. *Journal of Veterinary Medical Education* 42(4):332-9, 2015.
4. Read EK, Hecker KG. The development and delivery of a systematic veterinary clinical skills education program at the University of Calgary. *Journal of Veterinary Science and Technology* (Special issue), 2013.
5. Sabin EA, DeHaven WR. Veterinary education: a basis for good governance leading to effective veterinary services. *Revue scientifique et technique* (International Office of Epizootics) 31(2):519-31, 2012.
6. Kneebone R, Baillie S. Contextualized simulation and procedural skills: a view from medical education. *Journal of Veterinary Medical Education* 35(4):595-8, 2008.
7. Kelly A, Heider LE, Prasse KW. Renewed directions in veterinary medical education. *Journal of the American Veterinary Medical Association* 222(11):1511-2, 2003.
8. Prasse KW, Heider LE, Maccabe AT. Perspectives in professional education - Envisioning the future of veterinary medicine: the imperative for change in veterinary medical education. *Journal of the American Veterinary Medical Association* 231(9):1340-2, 2007.
9. Carraccio C, Wolfsthal SD, Englander R, Ferentz K, Martin C. Shifting paradigms: from Flexner to competencies. *Academic medicine: journal of the Association of American Medical Colleges* 77(5):361-7, 2002.
10. Carraccio C, Englander R, Van Melle E, Ten Cate O, Lockyer J, Chan MK, Frank JR, Snell LS. Advancing Competency-Based Medical Education: A Charter for Clinician-Educators. *Academic medicine: Journal of the Association of American Medical Colleges* 91(5):645-9, 2016.
11. Dilly M, Read EK, Baillie S. A Survey of Established Veterinary Clinical Skills Laboratories from Europe and North America: Present Practices and Recent Developments. *Journal of Veterinary Medical Education* 44(4):580-9, 2017.
12. Malone E. Challenges and issues: Evidence-based clinical skills teaching and learning: What Do We Really Know? *Journal of Veterinary Medical Education* 46(3):379-98, 2019.
13. Kreisler RE, Stackhouse NL, Graves TK. Arizona veterinarians' perceptions of and consensus regarding skills, knowledge, and attributes of day one veterinary graduates. *Journal of Veterinary Medical Education* 1-13, 2019.
14. Irons PC, Holm DE, Annandale CH. Curricular renewal at the southern tip of Africa: the 2016 veterinary curriculum at the University of Pretoria. *Journal of Veterinary Medical Education* 44(3):440-9, 2017.
15. Baillie S, N B, A C, N C, E C, Dilly M, Farrell R, R L, M OR, Read E. *A guide to veterinary clinical skills laboratories* 2015.
16. Halsted WS. The training of the surgeon. *JAMA Bulletin of the Johns Hopkins Hospital* XLIII(21):1553-4, 1904.

17. Van der Hem-Stokroos HH, Scherpbier AJ, Van der Vleuten CP, De Vries H, Haarman HJ. How effective is a clerkship as a learning environment? *Medical Teacher* 23(6):599-604, 2001.

18. Herrmann-Werner A, Nikendei C, Keifenheim K, Bosse HM, Lund F, Wagner R, Celebi N, Zipfel S, Weyrich P. 'Best practice' skills lab training vs. a 'see one, do one' approach in undergraduate medical education: an RCT on students' long-term ability to perform procedural clinical skills. *PLoS One* 8(9):e76354, 2013.

19. Smeak DD. Teaching surgery to the veterinary novice: the Ohio State University experience. *Journal of Veterinary Medical Education* 34(5):620-7, 2007.

20. Greenfield CL, Johnson AL, Schaeffer DJ, Hungerford LL. Comparison of surgical skills of veterinary students trained using models or live animals. *Journal of the American Veterinary Medical Association* 206(12):1840-5, 1995.

21. Griffon DJ, Cronin P, Kirby B, Cottrell DF. Evaluation of a hemostasis model for teaching ovariohysterectomy in veterinary surgery. *Veterinary Surgery* 29(4):309-16, 2000.

22. Holmberg DL, Cockshutt JR, Basher AWP. Use of a dog abdominal surrogate for teaching surgery. *Journal of Veterinary Medical Education* 20(2):61-2, 1993.

23. Gopinath D, McGreevy PD, Zuber RM, Klupiec C, Baguley J, Barrs VR. Developments in undergraduate teaching of small-animal soft-tissue surgical skills at the University of Sydney. *Journal of Veterinary Medical Education* 39(1):21-9, 2012.

24. Baillie S. Utilisation of simulators in veterinary training. *Cattle Practice* 15(3):224-8, 2007.

25. Kustritz MVR. Simulations in veterinary education. *Clinical Theriogenology* 6(4):607-10, 2014.

26. Scalese RJ, Issenberg SB. Effective use of simulations for the teaching and acquisition of veterinary professional and clinical skills. *Journal of Veterinary Medical Education* 32(4):461-7, 2005.

27. Iki Y, Ito T, Kudo K, Noda M, Kanehira M, Sueta T, Miyoshi I, Kagaya Y, Okada Y, Unno M. Animal ethics and welfare education in wet-lab training can foster residents' ethical values toward life. *Experimental Animals* 66(4):313-20, 2017.

28. Valliyate M, Robinson NG, Goodman JR. Current concepts in simulation and other alternatives for veterinary education: a review. *Veterinarni Medicina* 57(7):325-37, 2012.

29. Kneebone R, ApSimon D. Surgical skills training: simulation and multimedia combined. *Medical Education* 35:909-15, 2001.

30. De Boo J, Knight A. 'Concepts in Animal Welfare': A Syllabus in Animal Welfare Science and Ethics for Veterinary Schools. *Journal of Veterinary Medical Education* 32(4):451-3, 2005.

31. Weichbrod RH, Thompson GA, Norton JN. Management of animal care and use programs in research, education, and testing 2017.

32. Martinsen S, Jukes N. Towards a humane veterinary education. *Journal of Veterinary Medical Education* 32(4):454-60, 2005.

33. Wood MW, Hart LA, Weng H-Y. Effective bibliographic searching for animal alternatives in veterinary medical education: The UC Davis Web Site. *Journal of Veterinary Medical Education* 32(4):468-72, 2005.

34. Pereira GdG, Dieguez FJ, Demirbas YS, Menache A. Alternatives to animal use in veterinary education: a growing debate. *Ankara Universitesi Veteriner Fakultesi Dergisi* 64(3):235-9, 2017.

35. Bandiera G, Lee S, Tiberius R. Creating effective learning in today's emergency departments: how accomplished teachers get it done. *Annals of emergency medicine* 45(3):253-61, 2005.

36. Russell WMS, Burch RL. The principles of humane experimental technique: London: Methuen & Co. Ltd.; 1959.

37. Freeman LJ, Huse D, Lee R, Inoue T, Weil AB, Constable PD. Teaching veterinary anesthesia and surgery: the impact of instructor availability on anesthesia, operative, and recovery times in dogs undergoing ovariohysterectomy or castration. *Journal of Veterinary Medical Education* 41(4):390-9, 2014.

38. Campbell RD, Hecker KG, Biau DJ, Pang DSJ. Student Attainment of Proficiency in a Clinical Skill: The Assessment of Individual Learning Curves. *Plos One* 9(2):e88526, 2014.

39. Langebaek R, Eika B, Jensen AL, Tanggaard L, Toft N, Berendt M. Anxiety in veterinary surgical students: a quantitative study. *Journal of Veterinary Medical Education* 39(4):331-40, 2012.

40. Langebaek R, Eika B, Tanggaard L, Jensen AL, Berendt M. Emotions in veterinary surgical students: a qualitative study. *Journal of Veterinary Medical Education* 39(4):312-21, 2012.

41. Baillie S, Crossan A, Brewster S, Mellor D, Reid S. Validation of a bovine rectal palpation simulator for training veterinary students. *Studies in Health Technology and Informatics* 111:33-6, 2005.

42. Baillie S, Mellor DJ, Brewster SA, Reid SWJ. Integrating a bovine rectal palpation simulator into an undergraduate veterinary curriculum. *Journal of Veterinary Medical Education* 32:79-85, 2005.

43. Langebaek R, Toft N, Eriksen T. The SimSpay-student perceptions of a low-cost build-it-yourself model for novice training of surgical skills in canine ovariohysterectomy. *Journal of Veterinary Medical Education* 42(2):166-71, 2015.

44. Read EK, Vallevand A, Farrell RM. Evaluation of veterinary student surgical skills preparation for ovariohysterectomy using simulators: a pilot study. *Journal of Veterinary Medical Education* 43(2):190-213, 2016.

45. Fahie M, Cloke A, Lagman M, Levi O, Schmidt P. Training veterinary students to perform ovariectomy using the MOOSE spay model with traditional method versus the Dowling Spay Retractor. *Journal of Veterinary Medical Education* 43(2):176-83, 2016.

46. Annandale A, Scheepers E, Fosgate GT. The Effect of Ovariohysterectomy Model Practice on Surgical Times for Final-Year Veterinary Students' First Live-Animal Ovariohysterectomies. *Journal of Veterinary Medical Education* 1-12, 2019.

47. Romano JE, Fahning ML. Effects of early pregnancy diagnosis by per rectal palpation of the amniotic sac on pregnancy loss in dairy cattle. *Journal of the American Veterinary Medical Association* 243:1462-7, 2013.

48. Oltenacu PA, Ferguson JD, Lednor AJ. Economic evaluation of pregnancy diagnosis in dairy cattle: a decision analysis approach. *Journal of Dairy Science* 73:2826-31, 1990.

49. Nestel B, Creek M. The diagnosis of non-pregnancy in beef cattle in Jamaica. Its economic value to the farmer and to his veterinary surgeon. *Veterinary Record* 75:412-6, 1963.

50. Chenoweth P, Anderson M. Cow/calf production principles. *Beef practice: cow-calf production medicine: Blackwell* 9-28, 2005.

51. Fricke PM, Ricci A, Giordano JO, Carvalho PD. Methods for and Implementation of Pregnancy Diagnosis in Dairy Cows. *Veterinary Clinics of North America - Food Animal Practice* 32(1):165-80, 2016.

52. Matthews BJ, Morton JM. Accuracy of predicted calving dates in Holstein-Friesian dairy cows based on fetal ages estimated using manual rectal palpation. *New Zealand Veterinary Journal* 60(4):234-40, 2012.

53. Ott TL, Dechow C, O'Connor ML. Advances in reproductive management: pregnancy diagnosis in ruminants. *Animal Reproduction* (Belo Horizonte) 11(3):207-16, 2014.

54. Albuja C, Ortiz O, Lopez C, Hernandez-Ceron J. Economic impact of pregnancy loss in an intensive dairy farming system. *Veterinaria Mexico* OA 6(1):unpaginated, 2019.

55. Fodor I, Gabor G, Lang Z, Abonyi-Toth Z, Ozsvari L. Relationship between reproductive management practices and fertility in primiparous and multiparous dairy cows. *Canadian Journal of Veterinary Research* 83(3):218-27, 2019.

56. Jaskowski JM, Kaczmarowski M, Kulus J, Jaskowski BM, Herudzinska M, Gehrke M. Rectal palpation for pregnancy in cows: a relic or an alternative to modern diagnostic methods. *Medycyna Weterynaryjna* 75(5):259-64, 2019.

57. Morin DE, Constable PD, Troutt HF, Johnson AL. Individual animal medicine and animal production skills expected of entry-level veterinarians in bovine practice. J*ournal of the American Veterinary Medical Association* 221(7):959-68, 2002.

58. Luby CD, McIntyre K, Jelinski MD. Skills required of dairy veterinarians in western Canada: A survey of practicing veterinarians. *The Canadian Veterinary Journa*l 54(3):267-70, 2013.

59. Youngquist RS, Threlfall WR. Current therapy in large animal theriogenology. 2nd edition, St Louis, Missouri, *Saunders Elsevier* 294-303, 1997.

60. Sheldon M, Noakes D. Pregnancy diagnosis in cattle. *In Practice* 24:310-7, 2002.

61. Noakes D. Pregnancy diagnosis in cattle. *In Practice* 46, 8-9, 51, 1985.

62. Cowie TA. Pregnancy diagnosis tests: a review. *Commonwealth agricultural bureaux joint publication* No 13, Oxford, UK 11-7, 1948.

63. Zemjanis R. Diagnostic and therapeutic techniques in animal reproduction. 2nd edition, *Baltimore (MD): Williams and Wilkins* 29-45, 1970.

64. Wisnicky W, Cassida LE. A manual method for diagnosis of pregnancy in cattle. *Journal of the American Veterinary Medicine Association* 113:451, 1948.

65. Momont H. Rectal palpation: safety issues. *Bovine Practitioner* (25):122-3, 1990.

66. Romano JE, Thompson JA, Forrest DW, Westhusin ME, Tomaszweski MA, Kraemer DC. Early pregnancy diagnosis by transrectal ultrasonography in dairy cattle. *Theriogenology* 66:1034-41, 2006.

67. Farin PW, Youngquist RS, Parfet JR, Garverick HA. Diagnosis of luteal and follicular ovarian cysts by palpation per rectum and linear-array ultrasonography in dairy cows. *Journal of the American Veterinary Medical Association* 200:1085-9, 1992.

68. Alonso-Alanusa L, Galina-Hidalgo C, Romero-Zuniga JJ, Estrada-Konig S, Galindo-Badilla J. Usefulness of rectal palpation and transrectal ultrasonography in the diagnosis of gestation of the Zebu cattle in the humid tropical in Costa Rica Utilidad de la palpacion rectal y la ecografia transrectal en el diagnostico de gestacion del ganado cebu en el tropico humedo de Costa Rica. Revista Cientifica, Facultad de Ciencias Veterinarias, Universidad del Zulia 22(1):9-16, 2012.

69. Giordano JO, Fricke PM, Cabrera VE. Economics of resynchronization strategies including chemical tests to identify nonpregnant cows. *Journal of Dairy Science* 96(2):949-61, 2013.

70. Quintela LA, Barrio M, Pena AI, Becerra JJ, Cainzos J, Herradon PG, Diaz C. Use of ultrasound in the reproductive management of dairy cattle. *Reproduction in Domestic Animals* 47(s3):34-44, 2012.

71. Racewicz P, Jaskowski JM. Contemporary methods of early pregnancy diagnosis in cows. Współczesne metody wczesnej diagnozy ciąży u krów. *Medycyna Weterynaryjna* 69(11):655-61, 2013.

72. Zuo H, Chen X, Cai Y, Hao H, Qin T, Zhao X, Lu Y, Wang D. Advance of early pregnancy diagnosis technology in dairy cows. *Acta Veterinaria et Zootechnica Sinica* 45(10):1584-91, 2014.

73. Bossaert P, Leterme L, Caluwaerts T, Cools S, Hostens M, Kolkman I, De Kruif A. Teaching transrectal palpation of the internal genital organs in cattle. *Journal of Veterinary Medical Education* 36:451-60, 2009.

74. French HM, Dascanio JJ, Gilbert GE, Robinson JQ. Bovine reproductive palpation training: does the cow make a difference? *Journal of Veterinary Medical Education* 45(2):219-23, 2018.

75. Lopes G, Rocha A. Teaching bovine rectal palpation with live cows in the slaughterhouse: Is it worthwhile? *Reproduction in Domestic Animals* 41:510-3, 2006.

76. Norman ST, Dall'Alba G. Computer assisted learning for improving cattle palpation skills of veterinary students. *Open Journal of Veterinary Medicine* 3(08):9, 2013.

77. Baillie S, Crossan A, Reid S, Brewster S. Preliminary development and evaluation of a bovine rectal palpation simulator for training veterinary students. *Cattle Practice* 11, 2003.

78. Ericsson KA, Charness N. Expert performance: Its structure and acquisition. *American Psychologist* 49(8):725-47, 1994.

79. Jephcott SB, Norman ST. Pregnancy diagnosis in cattle. *Australian Cattle Veterinarians*, Brisbane 94, 2004, ISBN: 0958565457.

80. George JH, Doto FX. A simple five-step method for teaching clinical skills. *Family Medicine* 33(8):577-8, 2001.

81. Issenberg SB, McGaghie WC, Petrusa ER, Lee Gordon D, Scalese RJ. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. *Medical Teacher* 27(1):10-28, 2005.

82. McGaghie WC, Issenberg SB, Cohen ER, Barsuk JH, Wayne DB. Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. *Academic Medicine: Journal of the Association of American Medical Colleges* 86(6):706-11, 2011.

83. Baillie S, Crossan A, Brewster SA, May SA, Mellor DJ. Evaluating an automated haptic simulator designed for veterinary students to learn bovine rectal palpation. *Simulation in Healthcare: Journal of the Society for Simulation in Healthcare* 5:261-6, 2010.

84. Giese H, Gundelach Y, Dilly M. Simulationsbasiertes Training der transrektalen gynäkologischen Untersuchung beim Rind. Jahrestagung der Gesellschaft für Medizinische Ausbildung (GMA). Hamburg: Düsseldorf: *German Medical Science GMS Publishing House*; 2014.

85. Giese H, Gundelach Y, Geuenich K, Ehlers JP, Dilly M. Effects of training methods for rectal palpation in cattle on student's performance and self-evaluation. AMEE. Glasgow 2015.

86. Jelinski MD, Campbell JR, Lissemore K, Miller LM. Demographics and career path choices of graduates from three Canadian veterinary colleges. *Canadian Veterinary Journa*l 49(10):995-1001, 2008.

87. Jelinski MD, Campbell JR, Naylor JM, Lawson KL, Derkzen D. Factors associated with the career path choices of veterinarians in western Canada. *Canadian Veterinary Journal* 50(6):630-6, 2009.

88. Jelinski MD, Campbell JR, Naylor JM, Lawson KL, Derkzen D. Factors affecting the career path choices of graduates at the Western College of Veterinary Medicine. *Canadian Veterinary Journal* 49(2):161-6, 2008.

89. Serpell JA. Factors influencing veterinary students' career choices and attitudes to animals. *Journal of Veterinary Medical Education* 32(4):491-6, 2005.

90. Lenarduzzi R, Sheppard GA, Slater MR. Factors influencing the choice of a career in food-animal practice among recent graduates and current students of Texas A&M University, College of Veterinary Medicine. *Journal of Veterinary Medical Education* 36(1):7-15, 2009.

91. Fingland R. Comparison of skills oriented and procedure oriented junior surgery laboratory curriculum. *Alternatives in Veterinary Medical Education* 10:1-6, 1999.

Chapter 2
Training method and other factors affecting student accuracy in bovine pregnancy diagnosis

Annett Annandale, C Henry Annandale, Geoffrey T Fosgate, Dietmar E Holm

Published in:

Journal of Veterinary Medical Education 45(2) 2018. pp 224-231

Abstract

To optimize bovine pregnancy diagnosis (PD) training, factors influencing student performance were investigated. The objective was to determine whether training method, gender, background (farm, urban, or mixed), previous experience in bovine PD, and current career interest influenced the accuracy of bovine PD by transrectal palpation (TRP). Fourth-year (of a sixth-year program) veterinary students (n = 138) received one PD training session in groups using either simulator training on Breed'n Betsy® (BB) or training on live cows (C). Students completed a questionnaire on gender, background, and career interest. Students' PD accuracy (pregnancy status and stage) was determined after training when each student palpated six cows with known pregnancy status. Students' accuracy in determining pregnancy status was measured as sensitivity and specificity (the ability to correctly identify the presence and absence of pregnancy respectively). Factors that influenced overall accuracy with a higher student sensitivity of bovine PD by TRP were training method, farming background, an interest in a mixed animal career, and stage of gestation. Gender of students and previous experience in bovine PD did not have an influence. Training on BB simulators was associated with lower student sensitivity for pregnancy detection in cows < 6 months pregnant. Student sensitivity for pregnancy detection in cows > 6 months pregnant was similar for training on BB simulators and live cows. No evaluated factors were significantly associated with specificity of PD. Teaching efforts focusing on specificity of PD and repeated simulator-based training in conjunction with live cow exposure are recommended.

Key words: veterinary education, bovine pregnancy diagnosis, Breed'n Betsy® rectal examination simulator, veterinary students, simulation, demographic

Introduction

Pregnancy diagnosis (PD) by transrectal palpation (TRP) is commonly performed by veterinarians according to a well-defined method.[1, 2] In brief, palpation of the female reproductive tract is done through the rectal wall to determine positive signs of pregnancy as well as gestational age. While previous researchers suspected that early PD by TRP might cause embryo losses,[3, 4] more recent publications indicate that these losses most likely occur regardless of palpation.[5-8] Due to its economic importance and wide use in veterinary practice,[8-14] bovine PD by TRP is an important competency for veterinary graduates,[15] as indicated in Day One Competency lists published by the Royal Veterinary College[16] and the South African Veterinary Council.[a] However, because of limited resources, increasing student numbers, availability of teaching animals, and welfare issues, training opportunities on live animals in general are constrained,[17] and thus also influence PD training for veterinary students. The introduction of bovine rectal examination simulators like the Haptic Cow[b] or the Breed'n Betsy® (BB)[c] into veterinary teaching programs offers additional training alternatives to live cow training,[18-21] and may help reduce the requirement of live animal training. Several studies have evaluated rectal examination simulators[19-22] and concluded that training on simulators was superior to theoretical instruction only for locating the uterus and cervix,[22] while additional simulator training after live cow palpations significantly improved students' performance.[19] Using the BB simulator and live cows, Bossaert *et al*. showed that students trained on live cows were more skilled at evaluating the uterus and ovaries in non-pregnant cows while there was no difference between the two training groups in recognizing pregnant cows by TRP.[21]

Some studies have evaluated the effect of upbringing location, gender, and previous pet ownership on career choice of veterinary students.[23-27] Two of the key demographics shown to be positively correlated with a career in mixed or food animal practice are an upbringing in a small center or rural area and being male.[23, 25, 26] Experience working on a farm[26] and other agricultural exposure were positively associated with a preference for food animal employment.[27] It is hypothesized that some of the factors that have been shown to have an influence on career choice might also influence students' performance in bovine PD. The authors are not aware of publications linking factors that influence an interest in mixed or food animal practice to core skills like bovine PD via TRP.

To optimize PD training, the factors influencing student performance need to be investigated. The objective of the present study was therefore to determine if training method (using either the BB rectal examination simulator or live cows), gender, background (farm, urban, or mixed), previous experience in bovine PD, and current career interest influence the accuracy of bovine PD by TRP of fourth-year veterinary students.

Materials and methods

The fourth-year veterinary curriculum of the University of Pretoria's sixth-year program includes a one-year module on veterinary reproduction during which the theory of bovine PD is lectured to students before the onset of practical training. The latter consists of TRP on non-pregnant cows followed by bovine PD via TRP to recognize pregnancy status (yes/no) and stage of pregnancy. For purposes of this observational study, fourth-year veterinary students (n = 138) were assigned to six equal exposure cohorts within two different training programs. Three cohorts of students were assigned to PD training via TRP on the BB rectal examination simulator (BB cohort), and the other three cohorts were assigned to training on live cows (C cohort). Pre-existing practical groups (assigned according to an alphabetical class list) were used as cohorts and randomly assigned to training method.

The BB rectal examination simulators are models consisting of a steel frame with latex artificial cow perineum at the height similar to that of a cow, and with latex artificial rectum and female reproductive organs that are attached with spring-loaded clamps for easy removal and replacement.[21] After lubrication, a gloved hand is introduced into the artificial rectum, and the organs are palpated through the rectum. The latex artificial reproductive organs are designed to simulate weekly pregnancy stages from six to 20 weeks of gestation. In addition, rubber tubes simulating the size and consistency of the uterine arteries, and wooden disks simulating the size of cotyledons during the later stages of pregnancy were made available to students outside of the BB simulator to practice palpation skills. Three BB rectal examination simulators were set up to ensure palpation without visualization, whereas other students were encouraged to observe the palpation and to interact through peer instruction. Reproductive tracts were exchanged to ensure exposure of all students to all available gestational ages (6, 7, 8, 9, 10 and 11 weeks pregnant; 3-5 months pregnant; and non-pregnant uterus). One facilitator coordinated the training for all three cohorts trained on BB rectal examination simulators.

The live cows used for PD training were primiparous and multiparous Bonsmara cows from the University of Pretoria's beef herd located on a farm 20 km east of Pretoria, South Africa. Cows used for training were either in the last trimester of pregnancy (7-9 months pregnant) or not pregnant, due to the time of year during which training was done in relation to the breeding season. After application of a rectal glove and lubrication, students were allowed to palpate cows transrectally, and were individually assisted by the facilitator explaining what was supposed to be palpated in individual cows. Students were encouraged to palpate at least 10 cows and to record and discuss their palpation findings with each other and with the facilitator. No cow was palpated more than three times. One facilitator (not the same as for the BB training) coordinated the training for all three cohorts trained on live cows.

Immediately after the PD training session, all students (BB and C cohorts) were asked to write down the number of PDs performed during the training and were encouraged to give comments about the training session (BB or C).

All students visited a commercial Nguni beef cattle herd three weeks after training where their accuracy to correctly diagnose pregnancy status and stage by TRP was assessed. All cows were uniquely identified. On this day each student completed a questionnaire (Appendix 1). Following completion of the questionnaire, each student was offered 12 minutes to palpate a maximum of six cows transrectally, for which the pregnancy status and stage had already been determined by a specialist veterinarian experienced in bovine PD via TRP. Individual cows were palpated by either two or three students. Each student's PDs (pregnancy status and stage) were recorded on an individual data-capture sheet against the appropriate cow number. Students were blinded to each other's diagnoses and cows entered the crush in their own order of preference.

Data per palpation performed were transferred from individual data-capture sheets into a computer spreadsheet. Categorical data were described as frequencies, proportions, and 95% CIs. Student overall accuracy of PD was estimated as the proportion of correct diagnoses (pregnant or not pregnant, and correct staging of pregnancy where applicable according to the experienced veterinarian). Student sensitivity of pregnancy detection was estimated as the proportion of correctly identified pregnancies and included staging. Student specificity was similarly estimated as the proportion of cows correctly identified as not being pregnant. Proportions and CI were estimated using mixed-effects logistic regression because each student performed examinations on multiple cows and each cow was examined by multiple students. Models included random effect terms for student and cow and a fixed effect for exposure to BB or live cow training. Univariate associations between student sensitivity and specificity were also estimated using mixed-effects logistic regression. Multivariable models were fit using a backward stepwise process based on Student *t* statistic *p* values starting with all predictors that had $p < .20$ in the univariate screening models and continuing until only independent variables with $p < .05$ remained. Statistical analysis was performed in commercially available statistical software.[d] Unless stated otherwise, results were interpreted at the 5% level of significance.

This study was approved by the Animal Ethics Committee of the University of Pretoria (Protocol V052/14).

Table 1 Univariate results of factors associated with student sensitivity for pregnancy detection

Variable	Level	Parameter estimate (β)	OR (95% CI)	p
Training method	Breed'n Betsy®	-0.559	0.57 (0.31-1.07)	.08
	Live cows	Referent	-	
Gender of student	Female	-0.558	0.57 (0.27-1.20)	.14
	Male	Referent	-	
Background of student	Farm	1.152	3.16 (1.12-8.93)	.03
	Mixed	0.649	1.91 (0.85-4.33)	.12
	City	Referent	-	
Career choice of student	Mixed practice	1.137	3.12 (1.35-7.22)	< .01
	Other	0.534	1.71 (0.86-3.40)	.13
	Small animal	Referent	-	
Previous experience	Non-veterinary	-0.102	0.90 (0.40-2.04)	.806
	With veterinarian	0.719	2.05 (0.83-5.11)	.121
	None	Referent		
Pregnancy stage	2-3 months	Referent	-	
	4 months	0.267	1.31 (0.42-4.03)	.64
	5 months	0.518	1.68 (0.48-5.88)	.42
	6 months	1.679	5.36 (1.48-19.4)	.01
	7 months	1.063	2.89 (0.92-9.08)	.07
	8-9 months	2.125	8.37 (2.39-29.4)	< .01

Table 2 Multiple regression model of factors associated with student sensitivity for pregnancy detection (all stages of pregnancy)

Variable	Level	Parameter estimate (β)	OR (95% CI)	p
Training method*	Breed'n Betsy®	-0.600	0.55 (0.29-1.05)	.07
	Live cows	Referent	-	
Background of student	City	-0.838	0.43 (0.21-0.88)	.02
	Farm or mixed	Referent	-	
Pregnancy stage	< 6 months	-1.261	0.28 (0.15-0.53)	< .01
	≥ 6 months	Referent	-	

*Forced into model

Results

The study population consisted of 138 fourth-year veterinary students of which 94 students were female and 44 male (68% and 32%, respectively). Sixty-three out of 94 female students (72%) and 17 out of 44 male students (45%) were from a city background. Analysis of correctly completed questionnaires (n = 126) showed that 39%, 33%, 17%, and 9% of students indicated a career interest in small animal practice, mixed animal practice, other (specialized production animal practice, wildlife, state veterinary services, research, industry), and equine practice, respectively, whereas only a very small proportion (2.4%) of students did not have a career interest.

Forty-four students (35%) had bovine PD via TRP experience before the PD training session on BB or live cows, while 82 students (65%) had no experience. Out of the 44 students with previous experience, 28, 7, 6, and 3 students had performed 0-10, 10-25, 25-50, and more than 50 (range 50-500) bovine PDs via TRP, respectively, before the PD training session.

Students in the BB cohort performed between four and 26 PDs via TRP (mean 11, median 8) during the training session. Students in the C cohort performed between four and 18 PDs via TRP (mean 12, median 8) during the training session.

On the day of practical assessment, 463/749 (62%) student palpations were performed on pregnant cows, of which 213 were on cows < 6 months (46%) and 250 were on cows > 6 months (54%) pregnant. Compared to the diagnoses (pregnancy status) provided by the experienced veterinarian, the mean overall accuracy of pregnancy detection was 68% (95% CI = 61-74%) and 73% (95% CI = 66-78%) for students trained on BB rectal examination simulators and live cows, respectively (p = .20).

Factors that were significantly associated with higher student sensitivity of PD in the univariate analysis were students with a farming background, students interested in a mixed animal practice career, and stage of gestation (Table 1). Gender of students and previous experience in bovine PD did not have an influence on sensitivity of PD (Table 1). Although not statistically significant, student sensitivity of pregnancy detection tended to be lower for those who were trained on BB compared to those trained on live cows. Students trained on BB rectal examination simulators had significantly lower sensitivity to detect pregnancy in cows < 6 months pregnant than students trained on live cows. Farming background and pregnancy stage remained significant within the multivariable model (Table 2). Training method was forced into the final multivariable model and the measured effect was similar to the results of the univariate analysis.

No evaluated factors were significantly associated with the specificity of pregnancy detection (data not shown). Specificity of pregnancy detection was generally significantly lower than sensitivity and was similar for students trained on BB rectal examination simulators and those trained on live cows (Table 3).

Table 3 Mean student sensitivity and specificity for pregnancy detection by training method

	Training method			
	Breed'n Betsy®		**Live cows**	
	Sensitivity (%)*	**Specificity (%)***	**Sensitivity (%)***	**Specificity (%)***
All cows	84† (78-89)	39‡ (30-49)	90† (85-94)	42‡ (33-52)
< 6 months pregnant	68§ (54-79)	n/a	84† (72-91)	n/a
≥ 6 months pregnant	91† (85-95)	n/a	93† (87-97)	n/a

*Mean (95% CI)
$^{†, ‡, §}$ Means with different superscripts differ significantly after Bonferroni correction of p values for multiple post hoc tests (p < .05)

Discussion

In this study, overall accuracy of PD (pregnancy status and stage) was lower than what is considered acceptable accuracy for veterinarians.[3, 9, 28, 29] Although the time limit placed on students to complete the PDs may have affected their accuracy, the low accuracy is supported by Bossaert *et al*., who showed that students need extensive exposure to TRP in live cows as 200 TRPs were insufficient to ensure complete competency.[21] Students in the current study were exposed to one introductory TRP on non-pregnant cows before the PD training session by TRP in cattle or on BB rectal examination simulators. By the time of the practical assessment each student had performed between six and 28 TRPs, although this was most likely insufficient to prepare students to correctly correlate clinical findings to a diagnosis. On the other hand, it has been shown previously that a single training session on any one of two simulators (Haptic Cow or BB rectal examination simulator) was superior to theoretical instruction in terms of ability to localize uterus and cervix.[22] PD training should therefore aim at increasing palpation competency in veterinary students by providing sufficient palpation sessions. Rectal examination simulators can help overcome the deficiency in availability of teaching animals if training is provided in conjunction with live cow exposure. If repeated simulator training is offered before the first live cow palpation, this approach will not only result in higher competency levels among students but also help avoid overuse of and too many palpations on teaching animals, which is a welfare concern at teaching institutions. Only 35% (44/126) of students had previous experience in bovine PD via TRP before the training session on BB rectal examination simulators or live cows. The fact that out of those 44 students only three had extensive experience (> 50 PDs via TRP) indicates that bovine PD opportunities outside veterinary training programs are limited and not easily accessible to students. Furthermore, this might be an explanation as to why the demographic factor ‘previous experience’ did not significantly affect student sensitivity of PD in this study and confirms that TRP competency requires extensive exposure.[21]

The relatively low proportion (62%) of pregnant cows examined on the day of the practical assessment might have influenced sensitivity and specificity estimates. It is possible that students expected to perform PDs in a herd with a higher pregnancy proportion, in which case if any doubts existed on the pregnancy status of a cow, the student would have been more likely to guess that the cow was pregnant. We hypothesize that this contributed toward substantially lower student specificity compared to sensitivity in this trial. The fact that no predictors of specificity could be demonstrated in our data may therefore be attributed to guessing on the part of the students and their tendency to value sensitivity higher than specificity. Although false negative PD has an obvious disadvantage, in particular where cows that are not pregnant will be slaughtered, false positive pregnancy detection also has a significant negative impact on farm profitability.[3, 30] Based on this and on our data, we suggest that teaching efforts should focus on the specificity of pregnancy detection, and less on sensitivity. Training of students to palpate non-pregnant cows is likely to improve specificity of PD and is, for this reason, an appropriate strategy to obtain some of the initial skills for PD.

Although career interest was associated with student sensitivity of pregnancy detection in the univariate analysis, this appeared to have been confounded by the background of the student because it did not remain significant in the multivariable model that included farming background. This could indicate that the experience of living and working on a farm is positively associated not only with an interest in large animals[26, 27] but also with initial large animal clinical skills.

The lower sensitivity of pregnancy detection in early stages of pregnancy in our data is in agreement with previous findings.[3] It was interesting to find that student sensitivity in early pregnancy was lower for students trained on BB rectal examination simulators, because the simulators are specifically designed for early pregnancy detection, and they do not simulate pregnancy stages beyond five months. It may therefore be that if a higher proportion of cows were in early stages of pregnancy during the practical assessment, a more significant exposure effect due to training method might have been demonstrated. In this study, the cohort of students trained on live cows were not exposed to early pregnancy stages during training, but they were more sensitive for early pregnancy during the practical assessment. Reasons for this paradox need further investigation; however, taking student comments into consideration, it appears that overcoming the unusual experience of TRP may be more difficult than the actual ability to palpate. Students trained on BB rectal examination simulators indicated that the simulator-based PD training is a good starting point to learn bovine PD. Students responded positively to the visualization of structures palpated and the ability to palpate different pregnancy stages consecutively, which increased their understanding of pregnancy stages. However, many students indicated that the simulator training should be followed by a TRP session for PD in live cows to maximize the learning outcome. Some students with previous PD experience via TRP in live cows made negative remarks about the simulator experience while students without any prior live cow PD experience were exclusively positive. In general, it may be beneficial to focus on additional simulator-based training to increase competence and palpation accuracy among students before performing TRPs on live cows.

Demographics of the study population showed that 63 out of 94 female students (72%) and 17 out of 44 male students (45%) were from a city background, and more students from a city than from a farm background selected small animals as a career interest, which is in agreement with previous findings[25] and confirms that a farming background is positively associated with an interest in large animal practice.[26, 27]

The proportion of students choosing mixed practice as a career interest was not affected by gender, which is in contrast to previous studies where male veterinary students were significantly more likely to choose a farm animal or mixed practice career than female students.[23, 26, 31] Female and male students from a farming background showed equal interest in mixed practice, which supports previous findings that a rural upbringing,[23, 31] as well as the likely agricultural experience associated with the rural upbringing, increases an interest in farm animal practice.[26, 27] This previous experience and interest in large animals seems to be positively correlated with large animal clinical skills such as bovine PD via TRP.

It may have been better to use the phrase ‘career interest’ instead of ‘career choice’ in the questionnaire to ensure student answers were based on their actual interest. ‘Career choice’ could have left room for students to indicate choices based on practical or economic reasons rather than main interest.

Conclusions

Factors that influenced overall accuracy of bovine PD by TRP with a positive effect on student sensitivity were training method, farming background, an interest in mixed animal career, and stage of gestation. Training on the BB rectal examination simulator was associated with lower student sensitivity for pregnancy detection in cows < 6 months pregnant while no difference could be shown between the training groups in cows > 6 months pregnant. No evaluated factors were significantly associated with specificity of pregnancy detection. We therefore conclude that teaching efforts should focus on the specificity of pregnancy detection to obtain some of the initial skills for PD, and that repeated simulator-based training in conjunction with live cow exposure is an appropriate strategy to increase students' competency levels for bovine PD via TRP.

Acknowledgments

We acknowledge David and Susan Hill of Hall's Hill Farm, Doornpoort, South Africa and Zoetis South Africa for their support of this study.

Notes

- To request a copy of the competency list of the South African Veterinary Council, email education@savc.org.za. This list is currently available at
- http://www.savc.org.za/pdf_docs/2017_H_VETS_SAVC%20-Day%201%20Skills_v2.pdf, a URL that will eventually change.
- Haptic Cow, Virtalis Ltd, Cheshire, UK, https://www.virtalis.com/haptic-cow/
- Breed'n Betsy®, Brad Pickford, Australia, http://www.breednbetsy.com.au/
- IBM SPSS Statistics version 22, IBM Corp., Armonk, NY, USA

References

1. Youngquist RS, Threlfall WR. Current therapy in large animal theriogenology. 2nd edition, St. Louis, MO: *Saunders Elsevier* 1997.

2. Sheldon M, Noakes D. Pregnancy diagnosis in cattle. In Pract. 2002;24(6):310-7. https://doi.org/10.1136/inpract.24.6.310.

3. Warnick LD, Mohammed HO, White ME, *et al*. The relationship of the interval from breeding to uterine palpation for pregnancy diagnosis with calving outcomes in Holstein cows. *Theriogenology*. 1995;44(6):811-25. https://doi.org/10.1016/0093-691X(95)00267-C. Medline:16727777.

4. Paisley LG, Duane Mickelsen W, Frost OL. A survey of the incidence of prenatal mortality in cattle following pregnancy diagnosis by rectal palpation. *Theriogenology*. 1978;9(6):481-91. https://doi.org/10.1016/0093-691X(78)90113-9.

5. Romano JE, Thompson JA, Kraemer DC, *et al*. Effects of early pregnancy diagnosis by palpation per rectum on pregnancy loss in dairy cattle. *Journal of the American Veterinary Medical Association*. 2011;239(5):668-73. https://doi.org/10.2460/javma.239.5.668. Medline:21879969.

6. Romano JE, Thompson JA, Kraemer DC, *et al*. Early pregnancy diagnosis by palpation per rectum: influence on embryo/fetal viability in dairy cattle. *Theriogenology*. 2007;67(3):486-93. https://doi.org/10.1016/j.theriogenology.2006.08.011. Medline:17030359.

7. Alexander BM, Johnson MS, Guardia RO, *et al*. Embryonic loss from 30 to 60 days post breeding and the effect of palpation per rectum on pregnancy. *Theriogenology*. 1995;43(3):551-6. https://doi.org/10.1016/0093-691X(94)00060-8. Medline:16727646.

8. Romano JE, Fahning ML. Effects of early pregnancy diagnosis by per rectal palpation of the amniotic sac on pregnancy loss in dairy cattle. *Journal of the American Veterinary Medical Association*. 2013;243(10):1462-7. https://doi.org/10.2460/javma.243.10.1462. Medline: 24171377.

9. Oltenacu PA, Ferguson JD, Lednor AJ. Economic evaluation of pregnancy diagnosis in dairy cattle: a decision analysis approach. *Journal of Dairy Science*. *1990*;73(10):2826-31. https://doi.org/10.3168/jds.S0022-0302(90)78970-9. Medline:2126548

10. Nestel B, Creek M. The diagnosis of non-pregnancy in beef cattle in Jamaica: its economic value to the farmer and to his veterinary surgeon. *Veterinary Research*. 1963;75:412-6.

11. Chenoweth PJ. Cow/calf production principles. In: Chenoweth PJ, Sanderson MW, editors. Beef practice: cow-calf production medicine. *Ames, IA: Blackwell.* 2005; 9-28.

12. Fricke PM, Ricci A, Giordano JO, *et al*. Methods for and implementation of pregnancy diagnosis in dairy cows. *Veterinary Clinics of North America: Food Animal Practice*. 2016;32(1):165-80. https://doi.org/10.1016/j.cvfa.2015.09.006. Medline:26922118.

13. Matthews BJ, Morton JM. Accuracy of predicted calving dates in Holstein-Friesian dairy cows based on fetal ages estimated using manual rectal palpation. *New Zealand Veterinary Journal.* 2012;60(4):234-40. https://doi.org/10.1080/00480169.2012.670094. Medline: 22712775.

14. Ott TL, Dechow C, O'Connor ML. Advances in reproductive management: pregnancy diagnosis in ruminants. *Animal Reproduction (Belo Horizonte)*. 2014;11(3):207-16.

15. Luby CD, McIntyre K, Jelinski MD. Skills required of dairy veterinarians in western Canada: a survey of practicing veterinarians. *Canadian Veterinary Journal*. 2013;54(3):267-70. Medline:23997264.

16. Royal College of Veterinary Surgeons (RCVS). Day One Competences [Internet]. London: RCVS; *2014* [cited 2017 Oct 17]. Available from: https://www.rcvs.org.uk/document-library/day-one-competences/1day-one-competences-updated-26-march-2014.pdf.

17. Baillie S. Utilisation of simulators in veterinary training. *Cattle Pract*ice. 2007;15:224-8.

18. Baillie S, Mellor DJ, Brewster SA, *et al*. Integrating a bovine rectal palpation simulator into an undergraduate veterinary curriculum. *Journal of Veterinary Medical Educcation*. 2005; 32(1):79-85. https://doi.org/10.3138/jvme.32.1.79. Medline:15834825.

19. Baillie S, Crossan A, Brewster S, *et al*. Validation of a bovine rectal palpation simulator for training veterinary students. *Student in Health Technology Informatics*. 2005;111:33-6. Medline:15718694.

20. Baillie S, Crossan A, Brewster SA, *et al*. Evaluating an automated haptic simulator designed for veterinary students to learn bovine rectal palpation. *Simulation in Healthcare*. 2010;5(5):261-6. https://doi.org/10.1097/SIH.0b013e3181e369bf. Medline:21330807.

21. Bossaert P, Leterme L, Caluwaerts T, *et al*. Teaching transrectal palpation of the internal genital organs in cattle. *Journal of Veterinary Medical Education*. 2009;36(4):451-60. https://doi.org/10.3138/jvme.36.4.451. Medline:20054085.

22. Giese H, Gundelach Y, Dilly M. Simulationsbasiertes Training der transrektalen gyna¨kologischen Untersuchung beim Rind. *Jahrestagung der Gesellschaft für Medizinische Ausbildung (GMA)*; 2014 Sep 25-27; Hamburg, Germany. https://doi.org/10.3205/ 14gma211.

23. Jelinski MD, Campbell JR, Lissemore K, *et al*. Demographics and career path choices of graduates from three Canadian veterinary colleges. *Canadian Veterinary Journal*. 2008;49(10):995-1001. Medline:19119368.

24. Jelinski MD, Campbell JR, Naylor JM, *et al*. Factors associated with the career path choices of veterinarians in western Canada. *Canadian Veterinary Journal*. 2009;50(6):630-6. Medline:19721783.

25. Jelinski MD, Campbell JR, Naylor JM, *et al*. Factors affecting the career path choices of graduates at the Western College of Veterinary Medicine. *Canadian Veterinary Journal*. 2008;49(2):161-6. Medline:18309746.

26. Serpell JA. Factors influencing veterinary students career choices and attitudes to animals. *Journal of Veterinary Medical Education*. 2005;32(4):491-6. https://doi.org/10.3138/jvme. 32.4.491. Medline:16421833.

27. Lenarduzzi R, Sheppard GA, Slater MR. Factors influencing the choice of a career in food-animal practice among recent graduates and current students of Texas A&M University, College of Veterinary Medicine. *Journal of Veterinary Medical Education*. 2009;36(1):7-15. https://doi.org/10.3138/jvme.36.1.7. Medline:19435985.

28. Romano JE, Fahning ML. Accuracy of per rectum palpation for pregnancy diagnosis in cattle. XXVIII World Buiatrics Congress. 2014 Jul 27-Aug 1; Cairns, Australia.

29. Alonso-Alanusa L, Galina-Hidalgo C, Romero-Zuniga JJ, *et al*. Utilidad de la palpacion rectal y la ecografia transrectal en el diagnostico de gestacion del ganado cebu en el tropico humedo de Costa Rica [Usefulness of rectal palpation and transrectal ultrasonography in the diagnosis of gestation of the Zebu cattle in the humid tropical in Costa Rica]. Rev Cient. 2012;22(1):9-16. Available from: http://www.redalyc.org/articulo.oa?id=95921743002.

30. De Vries A. Economic value of pregnancy in dairy cattle. *Journal of Dairy Science*. 2006;89(10):3876-85. https://doi.org/10.3168/jds.S0022-0302(06)72430-4. Medline: 16960063.

31. Kinnison T, May SA. Veterinary career ambitions correlate with gender and past experience, with current experience influencing curricular perspectives. *Veterinary Research*. 2013;172(12):313. https://doi.org/10.1136/vr.101261. Medline:23377705.

Author information

Annett Annandale, DrMedVet, MSc, Diplomate ACT, is Senior Lecturer and Skills Laboratory Manager, Faculty of Veterinary Science, University of Pretoria, Private Bag X04, Onderstepoort 0110, South Africa. Email: annett.annandale@up.ac.za. Her research interests include veterinary education and equine reproduction.

C Henry Annandale, BVSc (Hons), MMedVet (Gyn), MBA, Diplomate ACT, is Associate Professor, Department of Production Animal Studies and Director Clinical Services, Faculty of Veterinary Science, University of Pretoria, Private Bag X04, Onderstepoort 0110, South Africa. Email: henry.annandale@up.ac.za.

Geoffrey T Fosgate, DVM, PhD, Diplomate ACVPM, is Professor of Veterinary Epidemiology, Department of Production Animal Studies, Faculty of Veterinary Science, University of Pretoria, Private Bag X04, Onderstepoort 0110, South Africa. Email: geoffrey.fosgate@up.ac.za. His area of research is analytical epidemiology and the study of diseases at the wildlife-livestock interface.

Dietmar E Holm, BVSc, MSc, PhD, is Associate Professor and Deputy Dean, Teaching and Learning, Faculty of Veterinary Science, University of Pretoria, Private Bag X04, Onderstepoort 0110, South Africa. Email: dietmar.holm@up.ac.za. His research interests include bovine herd health and veterinary education.

Appendix 1:
2014 OP PD challenge student questionnaire

2014 OP PD Challenge student questionnaire

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Student: Student number: Group:

Gender: Male ☐ Female ☐

Back-ground: Farm ☐ City ☐ Mixed ☐

Experience in bovine pregnancy diagnosis/rectal palpation prior to OP PD Challenge:

Only what I've done at Onderstepoort ☐

Some previous exposure without a veterinarian ☐

Some previous exposure with a veterinarian ☐

Extensive previous exposure ☐

Indicate no of PDs done in total prior to OP PD Challenge ☐

Exposure obtained since start of OP PD Challenge:

Only one training session as provided ☐

Some additional exposure without a veterinarian ☐

Some additional exposure with a veterinarian ☐

Indicate no of PDs done in total since start of OP PD Challenge ☐

Current career choice:

Small animal practice ☐

Rural (mixed) practice ☐

Equine practice ☐

Specialised production animal practice ☐

Specialised wildlife practice ☐

State veterinary practice ☐

Research/Academia ☐

Pharmaceutical industry ☐

Other ☐

Chapter 3

Ability of a bovine transrectal palpation objective structured clinical examination to predict veterinary students' pregnancy diagnosis accuracy

Annett Annandale, Geoffrey T Fosgate, Harold Bok, Dietmar E Holm

Published in:

Veterinary Record 185 (6) 2019. pp 171-180

Abstract

Bovine pregnancy diagnosis (PD) by transrectal palpation (TRP) is one of the most frequently performed procedures in bovine practice, and an important competency for veterinary graduates. It is currently not known if pre-existing TRP skills on non-pregnant cows can be used to predict students' future PD accuracy. The study objective was to evaluate if TRP objective structured clinical examination (OSCE) scores can predict students' future PD accuracy.

Fourth-year (of a six-year programme) veterinary students (n = 128) received TRP and PD training on Breed'n Betsy® (BB) simulators and live cows. Students' TRP skills were assessed using a live cow TRP OSCE after completion of the fourth-year training. The same students received additional TRP (BB and live cows) and PD (BB) training sessions in the first semester of their fifth-year. PD accuracy was assessed after the additional TRP and PD training, five months after the TRP OSCE assessment and measured as sensitivity and specificity (the ability to correctly identify the presence and absence of pregnancy, respectively). Each student palpated six cows transrectally to diagnose pregnancy status and stage for the PD assessment. The TRP OSCE results were analysed as predictors for students' PD accuracy.

Students with 'competent palpation skills' on the TRP OSCE had higher PD specificity. The individual OSCE components that were predictive of higher PD accuracy were students' ability to estimate ovarian size, identify uterine position and exclude intrauterine fluid. It was concluded that a TRP OSCE has the ability to predict students' future PD accuracy.

Introduction

Bovine pregnancy diagnosis (PD) by transrectal palpation (TRP) is widely used in veterinary practice and is of economic importance.[1-4] It is also one of the most frequently performed procedures in bovine practice,[5] and therefore an important competency for veterinary graduates.[6] Bovine TRP and PD training is challenging since it requires extensive exposure to TRP in live cows to ensure competency.[7, 8] However, limited resources, increasing student numbers, availability of teaching animals and welfare issues reduce training opportunities on live animals in general,[9] and thus influence PD training for veterinary students. Furthermore, it seems difficult for students to get additional bovine PD and TRP exposure outside the veterinary course.[10]

Several studies have evaluated the use of simulators and live cows in an effort to improve bovine TRP training.[7, 8, 10-15] The effectiveness of simulators such as the Breed'n Betsy® (BB; Brad Pickford, Australia, http://www.breednbetsy.com.au/) and the Haptic Cow (Virtalis, Cheshire, UK, https://www.virtalis.com/haptic-cow/) to teach TRP and PD skills has been explored.[7, 10-15] The use of a TRP simulator is superior to theoretical instruction only,[11, 14] but live cow training in conjunction with simulator training is advised to optimise learning outcomes.[10, 11, 14] French *et al*. have investigated different methods for TRP training on live cattle.[8] This study concluded that having students identify specific reproductive landmarks such as the cervix and uterine horns with quantitative size measurements and choosing cows that are easy to handle have a positive impact on student training.[8] Reported overall PD accuracy (pregnancy status and stage) of students is lower than what is considered acceptable accuracy for veterinarians.[10, 16-19] Student specificity (correctly identify non-pregnant cows) was lower than sensitivity (correctly identify pregnant cows) and additional student training on non-pregnant cows could be a strategy to improve the necessary palpation skills.[10] However, it is not known if pre-existing TRP skills on non-pregnant cows can be used to predict future PD accuracy.

Objective structured clinical examinations (OSCE) are used to test clinical skills.[20-25] A wide range of clinical skills can be tested under simulated examination conditions evaluating the candidate's practical competence. However, practical competence is not the same as clinical performance.[25] Since OSCEs are conducted under simulated examination conditions, they do not provide valid information on the candidate's ability to perform the skill in real-life situations.[25] For example, the performance level of Dutch general practitioners was lower than their competence level based on OSCE assessments.[26]

Bovine PD via TRP is the practical application of TRP skills that students acquire via TRP training. The objective of this study was to determine if OSCE scores on bovine TRPs (competence) can be used as predictors for students' future bovine PD accuracy (performance). It was hypothesised that palpation competency level based on OSCE scores is predictive of students' subsequent PD accuracy. Another aim of the study was to examine if the TRP OSCE is a valid and reliable assessment for TRP skills of veterinary students.

Materials and methods

Student TRP and PD training

The fourth-year veterinary curriculum of the University of Pretoria's six-year programme includes a one-year module on veterinary reproduction of all domestic species.[27] Bovine, small stock, small animal and equine reproduction are taught separately throughout the year and one examination at the end of the year assesses knowledge and skills for all species. The bovine part of the veterinary reproduction module covers aspects of male and female theriogenology, of which TRP and PD is one part. The 2015 fourth-year TRP and PD practical training consisted of three sessions. The first TRP training session included three components: inspection of abattoir-obtained female reproductive organs, palpation of non-pregnant BB models and palpation of non-pregnant live cows with facilitator guidance. The abattoir-obtained reproductive organs included non-pregnant uteri as well as a variety of pregnant uteri of various pregnancy stages. The variety of abattoir reproductive organs was fairly similar for all student groups. The first TRP training session was presented either before or just after the theoretical lectures on PD. The second and third practical TRP training sessions followed 2-3 months after the theory component of PD. The second TRP training session consisted of bovine PD via TRP on BB models. The BB simulators were set up using the seven different uteri models to allow for palpation of weekly pregnancy stages from six to 11 weeks, and four to five months of gestation.[10] The third TRP training session consisted of bovine PD via TRP on live cows (one week after the PD training on BB models). Training focused on pregnancy status determination (pregnant or not pregnant) and estimating stage of pregnancy. During the palpation training, students were encouraged to measure the width of their fingers and hand and practise estimating sizes of structures that were palpated. Students performed an average of five non-pregnant TRPs on live cows and BBs and an average of 16 pregnant TRPs on live cows and BBs during the training module. No cow was palpated more than three times during any of the training sessions.

Reproduction module and TRP assessment

Students had to pass an examination at the end of the reproduction module consisting of theory assessment via computer-based testing and practical skills assessment in an OSCE examination consisting of two OSCE stations (Figure 1) Students knew which OSCE stations they might be subjected to and that all students would be assessed at the bovine TRP OSCE station. Students had access to the OSCE marking sheets before the examination. Examination time was restricted to 10 minutes per OSCE station. For all students, 'Station one' was bovine TRP on a live cow where each student palpated one live cow and wrote down his or her findings on an OSCE marking sheet (Figure 2). The OSCE marking sheet was handed to the student before the palpation. No cow was palpated more than three times. The TRP findings on cows used during the OSCE examination were predetermined by two specialist veterinary examiners experienced in bovine TRP. None of the cows used on the day of the OSCE examination was pregnant or showed any reproductive abnormalities such as intrauterine fluid accumulation. Fifteen marks for the TRP OSCE station were allocated for correctly inserting the hand into the rectum; identifying uterine position and tone, location and estimation of the diameter of the cervix, symmetry of the uterine horns, ovarian size, ovarian structures (corpus luteum and follicle for left and right ovaries), pregnancy (yes/no) and, if yes, staging of the pregnancy (Figure 2). Scores were assigned to the OSCE marking sheet as follows: one mark was scored for each finding of the student who agreed with that of the examiners, and in the case of reproductive organ and ovarian structure sizes, students were assigned the score if their finding was within 1 cm of the examiners' findings.

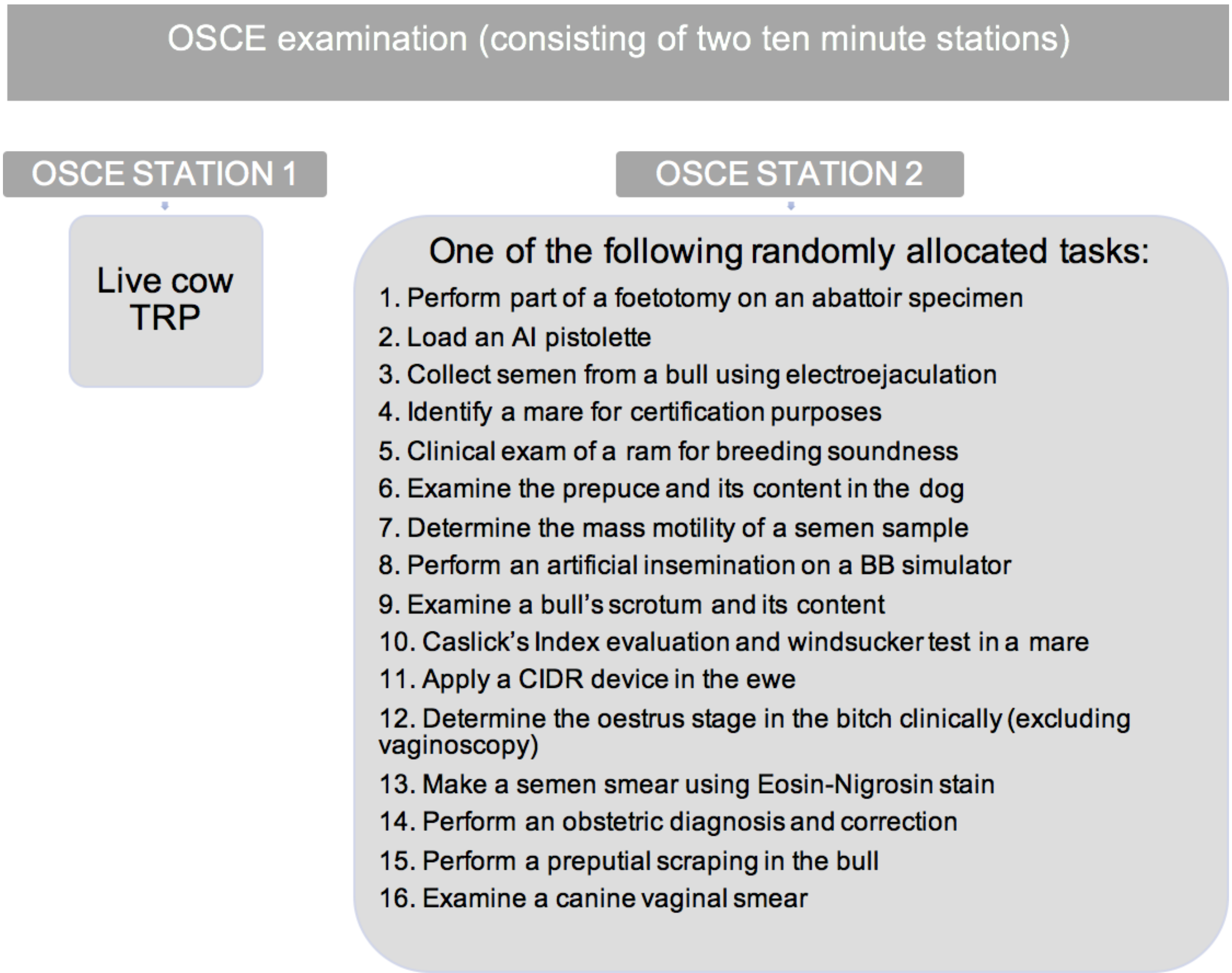


Figure 1 Reproduction module OSCE set-up for 128 fourth-year students in November 2015

BB = Breed'n Betsy®; OSCE = objective structured clinical examination; TRP = transrectal palpation; AI = artificial insemination; CIDR = controlled internal drug release

The nine scores that evaluated palpation skills (size and position of the cervix; size, tone and symmetry of uterine horns; size and presence of pertinent structures on the ovaries) were ordinally transformed: no palpation skills (0-1/9), deficient palpation skills (2-3/9), some palpation skills (4-5/9), good palpation skills (6-7/9) and competent in palpation (8-9/9) (Table 1). This was given as feedback to the students by the assessors on ClickUP (the Blackboard Learning Management Tool of the University of Pretoria) after completion of the examination.

Study design and participants

The same veterinary students (n = 128) received additional supervised bovine TRP training during their fifth-year, four months after the TRP OSCE examination (Figure 3). The additional bovine TRP training consisted of three training sessions. Training session 1 consisted of palpation of non-pregnant BB models. Training session 2 involved non-pregnant live cow palpations.

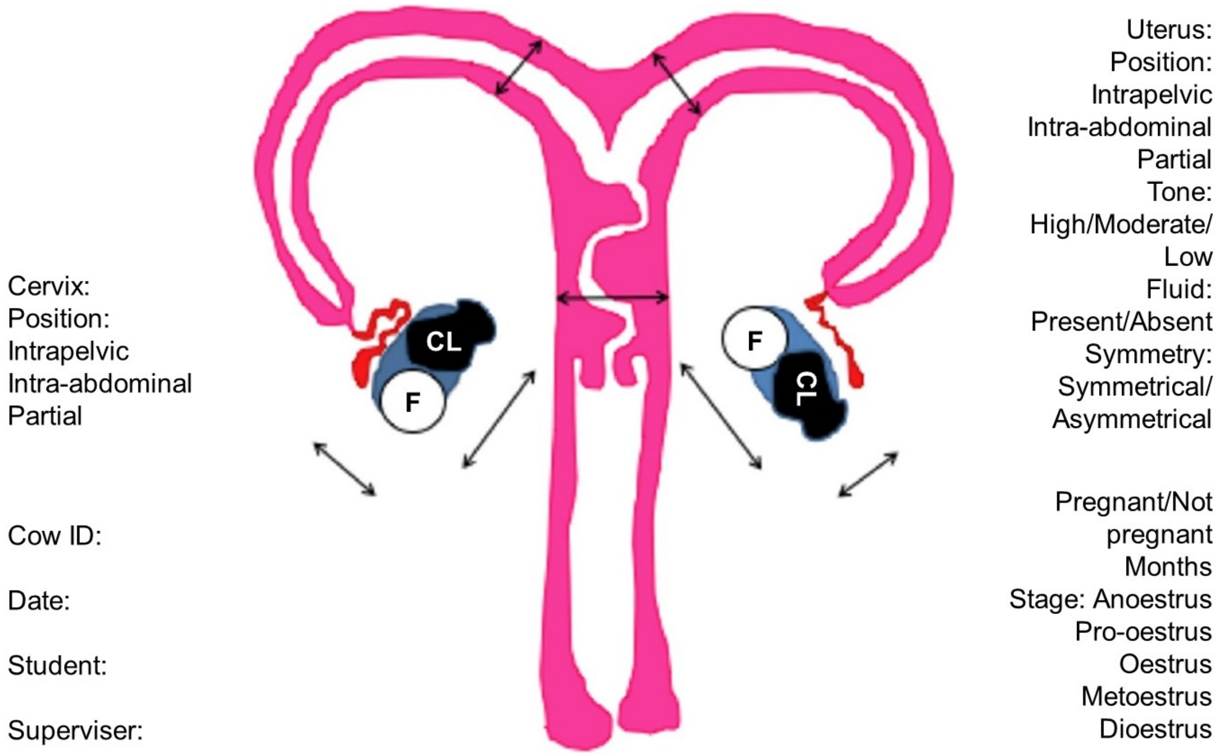


Figure 2 Objective structured clinical examination (OSCE) marking sheet for the bovine transrectal palpation (TRP) station filled in by 128 fourth-year veterinary students in November 2015. Students recorded their TRP findings by ticking the correct option on the OSCE marking sheet and writing down their findings where applicable.

CL = corpus luteum; F = follicle

Table 1 Categorisation of palpation skills for student feedback purposes. To determine the palpation skills level only the points of the objective structured clinical examination (OSCE) sheet were considered that actually measured students' ability to palpate. Maximum possible score was 9.

Scores*	Palpation skill categorisation
0-1	No palpation skills
2-3	Deficient palpation skills
4-5	Some palpation skills
6-7	Good palpation skills
8-9	Competent in palpation

*Scores included to determine palpation skill categorisation:
Did the student correctly identify the position of the uterus (intrapelvic/intra-abdominal/partially intra-abdominal)?
Did the student correctly indicate the tone of the uterine horns (high/moderate/low)?
Did the student estimate the diameter of the cervix within 1 cm of the actual measure (as determined by two experienced veterinarians)?
Did the student correctly identify the presence or absence of asymmetry between the uterine horns?
Did the student correctly identify the length of both ovaries within 1 cm of the actual measure (as determined by two experienced veterinarians)?
Did the student correctly identify the presence or absence of a palpable corpus luteum on the left ovary?
Did the student correctly identify the presence or absence of a palpable corpus luteum on the right ovary?
Did the student correctly identify the presence or absence of a follicle > 9 mm on the left ovary?
Did the student correctly identify the presence or absence of a follicle > 9 mm on the right ovary?

No cow was palpated more than three times during the additional training. Training session 3 entailed bovine PD via TRP on BB models. The BB simulators were set up using the seven different uteri models to allow for palpation of weekly pregnancy stages from six to 11 weeks, and four to five months of gestation.[10]

All students visited a commercial Nguni beef cattle herd three weeks after training where their accuracy to correctly diagnose pregnancy status and stage by TRP was assessed. Each student was allowed 12 minutes to palpate a total of six cows transrectally of which the pregnancy status and stage was predetermined by a specialist veterinarian with more than 10 years of experience (a second specialist was available to confirm findings in case of doubt on pregnancy status or stage). Individual cows were palpated by a maximum of three students (Figure 4). Students were blinded to each other's diagnoses. Cows were not formally randomised but taken into the crush in a convenient manner out of a group of available cows. Each cow was only used and palpated on one of the three assessment days.

Data analysis

Data per palpation performed were transferred from individual data capture sheets into a computer spreadsheet. Categorical data were described as frequencies, proportions and 95% CIs. Student's overall accuracy of PD was estimated as the proportion of correct diagnoses (pregnant or not pregnant, and correct staging of pregnancy where applicable according to the experienced veterinarian). Sensitivity was defined as the proportion of cows determined to be pregnant by the specialist veterinarian that were correctly identified by the student. Specificity was defined as the proportion of non-pregnant cows as determined by the specialist veterinarian correctly identified by the student. Sensitivity and specificity were estimated using a generalised linear model assuming a binomial error distribution and included random effects terms for students (each student examined multiple cows) and individual cows (the same cow was examined by up to 3 students). The effects of student's practical assessment scores on estimates of sensitivity and specificity were evaluated using univariate logistic regression. OSCE reliability was assessed by estimating Cronbach's alpha. Commercial software was used for all statistical analyses (IBM SPSS Statistics V.24, International Business Machines) and results were interpreted at the 5% level of significance.

Results

The study population consisted of 128 fifth-year veterinary students of which 96 students were female and 32 were male (75 and 25%, respectively).

All 128 students had passed the Veterinary Reproduction module during their fourth-year of study (2015). Based on the bovine TRP OSCE station results from November 2015, 18 students (14.1%) had no palpation skills; 26 students (20.3%) had deficient palpation skills; 35 students (27.3%) had some palpation skills; 35 students (27.3%) had good palpation skills; and 14 students (10.9%) had competent palpation skills (Figure 5).

On the day of the practical PD assessment five months after the bovine TRP OSCE examination, 374/771 (49%) student palpations were performed on pregnant cows, of which 262 were on cows <6 months (70%) pregnant and 112 were on cows at least six months (30%) pregnant. The remaining 397 student palpations were performed on non-pregnant cows. One hundred and twenty-five students palpated six cows in the 12 minutes' time limit. One student did not finish on time and only palpated five cows. Two students only examined non-pregnant cows initially and were subsequently assigned two pregnant cow palpations. This occurred because the order that cows entered the crush was haphazard without consideration of pregnancy status. Compared with the diagnoses provided by the experienced veterinarian, the mean overall student accuracy of PD was 61% (95% CI 55-65%) for pregnancy status alone and 31% (95% CI 27-36%) for pregnancy status with correct stage. The mean sensitivity (to correctly identify pregnant cows) was 79% (95% CI 73-83%). The mean specificity (to correctly identify non-pregnant cows) was 42% (95% CI 35-49%). The student's ability to correctly estimate ovary dimensions during the previous OSCE was positively correlated to PD sensitivity (Table 2). The student's ability to correctly identify uterine position, absence of intrauterine fluid and a student classification into the category 'competent palpation skills' at the time of the OSCE was positively associated with the ability to correctly identify non-pregnant cows (PD specificity) at the subsequent practical PD assessment (Table 3).

Cronbach's alpha for the 15 items within the OSCE station was 0.78.

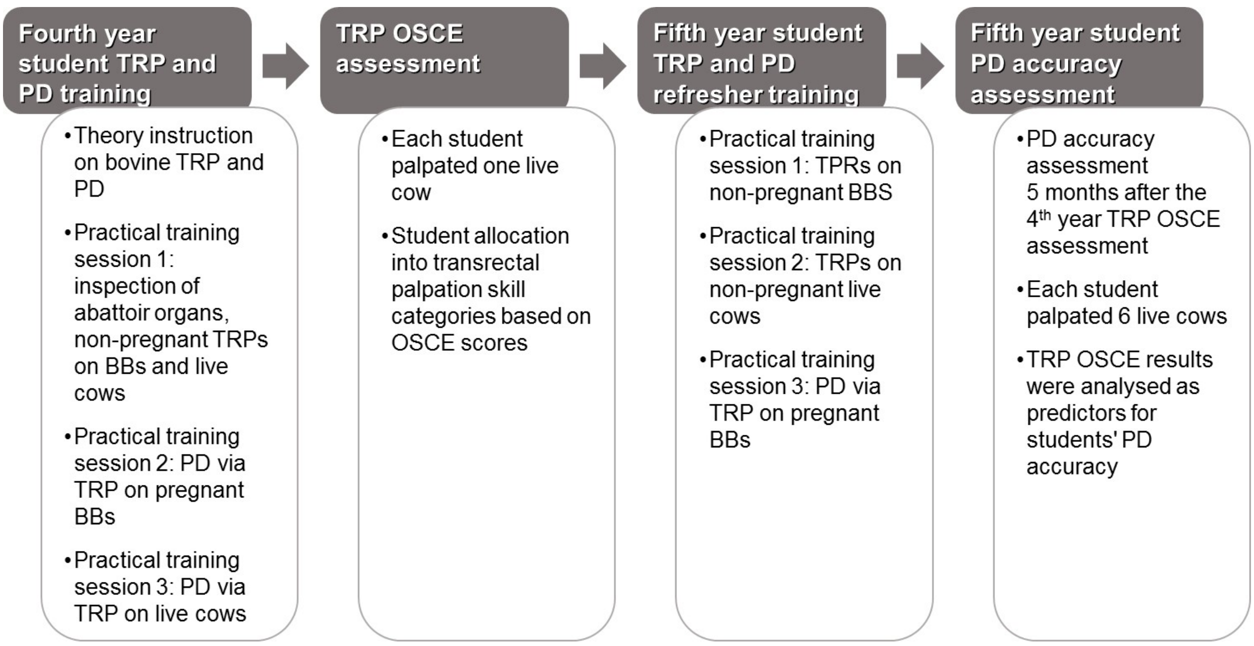


Figure 3 Schematic display of the fourth- and fifth-year TRP and PD training and assessment for 128 veterinary students

BB = Breed'n Betsy®; OSCE = objective structured clinical examination; PD = pregnancy diagnosis; TRP = transrectal palpation

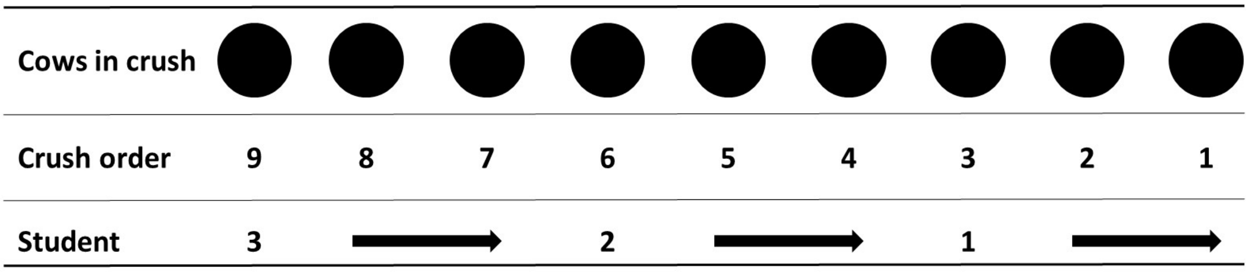


Figure 4 Schematic display of cow allocation to students. Nine cows were taken into the examination crush at the same time. The specialist veterinarian wrote down cow crush order, individual cows' identification and which cows were allocated to which student on a spreadsheet. Three students were allocated to palpate at the same time. Student 1 started at cow 3 to palpate cows 3, 2, 1, 9, 8 and 7. Student 2 started at cow 6 to palpate cows 6 to 1. Student 3 started at cow 9 to palpate cows 9 to 4. Each student noted crush order of palpated cows, individual cows' identifications and their PD findings on a data collection sheet. This data collection sheet was handed to the specialist veterinarian by the student on completion of the TRPs. Each cow was palpated by two students and subsequently by the specialist veterinarian. New cows were then taken into the crush for the next students.

Discussion

The main finding of this study is that specific OSCE scores on bovine TRPs (competence) are predictors for students' future bovine PD accuracy (performance). This seems to be more applicable for student specificity (to correctly identify non-pregnant cows) than for sensitivity (to correctly identify pregnant cows) as 'competent palpation skills' were shown to be positively correlated to student PD specificity but not sensitivity. The only individual OSCE component predicting higher student PD sensitivity was the ability to estimate ovary dimensions. This finding is in agreement with the fact that asking students to give quantitative measurements of reproductive organs during bovine TRPs was found to have a positive effect on student TRP training.[8] In order to accurately estimate ovarian size, students must be able to find the ovaries by following the uterine horns, fixing them and feel around them to give a size estimate. This skill is more advanced than simply locating the cervix and uterus. Therefore, students who are able to do that should be more successful at identifying pregnant cows as well. The ability to locate the cervix or uterus can be mastered by more students, but this is not necessarily linked to the ability to recognise a pregnant cow. The ability to correctly identify uterine position, absence of intrauterine fluid and a student classification into the category 'competent palpation skills' was positively correlated to the ability to correctly identify non-pregnant cows. The ability to correctly identify uterine position as intrapelvic or intra-abdominal is a necessary skill to identify a pregnancy and the stage thereof and indirectly linked to the ability to make the diagnosis of non-pregnancy. The same holds true for the more advanced rectal palpation skill to correctly identify absence of fluid in the uterus. This skill is necessary to identify early pregnancies, and therefore indirectly necessary to exclude pregnancy and confirm a cow to be non-pregnant. Since no cows were pregnant or had uterine pathologies such as intrauterine fluid accumulations on the day of the OSCE examination, it can be assumed that 'guess work' influenced the students' decisions when they indicated that there was fluid in the uterus. If they said there is no fluid in the uterus, it either meant that they can palpate the absence of fluid, or that they guessed correctly. It is not surprising that students categorised as 'competent' in TRP had a higher PD specificity as compared with students in all other categories. It is more difficult for students to correctly identify non-pregnant cows than pregnant cows as shown by the low PD specificity in this study and as reported previously.[10] Therefore, students with 'competent palpation skills' would be expected to have a higher PD specificity. The fact that no more individual OSCE components were predictive of sensitivity or specificity could be due to the fact that the majority of students (n = 79, 62%) had insufficient palpation skills (Figure 5). If a higher percentage of students had sufficient palpation skills (categorised as students with good or competent palpation skills) then more individual OSCE components might have been identified. The effect of guessing on the students' side may have been reduced if more students were competent at TRP. This assumes that students would fill in OSCE marking sheets with guesses if in fact they did not palpate the structure or are unsure of their findings. The 'microscopic approach' to validity[28] could be applied to evaluate whether or not individual OSCE items are appropriate and sample the domain of interest (palpation skills in this case).[28, 29] This approach evaluates validity on the fact that when item scores (individual OSCE items in this case) are valid, the total test scores (categorisation into the different palpation skill levels) should also be valid. The fact that student categorisation into 'competent palpation skills' was linked to higher PD specificity provides evidence for the OSCE validity. The reliability of an assessment is an estimation of correlation of scores on the given examination (TRP OSCE in this case) with scores on a hypothetical alternative examination or test.[30] Or in other words, reliability of an assessment is high if students who failed or passed in the evaluated assessment would be expected to also pass or fail an alternative assessment for the same skill. Alpha values across items estimate consistency of behaviour within a station and are computed using correlations between items.[30] Such an estimate would consider, for example, if students who were able to estimate cervical size were also able to estimate ovarian size correctly. A large-scale OSCE reliability meta-analysis of reported Cronbach's alpha values showed an overall mean alpha value within stations across items of 0.78 (95% CI 0.73 to 0.82).[30] The Cronbach's alpha for the 15 items within the TRP OSCE determined in this study was which indicates reasonable[30] to very good reliability.[20] The findings of this study suggest that the student's exposure within practical sessions of the fourth-year reproduction module is insufficient to ensure palpation competency. The fact that only 49 students (38%) had either good (n = 35, 27%) or competent (n = 14, 11%) palpation skills on the day of the OSCE examination, while the majority of students (n = 79, 62%) had insufficient palpation skills, confirms the need for extensive exposure to TRP in live cows to ensure competency.[7, 8, 10] It also confirms the need to investigate into alternative bovine TRP training to improve the training outcome and provide the TRP and PD competency required of new graduates.[6]

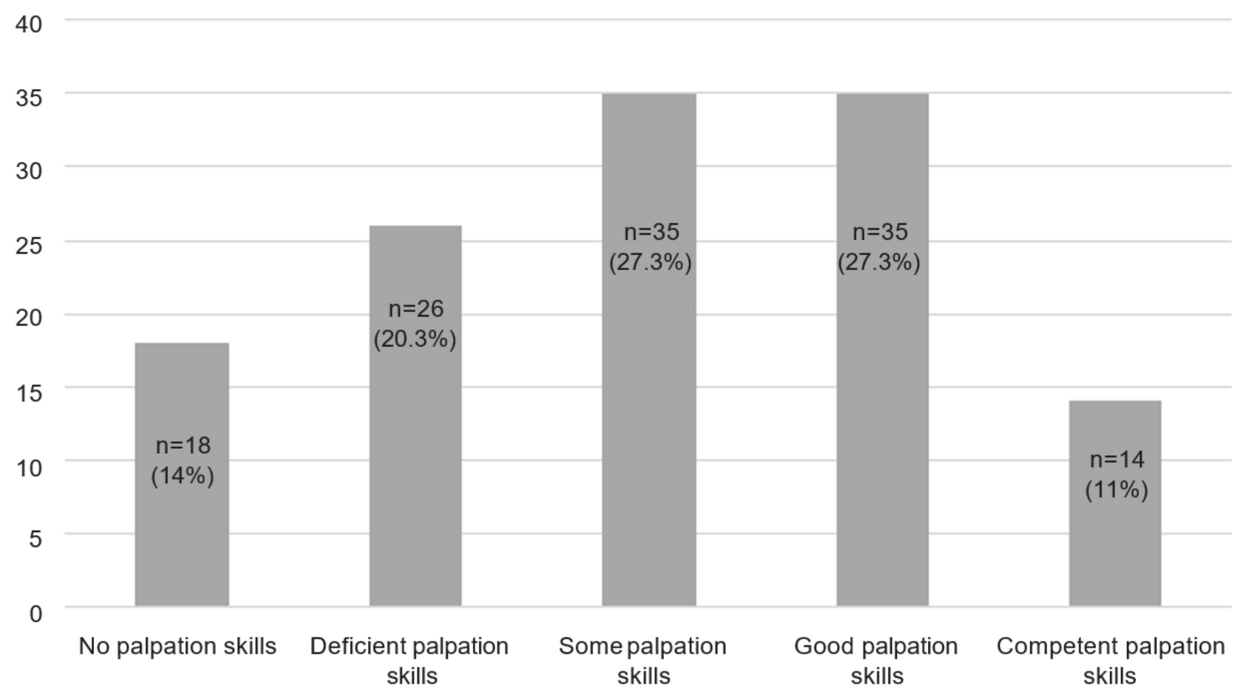


Figure 5 Number of students allocated to the individual categories of palpation skills based on the bovine transrectal palpation (TRP) objective structured clinical examination (OSCE) outcome.

Table 2 Univariate associations between student TRP OSCE assessment scores and pregnancy diagnosis sensitivity for 128 veterinary students in South Africa

Variable	Parameter estimate (β)	OR (95% CI)	P value
Hand	-0.476	0.62 (0.12 to 3.14)	0.564
Cervix position	0.058	1.06 (0.53 to 2.12)	0.869
Uterus position	-0.353	0.70 (0.41 to 1.20)	0.194
Uterine tone	0.331	1.39 (0.81 to 2.39)	0.228
Cervix diameter	-0.433	0.65 (0.37 to 1.14)	0.133
Symmetry of uterine horns	-0.183	0.83 (0.49 to 1.43)	0.505
Uterus diameter	-0.166	0.85 (0.49 to 1.45)	0.546
Intrauterine fluid	-0.013	0.99 (0.56 to 1.75)	0.965
Ovary dimensions	0.669	1.95 (1.10 to 3.48)	0.023
Corpus luteum left	0.441	1.56 (0.90 to 2.69)	0.113
Corpus luteum right	0.137	1.15 (0.67 to 1.97)	0.618
Follicle left	0.217	1.24 (0.72 to 2.13)	0.430
Follicle right	-0.042	0.96 (0.56 to 1.64)	0.877
Total*	-0.006	0.99 (0.92 to 1.07)	0.874
Palpation skills†	0.031	1.03 (0.87 to 1.22)	0.715
Competent palpation skills‡	0.183	1.20 (0.47 to 3.04)	0.699

*Sum of the 15 individual assessment components and modelled as a continuous predictor
†Ordinal scale skill left assessed by lecturer and analysed as a continuous predictor
‡The highest ordinal category compared with all other lower categories. OSCE, objective structured clinical examination; TRP, transrectal palpation

Table 3 Univariate associations between student TRP OSCE assessment scores and pregnancy diagnosis specificity for 128 veterinary students in South Africa

Variable	Parameter estimate (β)	OR (95% CI)	P value
Hand	0.600	1.82 (0.31 to 10.8)	0.507
Cervix position	-0.045	0.96 (0.46 to 1.99)	0.904
Uterus position	0.678	1.97 (1.12 to 3.47)	0.019
Uterine tone	0.335	1.40 (0.79 to 2.47)	0.247
Cervix diameter	0.492	1.64 (0.89 to 3.02)	0.114
Symmetry of uterine horns	0.162	1.18 (0.67 to 2.08)	0.576
Uterus diameter	0.360	1.43 (0.81 to 2.53)	0.215
Intrauterine fluid	0.793	2.21 (1.23 to 3.98)	0.008
Ovary dimensions	0.304	1.36 (0.76 to 2.42)	0.303
Corpus luteum left	0.305	1.36 (0.77 to 2.39)	0.291
Corpus luteum right	-0.267	0.77 (0.44 to 1.35)	0.355
Follicle left	0.527	1.69 (0.96 to 3.00)	0.072
Follicle right	0.482	1.62 (0.92 to 2.86)	0.095
Total*	0.077	1.08 (1.00 to 1.17)	0.054
Palpation skills†	0.155	1.17 (0.98 to 1.39)	0.077
Competent palpation skills‡	1.109	3.03 (1.26 to 7.29)	0.013

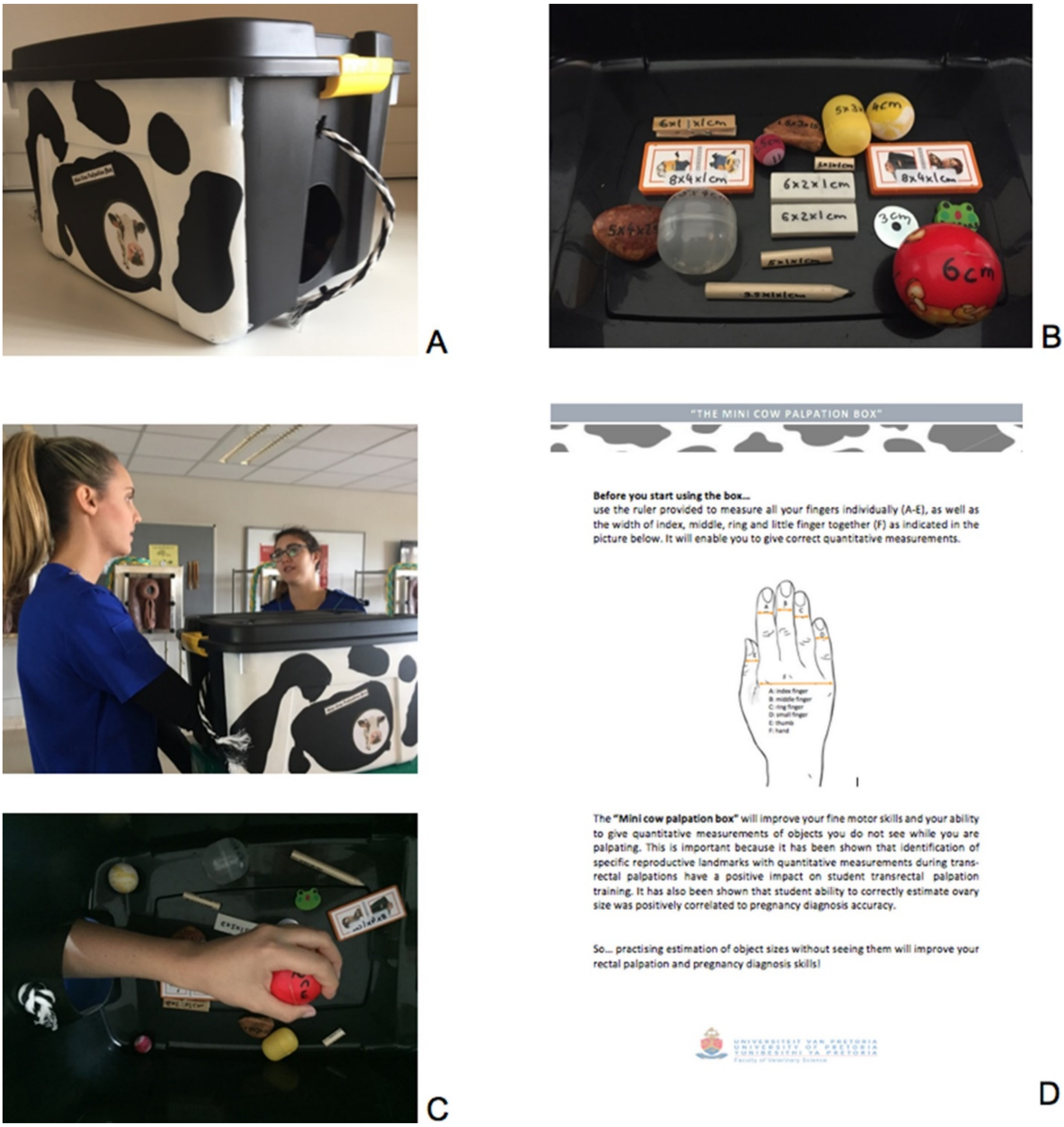


Figure 6 'Mini Cow Palpation Box'. (A) Modified plastic box with hand entrance holes. (B) Three-dimensional objects of varying sizes inside the box. All objects are labelled with the correct length, width and height measurements in centimetres. (C) Students using the palpation box. (D) Student instruction/information sheet on the palpation box.

Students' overall PD accuracy (pregnancy status alone) and PD accuracy including pregnancy status and stage was lower than what is considered acceptable accuracy for veterinarians,[16-19] and is in agreement with previous findings.[10] Overall PD accuracy for experienced large animal practitioners has been reported as high as 99.7% for TRPs performed from day 35 of pregnancy, with a sensitivity of 100% and a specificity of 99.4%.[18] While students at this stage in their studies are not expected to perform at these accuracy levels, the reported 31% overall accuracy (including pregnancy state and stage) is very low compared with the reported values of large animal practitioners. The additional palpation sessions (TRPs on non-pregnant and pregnant BBs and non-pregnant live cows) offered to the students as 'refresher' training during their fifth-year were not sufficient to ensure acceptable palpation skills. This is in accordance with previous studies,[7, 10] and confirms that additional TRP exposure is essential.

Standard criteria are necessary to determine whether an assessment measures what it is supposed to measure.[28] The validity of an assessment is demonstrated by low correlations between scores of methods measuring different traits with high correlations present between methods measuring similar traits.[28] If it is assumed that measuring palpation accuracy via a TRP OSCE and testing students' PD accuracy are two methods that measure a similar trait (TRP skill), the outcome of this study provides supporting evidence for OSCE validity because the low PD accuracy is consistent with the low percentage of students with 'good or competent palpation skills'. The fact that the majority of students were not competent in TRP is an explanation of the low overall PD accuracy, sensitivity and, especially, specificity. This is further supported by the fact that student categorisation into 'competent palpation skills' was associated with higher PD specificity. An approach to improve PD training could therefore be to introduce the TRP OSCE as a formative assessment for ongoing feedback throughout the reproduction module and to make it compulsory for students to pass the TRP OSCE with 'good or competent palpation skills' before advancing to PD training on live cows. An additional approach to improve TRP competency could be implementation of focused access to live cow palpations during later stages of the curriculum. This could involve additional TRP and PD training for students intending to follow a career in food animal practice.

Furthermore, implementation of an additional teaching tool like the 'palpation box' as described by French *et al*. is recommended.[8] This is based on the result of this study that the ability to estimate ovarian size was positively correlated to PD sensitivity. Such a tool might also help advance the fine motor skills necessary to accurately estimate the size of the cervix and uterine horns and to identify ovarian structures.[8] A locally manufactured 'Mini Cow Palpation Box' (Figure 6) has been added to TRP training sessions at our institution. It uses three-dimensional objects varying in size from 2-8 cm. All objects are labelled with the correct length, width and height measurements in centimetres. The objects are placed in a plastic box with hand entrance holes to ensure palpation and size estimation of objects without visualisation.

Conclusions

A well-structured TRP OSCE has the ability to predict students' future PD accuracy. This is more applicable for specificity than sensitivity and the categorisation of students into having 'competent palpation skills' is associated with higher PD specificity. Individual OSCE components that have been identified with higher PD accuracy are students' ability to estimate ovarian size, correctly identify uterine position and exclude intrauterine fluid. Student training should focus on these items in combination with additional palpation exposure to improve overall student PD accuracy. Furthermore, including a TRP OSCE in practical training sessions for formative feedback aiming at student improvement before advancing to PD training on live cows is recommended.

Acknowledgements

We acknowledge David and Susan Hill of Hall's Hill Farm, Doornpoort, South Africa, The Health and Welfare Sector Education and Training Authority (HWSETA), South Africa and Zoetis South Africa for their support of this study.

Funding

This study was funded through a Health and Welfare Sector Education and Training Authority (HWSETA) research grant and a University of Pretoria's Research Development Programme (RDP) grant.

Competing interests

None declared

Ethics approval

The study was approved by the Animal Ethics and Research Committee of the University of Pretoria (Protocol V122-15).

References

1. Alexander BM, Johnson MS, Guardia RO, *et al*. Embryonic loss from 30 to 60 days post breeding and the effect of palpation per rectum on pregnancy. *Theriogenology* 1995;43:551-6.

2. Romano JE, Thompson JA, Kraemer DC, *et al*. Early pregnancy diagnosis by palpation per rectum: influence on embryo/fetal viability in dairy cattle. *Theriogenology* 2007;67:486-93.

3. Romano JE, Thompson JA, Kraemer DC, *et al*. Effects of early pregnancy diagnosis by palpation per rectum on pregnancy loss in dairy cattle. *Journal of the American Veterinary Medical Association* 2011;239:668-73.

4. Romano JE, Fahning ML. Effects of early pregnancy diagnosis by per rectal palpation of the amniotic sac on pregnancy loss in dairy cattle. *Journal of the American Veterinary Medical Association* 2013;243:1462-7.

5. Morin DE, Constable PD, Troutt HF, *et al*. Individual animal medicine and animal production skills expected of entry-level veterinarians in bovine practice. *Journal of the American Veterinary Medical Association* 2002;221:959-68.

6. Luby CD, McIntyre K, Jelinski MD. Skills required of dairy veterinarians in western Canada: a survey of practicing veterinarians. *Canadian Veterinary Journal* 2013;54:267-70.

7. Bossaert P, Leterme L, Caluwaerts T, *et al*. Teaching transrectal palpation of the internal genital organs in cattle. *Journal of Veterinary Medical Education* 2009;36:451-60.

8. French HM, Dascanio JJ, Gilbert GE, *et al*. Bovine Reproductive Palpation Training: Does the Cow Make a Difference? *Journal of Veterinary Medical Education* 2018;45:219-23.

9. Baillie S. Utilisation of simulators in veterinary training. *Cattle Practice* 2007;15:224-8.

10. Annandale A, Annandale CH, Fosgate GT, *et al*. Training Method and Other Factors Affecting Student Accuracy in Bovine Pregnancy Diagnosis. *Journal of Veterinary Medical Education* 2018;45:224-31.

11. Baillie S, Crossan A, Brewster S, *et al*. Validation of a bovine rectal palpation simulator for training veterinary students. *Studies in Health Technology and Informatics* 2005;111:33-6.

12. Baillie S, Mellor DJ, Brewster SA, *et al*. Integrating a bovine rectal palpation simulator into an undergraduate veterinary curriculum. *Journal of Veterinary Medical Education* 2005;32:79-85.

13. Baillie S, Crossan A, Brewster SA, *et al*. Evaluating an automated haptic simulator designed for veterinary students to learn bovine rectal palpation. *Simulation in Healthcare* 2010;5:261-6.

14. Giese H, Gundelach Y, Dilly M. Simulationsbasiertes training der transrektalen gynäkologischen Untersuchung beim Rind. Hamburg: Düsseldorf: German Medical Science GMS Publishing House, 2014.

15. Giese H, Gundelach Y, Geuenich K, *et al*. Effects of training methods for rectal palpation in cattle on student's performance and self-evaluation. Proceedings of the AMEE conference. Glasgow, UK, 2015.

16. Warnick LD, Mohammed HO, White ME, *et al*. The relationship of the interval from breeding to uterine palpation for pregnancy diagnosis with calving outcomes in holstein cows. *Theriogenology* 1995;44:811-25.

17. Oltenacu PA, Ferguson JD, Lednor AJ. Economic evaluation of pregnancy diagnosis in dairy cattle: a decision analysis approach. *Journal of Dairy Science* 1990;73:2826-31.

18. Romano JE, Fahning ML. Accuracy of per rectum palpation for pregnancy diagnosis in cattle. Proceedings of the XXVIII World Buiatrics Congress. Cairns, Australia, 2014.

19. Alonso-Alanusa L, Galina-Hidalgo C, Romero-Zuniga JJ, *et al*. Usefulness of rectal palpation and transrectal ultrasonography in the diagnosis of gestation of the Zebu cattle in the humid tropical in Costa Rica Utilidad de la palpacion rectal y la ecografia transrectal en el diagnostico de gestacion del ganado cebu en el tropico humedo de Costa Rica. : Facultad de Ciencias Veterinarias, Universidad del Zulia, 2012:22: 9-16.

20. Hecker K, Read EK, Vallevand A, *et al*. Assessment of first-year veterinary students' clinical skills using objective structured clinical examinations. *Journal of Veterinary Medical Education* 2010;37:395-402.

21. Hodges B. Validity and the OSCE. *Medical Teacher* 2003;25:250-4.

22. Hodges BD. The objective structured clinical examination: three decades of development. *Journal of Veterinary Medical Education* 2006;33:571-7.

23. Bark H, Shahar R. The use of the Objective Structured Clinical Examination (OSCE) in small-animal internal medicine and surgery. *Journal of Veterinary Medical Education* 2006;33:588-92.

24. 24 May SA, Head SD. Assessment of technical skills: best practices. *Journal of Veterinary Medical Education* 2010;37:258-65.

25. Davis MH, Ponnamperuma GG, McAleer S, *et al*. The Objective Structured Clinical Examination (OSCE) as a determinant of veterinary clinical skills. *Journal of Veterinary Medical Education* 2006;33:578-87.

26. Rethans JJ, Sturmans F, Drop R, *et al*. Assessment of the performance of general practitioners by the use of standardized (simulated) patients. *British Journal of General Practice* 1991;41:97.

27. Irons PC, Holm DE, Annandale CH. Curricular renewal at the southern tip of africa: the 2016 veterinary curriculum at the University of Pretoria. *Journal of Veterinary Medical Education* 2017;44:440-9.

28. Van der Vleuten CP. The assessment of professional competence: developments, research and practical implications. *Advances in Health Sciences Education: Theory and Practice* 1996;1:41-67.

29. Van der Vleuten CP, Norman GR, De Graaff E. Pitfalls in the pursuit of objectivity: issues of reliability. *Medical Education* 1991;25:110-8.

30. Brannick MT, Erol-Korkmaz HT, Prewett M. A systematic review of the reliability of objective structured clinical examination scores. *Medical Education* 2011;45:1181-9.

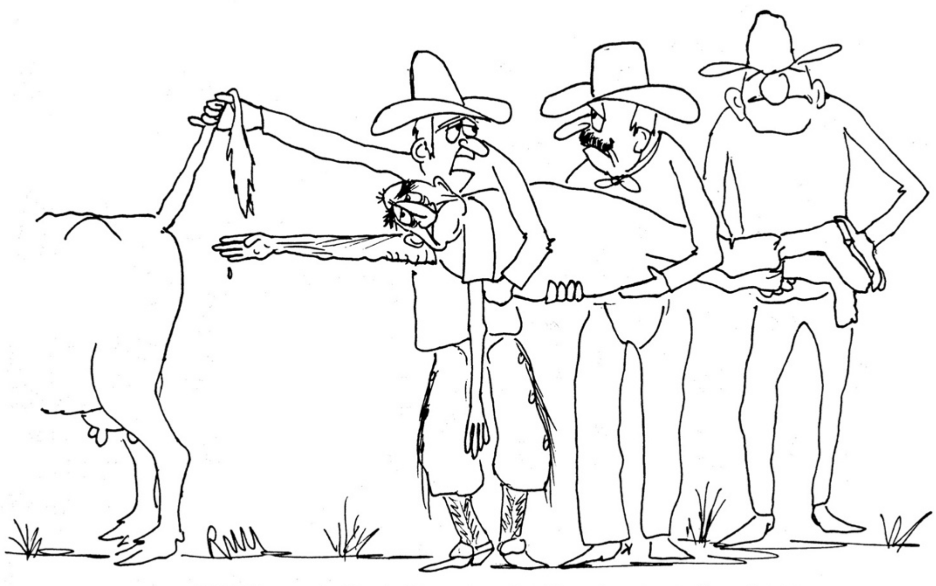
Chapter 4

Influence of an exercise programme, muscle strength, proprioception and arm length on veterinary students' bovine pregnancy diagnosis accuracy

Annett Annandale, Geoffrey T Fosgate, Carina A Eksteen, Wim D J Kremer, Harold G J Bok, Dietmar E Holm

Accepted for publication in:

Journal of Veterinary Medical Education



"Old Doc gets tired after a hundred head or so, and we try to help him out."

Abstract

Bovine pregnancy diagnosis (PD) by transrectal palpation (TRP) is an important skill for veterinary graduates. Factors influencing students' PD accuracy were investigated in order to optimize bovine PD by TRP training without increasing live animal exposure. The objective was to determine whether arm length and strength, proprioception and exposure to a six-week exercise training program were significantly associated with students' PD accuracy.

Veterinary students (n = 128) who had previously received formal theoretical and practical training in bovine TRP and PD (live cows and TRP simulators) were assessed for PD accuracy on live cows. Prior to assessment, arm muscle strength measurement, an exercise program and additional TRP sessions on Breed'n Betsy® simulators and live cows were offered to the students. Seventy-eight students volunteered to participate in the arm length measurement, muscle strength and proprioception testing. Of these students, 35 randomly allocated students completed a six-week exercise program after which muscle strength was reassessed. Each student performed PDs on six cows of which the pregnancy status was predetermined by an experienced veterinarian, and ranged from six weeks to nine months or not pregnant. Students' PD accuracy was measured as sensitivity and specificity, being defined as the proportion of pregnant or non-pregnant cows respectively, correctly identified by the student. It is concluded that hand grip strength and participation in an exercise program are significant predictors of veterinary students' PD accuracy. Implementation of an exercise program aimed at improving grip strength in the veterinary curriculum is a novel approach to improve bovine TRP and PD training.

Key words: Veterinary education, bovine pregnancy diagnosis, transrectal palpation training, veterinary students, isokinetic muscle strength testing

Introduction

Bovine pregnancy diagnosis (PD) by transrectal palpation (TRP) is one of the most frequently performed procedures in bovine practice,[1] and therefore an important skill for veterinary graduates.[2] While it is widely used in veterinary practice and is of economic importance,[3-6] it has recently been shown that fourth-year students' (of a six-year course) overall PD accuracy (pregnancy status and stage) was lower than what is considered acceptable accuracy.[7-11] It was furthermore reported that student specificity (ability to correctly identify non-pregnant cows) was lower than sensitivity (ability to correctly identify pregnant cows), and additional student training on non-pregnant cows was recommended.[10] However, providing additional TRP exposure in existing training programs is challenging since live cow training opportunities within veterinary courses are already limited and do not offer the extensive exposure needed to ensure competency.[10, 12-15] Furthermore, TRP training opportunities outside the veterinary course for veterinary students are not easily accessible.[10, 14] To overcome the shortage of live cow palpation exposure, several investigations into TRP and PD training using simulators and best training options for live cow palpations have been performed.[10, 12-14, 16-20] The effectiveness of simulators including the Breed'n Betsy® (Breed'n Betsy®, Brad Pickford, Australia, http://www.breednbetsy.com.au/) and the Haptic cow (Haptic Cow, Virtalis Ltd, Cheshire, UK, https://www.virtalis.com/haptic-cow/) has been explored.[10, 12, 16-20] While simulator training is superior to theoretical instruction only,[16, 20] live cow training results in better student PD accuracy and is therefore advised to be done in addition to simulator training to optimise the learning outcome.[10, 12] Having students identify specific reproductive landmarks such as uterine horns and ovaries with quantitative measurements and choosing cows that are easy to handle had a positive impact on TRP training through better student engagement.[13] The importance of quantitative measurements is supported by a recent study,[21] showing that students' ability to estimate ovary size, identify uterine position and palpate the presence or absence of intra-uterine fluid was positively correlated to PD accuracy. Previously reported factors that were associated with higher overall sensitivity of bovine PD by TRP were a farming background and a career interest in mixed animal practice.[10]

Palpation of the female reproductive tract is performed through the rectal wall after insertion of a gloved lubricated hand into the cow rectum. The arm and hand movements and technique for palpation of cervix, retraction of the uterus, following uterine horns and palpation of the ovaries,[22] require an unusual physical effort with repetitive motions that can cause fatigue, especially in examiners not used to TRPs. Therefore, it is hypothesized that arm strength may influence PD accuracy and that an exercise program aimed at improving arm muscle strength could improve PD accuracy amongst students. Other factors that might influence palpation accuracy are proprioception and arm length.

Proprioception was first described by Sherrington in 1906 as 'our perception of joint movement and positioning in space in the absence of visual feedback'.[23] Proprioception is critical for controlling motor activities and the importance of proprioceptive feedback during sensorimotor performance has been described.[24] Individuals who lack proprioceptive sense while the motor systems remain fully intact, show deficits in motor control.[25] These deficits include, but are not limited to, poor endpoint accuracy, reduced control of multi-segmental dynamic movements, and an inability to perform complex movement sequences.[25] Transrectal palpations involve body positioning and movement independent of vision. It is therefore hypothesized that poor proprioception could lead to lower palpation accuracy and decreased PD accuracy, while good proprioception might be linked to higher PD accuracy.

In order to optimize and investigate alternative approaches to bovine PD training that do not include live cow palpations, factors influencing student performance need to be explored. The first objective of this study was to determine if arm length and strength, and proprioception influence the accuracy of bovine PD by TRP in fifth-year veterinary students. The second objective was to determine if a six-week exercise program can improve arm strength and students' PD accuracy. It is hypothesized that greater arm length and strength, and good proprioception are positively correlated to PD accuracy. It is furthermore hypothesized that a six-week exercise program improves arm strength and students' PD accuracy. Although it is possible that sub-optimal proprioception could be addressed with physiotherapy, such a procedure was not addressed in this study.

Materials and Methods

Participants and setting

Study participants were fifth-year veterinary students (n = 128) who had successfully passed the veterinary reproduction module during their fourth-year of study. The University of Pretoria's six-year Bachelor of Veterinary Science (BVSc) program includes nine semesters of didactic pre-clinical training and three semesters of clinical work-integrated learning.[26] After obtaining written, informed consent, a subset of 78 students voluntarily enrolled into the arm length, arm strength and proprioception testing component of the experiment, of which 40 students were initially randomised within five predetermined stratified strength categories (eight per category) to participate in the six-week exercise program. Strength categories were based on best repetition shoulder extension (in NM) as determined through isokinetic muscle strength testing (shoulder extension/flexion, speed: 60° /sec for five repetitions) expressed as a per cent body weight (in kg): category 1: > 80% BW, 2: 71-80% BW, 3: 61-70% BW, 4: 51-60% BW and 5: < 50% BW, respectively. Thirty-five of the 40 students allocated to the exercise program participated and completed the program. Students (n = 128) were allocated to one of three groups. Group 1 (G1): students who volunteered for the strength testing and participated in the exercise program (n = 35), group 2 (G2): students who volunteered for the strength testing but did not participate in the exercise program (n = 43, this group includes the five students initially allocated to the exercise group but who did not participate) and group 3 (G3): students who did not participate in strength testing or the exercise program (n = 50). All three groups of students (n = 128) underwent additional fifth-year TRP and PD training, and PD assessment (Figure 1).

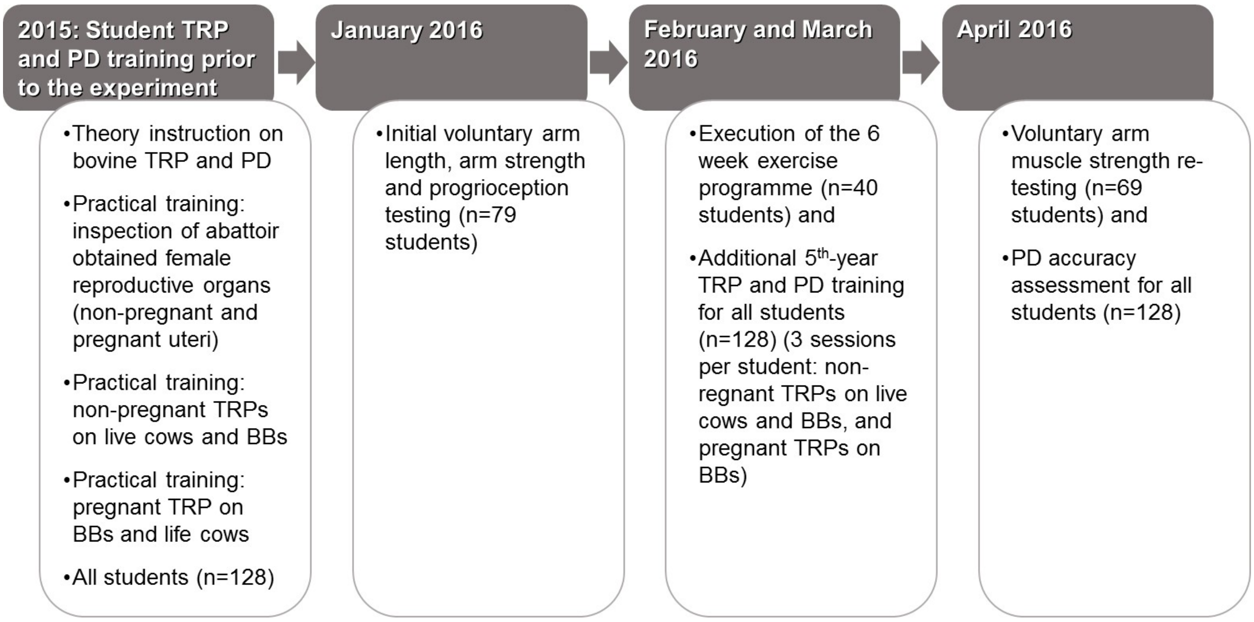


Figure 1 Schematic timeline display of the TRP and PD training, strength measurements, exercise program and PD assessment for 128 veterinary students

Student TRP and PD training prior to the experiment

The fourth-year veterinary curriculum of the University of Pretoria's six-year program includes a one-year module on reproduction of all domestic species.[26] Bovine, small stock, small animal and equine reproduction are taught separately throughout the year and one examination assesses knowledge and skills for all species. The bovine part of the veterinary reproduction module covers aspects of male and female reproduction, including TRP and PD. The fourth-year TRP and PD practical training consisted of three sessions per student presented in separate sessions to groups of 19-23 students at a time. The training periods were standardized for all student groups. The first TRP training session included three components: inspection of abattoir obtained female reproductive organs, palpation of the non-pregnant Breed'n Betsy® (BB) models and palpation of non-pregnant live cows with lecturer guidance. Abattoir obtained reproductive organs included non-pregnant uteri and pregnant uteri of various stages in effort to demonstrate important signs of pregnancy and pregnancy staging (including various fetal sizes, cotyledons, asymetrical uterine horns, and corpora lutea of pregnancy). The variety of abattoir reproductive organs was relatively similar for all student groups. The first TRP training session was presented either before or just after the theoretical lectures on PD. The second and third practical TRP training sessions followed two to three months after the PD theory component. The second TRP training session consisted of bovine PD via TRP on BB models. The BB models allowed for the palpation of weekly pregnancy stages from 6-20 weeks of gestation.[10] The third TRP training session consisted of bovine PD via TRP on live cows, one week after the PD training on BB models. Training focused on pregnancy status determination (pregnant or not pregnant) and estimating stage of pregnancy.

Additional fifth-year TRP and PD training for the 128 study participants

All 128 fifth-year veterinary students received additional supervised bovine TRP training in February and March 2016 (Figure 1). The additional bovine TRP training included three separate training sessions presented to groups of 19-23 students at a time. Training session one consisted of palpation of non-pregnant BB models. Training session two involved non-pregnant live cow palpations. Training session three entailed bovine PD via TRP on BB models. The BB models allowed for palpation of weekly pregnancy stages from six to 20 weeks of gestation. Students were also encouraged to arrange additional TRP exposure outside the formal veterinary course.

Arm strength testing, arm length measurement and proprioception testing

Testing was performed at the High Performance Centre, LC De Villiers Campus of the University of Pretoria, Hatfield, Pretoria, South Africa. All grip and isokinetic muscle strength testing was executed by experienced biokineticists. Arm length measurement and proprioception testing was done by a physiotherapist [CAE]. On arrival at the High Performance Centre, students' identification, date of birth, dominant hand and BW were recorded. Each student was weighed using a mechanical scale.

Arm muscle strength testing

Arm muscle strength measurement was subdivided into grip strength to determine hand, wrist and forearm muscle strength, and shoulder extension and flexion to measure upper arm, shoulder and back muscle strength. Muscles collectively tested via grip strength were forearm flexors (flexor digitorum superficialis, digitorum profondus and policus longus muscle), forearm extensors (extensor carpi radialis longus, carpi brevis and carpi ulnaris), and finger and thumb muscles (flexor pollicis longus, digitorum superficialis and digitorum profundus, extensor pollicis longus and brevis, extensor digiti minimi, extensor indicis, extensor digitorum). Muscles collectively evaluated via shoulder extension were the deltoid, infraspinatus, latissimus dorsi, teres major and triceps brachii muscle. Muscles collectively evaluated via shoulder flexion were the pectoralis major, anterior deltoid, biceps brachii, coracobrachialis, teres major and subscapularis muscle.

Grip strength measurement

Grip strength was measured in kilogram using the handheld digital Grip Strength Dynamometer T.K.K 5401 (Takei Scientific Instruments Co., Ltd., Niigata City, Japan). Students were standing upright with the feet hip-width apart and toes pointing forward while the arm was flexed at a 90 degree angle to the shoulder joint, palm facing down (Figure 2 F). The dynamometer was grasped between the fingers and the palm at the base of the thumb. Students were then asked to squeeze the hand grip with maximal effort for five seconds. Right and left hand grip strength was measured individually.

Figure 2 Strength and proprioception testing

A*, B, C and D: Shoulder extension and flexion test using the Humac®/Norm™ Testing System. E: Proprioception test using Contralateral Joint Position (CJP) matching task. F: Grip strength test using the using the handheld digital Grip Strength Dynamometer T.K.K 5401 (Takei Scientific Instruments Co., Ltd., Niigata City, Japan)

*Image A from the HUMAC NORM System User's Guide page 5-23
Computer Sports Medicine, Inc. (CSMI) Humac®/Norm™ Testing & Rehabilitation System User's Guide Model 770

Isokinetic shoulder extension and flexion strength measurement

The Humac®/Norm™ Testing System (Model 770, Computer Sports Medicine, Inc., Stoughton, MA, USA) was used for the isokinetic muscle strength testing. Student details (name, date of birth, gender, dominant hand, body weight) were entered into the computer system before onset of data collection to uniquely identify each data sheet and to enable the system to normalize absolute strength to BW. Absolute muscle strength was measured in torque (Newton-Meters).

The isokinetic testing evaluated muscle strength of the whole arm through shoulder extension or flexion to achieve a pre-selected fixed speed (degrees per second) against an accommodating resistance (Figure 2 A, C and D). The standard settings for speed (degrees per second) and repetitions as per manufacturer's instructions were used to measure both maximum strength (peak torque at slow speed and high resistance) and work ability (torque measurements at high speed for more repetitions and less resistance) of shoulder extension and flexion. Since torque is produced in an effort to overcome the pre-selected speed, the resistance created by the Humac®/Norm™ Testing System varies to exactly match the force applied at every point in the range of motion.

Measurements were performed with students in supine position (Figure 2 A, C and D) while holding the handle of the lever tightly (page 5-22, Humac®/Norm™ user's guide Model 770, http://www.csmisolutions.com/sites/default/files/300004d-409_humac_norm_user_guide_english_0.pdf). Both arms were tested individually. During the performance of the flexion and extension movements, students were asked to keep the wrist locked in neutral position. Each student was first tested at settings for maximum strength (speed: 60° /sec) and asked to do five repetitions. After a one-minute break, work ability testing was done at settings with less resistance (speed: 180° /sec) but more repetitions (n = 10). Strength data for shoulder extension and flexion were recorded simultaneously.

Arm length measurements

Left and right arm length was measured using a measuring tape from the shoulder joint (acromion) to the radial styloid process at the wrist and captured in centimetre. Acromion and radial styloid process were palpated and length measurements were done on fully extended arms.

Proprioception testing

Contralateral Joint Position (CJP) matching task was used to assess proprioceptive acuity by matching a reference joint angle with the opposite (i.e., contralateral) arm.[25] Since all PD assessment palpations were done left-handed by all students, the left arm proprioceptive acuity was of interest and evaluated. Students were seated upright on a chair and blind folded (Figure 2 E). The physiotherapist [CAE] then placed the student's right arm (shoulder, elbow and wrist) in a random position (Figure 2 E). The student was requested to position the contralateral left arm in exactly the same matching position as the right arm.[25] The CJP matching was performed five times at random positions and a point was allocated for each accurately matched position adopted by the student. The students' proprioceptive acuity scores were determined by the number of positions that they could accurately match. The accuracy of matching was visually observed by two trained independent observers and noted as a score out of five (one score per position). An exact match of all random positions was recorded as a 5/5 proprioception score. A 3/5 proprioception score would indicate that the student matched three of the five random positions.

The six-week exercise program

The exercise equipment for the program was purchased from Hitech Therapy CC (Bryanston, South Africa). It consisted of Yoga mats, Powercore Exercise balls (65 cm, 150 kg carrying capacity) and different strengths of TheraBand® latex exercise bands. TheraBand® exercise bands were bought in five color-coded levels of resistance. Resistance is described in kilogram at 100% elongation. TheraBand® information and allocation to students based on arm strength per % BW is shown in Table 1. After an initial two weeks of training, a subjective assessment based on individual student perception of exertion during the exercises was used to progress the student to a higher level of resistance band, where applicable. Progression of resistance bands was repeated after week four for the last two weeks of the exercise program, where applicable.

Table 1 TheraBand® information and allocation to students based on arm strength (Nm/kg BW)

TheraBand® color	TheraBand® thickness	Resistance in kg at 100% elongation	TheraBand® users	Allocation of TheraBands® based on shoulder extension in Nm/kg BW at the beginning of the exercise program
Yellow	Thin	1.3	Beginner	< 40
Red	Medium	1.7	Beginner and intermediate	40-60
Green	Heavy	2.1	Intermediate	60-70
Blue	Extra heavy	2.6	Intermediate and advanced	> 70
Black	Special heavy	3.3	Advanced	(Not allocated at the beginning of the program)

The 45-minute exercise program was presented three times a week (Mondays, Wednesdays and Fridays) from 13:00-13:45 in the skills laboratory of the Faculty of Veterinary Science, University of Pretoria. The exercise instructor demonstrating and supervising each exercise session was a physiotherapist who designed the exercise program and allocated the TheraBands® based on student strength prior to the start of the six-week exercise program (Table 1). Exercises were performed to the rhythm of music. The program was divided into individual student exercises as well as paired exercises. Each student performed all exercises during the sessions. The sessions consisted of a warm-up, progressive strengthening and endurance, and a cool down period. The warm up period of 5-10 minutes was used for elevation, retraction, protraction and depression of scapulae; rolling the scapulae through full range motion; shoulder flexion (elevation) and extension; shoulder abduction and adduction; elbow flexion and extension as well as hand warm-up exercises (quick reciprocal flexion adduction and extension abduction of the fingers, commonly known as 'finger flicking').

The progressive strengthening and endurance part consisted of exercises in sitting, kneeling and prone lying over an exercise ball, standing and lying on the mat positions (Figure 3). General exercise principles were applied to prevent students performing abnormal movements due to compensation for poor central (trunk) and/or proximal joint control. Students were therefore asked to perform all arm exercises in standing position with their knees slightly flexed while stabilizing the core (trunk muscles). TheraBands® were held using whole hand grip and not wrapped around hands or wrists at any stage (Figure 3 A-D and H-J). Exercises focused on grip strength, lower arm, upper arm, shoulder girdle and trunk muscles. An illustration of exercise types is shown in Figure 3.

Figure 3 Exercises

A. **Standing, stabilize core**: diagonal stretching the TheraBand®; reverse the action in the opposite diagonal.
Avoid low back extension and shoulder girdle elevation.
Muscles working: Trunk stabilizers, Shoulder flexors, abductors, back extensors, elbow extensors and hand muscles; Alternative arm: Shoulder extensors, abductors, elbow extensors and hand.
For external rotation maintain position but grasp the TheraBand® with the opposite hand and perform external rotation.

B. **Standing, stabilize core and one (R) arm stabilize in 90° flexion against the wall**: Rotate trunk away from the wall by horizontally abducting and extending the opposite arm.
Avoid low back extension and shoulder girdle elevation, lifting of the medial border of the scapula of the supporting arm.
Muscles working: Trunk stabilizers; Shoulder (gleno-humeral) abductors and shoulder girdle (scapulae) adductors (asymmetrical arm exercise). Alternate stabilizing arm.
Progression: stand with feet further away from the wall

C. **Standing, stabilize core and one (R) arm stabilize in 90° abduction against the wall**: Horizontal abduction of the opposite arm.
Avoid elevation of the shoulder girdles.
Muscles working: Trunk stabilizers, shoulder (gleno-humeral) abductors and horizontal (shoulder girdle) adductors. Alternate stabilizing arm.
Progression: Stand with feet further away from the wall.
Muscles work in different ranges and types of muscle work.

D. **Standing and stabilize core**: Wrap TheraBand® around the base of the skull, shoulders both in 90°.
Horizontal flexion and elbows in 90° flexion: Extend elbows while holding neck stabile in a lengthening position.
Avoid active neck extension; shoulder girdle elevation.
Muscles working: Trunk and leg muscles to stabilize during exercise. Shoulder flexors, elbow extensors and hands

E. **Supine lying with hip flexion and knee extension. Middle of TheraBand® wrapped around the feet and holding the two ends of the TheraBand® in the hands (shoulders in 90° flexion)**: Do flexion abduction with the arms while keeping the elbows in extension.
Avoid hyperextension of the low back (keep low back on the floor).
Muscles working: Trunk and hip flexors stabilizing, shoulder flexors, abductors, trunk extensors.

F. **Prone lying on an exercise ball under the hips with arms stabilizing on the floor, stabilize with arms on the floor**. Stretch 1 arm forward while stabilizing with the other arm. Alternate the arms stretching forward.
Avoid hyper-extension of the back, trunk rotation when lifting one arm, and lifting of the medial border of the scapulae.
Muscles working: Trunk, hip and one arm stabilizers. Arm stretching forward – gleno-humeral flexors and abductors, shoulder girdle adduction, anterior and posterior trunk rotators stabilizing.

G. **Stand opposite a partner. Stabilizing the trunk. Both partners hold the ball between them with the elbows in 90° flexion**. Both partners attempt to pull or rotating the ball from the other partner's hands. Both partners attempt to keep the ball still.
Avoid trunk movement.
Muscles working: trunk, arm and leg muscles stabilizing. Focus is on strengthening the forearm, wrist and hand muscles.

H. **Standing next to a partner and stabilize core**: Both partners grasp the TheraBand® with their hands and with the elbows in flexion and hands facing forward. Both partners rotate their hands towards the abdomen while keeping the elbow against the body.
Avoid movement of the body instead of medial rotation of the arm.
Muscles working: Shoulder (gleno-humeral) adduction and medial rotation.

I. **Stand on the middle of the TheraBand® holding the two end in the hands with elbows in extension**: Stabilize core while flexing the elbows through full range of motion.
Avoid shoulder girdle elevation and extension of the back.
Muscles working: Trunk and leg muscles to stabilize, elbow flexors and hands.

J. **Stand on the middle of the TheraBand®, elbows in extension and holding the two loose ends of the TheraBand® in the hands**: Do flexion-abduction of the arms with elbows in extension to full gleno-humeral range of motion.
Avoid extension of the lower back.
Muscles working: Trunk and legs stabilizing shoulder (gleno-humeral) flexors, abductors and shoulder girdle extension and adduction.

K. **Kneel on an exercise ball and stabilize with hands on the floor**. Rotate hips and knees to alternative sides while maintaining stabilizing position of the hands on the floor.
Avoid flexion and extension of the neck (keep head in mid-position).
Muscles working: trunk rotators and stabilizers, hip stabilizers, arm stabilizers, gleno-humeral rotator cuff.

L. Prone lying on an exercise ball under the thighs/knees/lower legs with arms stabilizing on the floor: Push upper body up with the arms – ensure that medial border of the scapulae are flat against the thorax.
Avoid hyper-extension of the trunk and winging of the scapulae.
Muscles working: trunk and arms stabilizing, shoulder flexors, elbow extensors, wrist flexors.

M. Prone lying on an exercise ball under the hips with arms stabilizing on the floor: While maintaining balance, clap the hands.
Avoid hyper-extension of the neck.
Muscles working: trunk stabilizers followed by back extensors, hip extensors, knee extensors and plantar flexors.

The cool down period of five minutes was used for stretching and resistance-free (free-active) exercises of all upper limb and trunk muscles that were strengthened. Stretching of the following muscles were done: triceps surae, biceps brachii, rhomboids, pectoralis minor and major, trunk extensors, as well as wrist and fingers.

Arm muscle strength re-testing

Students in the arm length, arm strength and proprioception testing part of the experiment (G1 and G2) voluntarily took part in the re-testing session in April 2016 (Figure 1). All previously described measurements were repeated for each student. Students who had participated in the exercise program were also asked to complete a questionnaire (questionnaire A) about the exercise program (Appendix 1).

PD accuracy assessment

Students' bovine PD accuracy via TRP was assessed as described previously.[10, 21] All students (n = 128) visited a commercial Nguni beef cattle herd three weeks after the third additional TRP training session. Each student completed a questionnaire (questionnaire B) on student background, previous bovine TRP and PD experience and career interest.[10] Following completion of the questionnaire, each student was allowed a total of 12 minutes to palpate six cows transrectally. The pregnancy status and stage of these cows were pre-determined by a specialist veterinarian with more than ten years' experience. A student's stage of pregnancy estimation was considered to be correct if it was within one month of the finding of the specialist for cows < 6 months pregnant according to the specialist, and if it was within two months of the finding of the specialist for cows ≥ 6 months pregnant according to the specialist. All student palpations were performed left-handed due to the examination crush set-up on the farm. Each student's pregnancy diagnoses (pregnancy status and stage) were recorded on an individual data capture sheet against the appropriate cow number, and students were blinded to each other's diagnoses.[10, 21] Cows were not formally randomised but taken into the crush in a convenient manner out of a group of available cows. Each cow was only used and palpated on one of the three assessment days.

Statistical analysis

Statistical analysis of strength measurements for first test and re-testing

Differences in strength measurements were calculated by subtracting the baseline measurements from the values determined at the end of the study. The normality assumption of these differences was assessed by calculating descriptive statistics, plotting histograms, and performing the Anderson-Darling test (MINITAB Statistical Software, Release 13.32, Minitab Inc, State College, Pennsylvania, USA). Muscle strength differences, which appeared normally distributed, were compared between the students that participated in the exercise program to those that did not using independent t tests. Statistical analysis was performed using available software (IBM SPSS Statistics Version 24, International Business Machines Corp., Armonk, NY, USA) and results were interpreted at $P < 0.05$.

Statistical analysis of factors affecting PD accuracy

Sensitivity (Se) was defined as the proportion of cows determined to be pregnant by the specialist veterinarian that were correctly identified by the student. Stage corrected sensitivity was defined as the proportion of pregnant cows in which pregnancy stage was correctly identified by the student. Specificity (Sp) was defined as the proportion of non-pregnant cows as determined by the specialist veterinarian correctly identified by the student. Overall accuracy was calculated as the proportion of cows in which the student determination of pregnancy was the same as the specialist veterinarian's. Students were divided into three groups for the calculations: (1) Students who volunteered for the strength testing and participated in the exercise program (n = 35), (2) students who volunteered for the strength testing but did not participate in the exercise program (n = 43) and (3) students who did not participate in strength testing or the exercise program (n = 50). Correlations between student-level pregnancy diagnostic accuracy (Se, Sp, accuracy) and muscle strength measures were estimated using Spearman's rho. The primary exposure of interest was student participation in the exercise program. Sensitivity is the probability that the student correctly recognized a pregnancy and therefore factors associated with the sensitivity of student pregnancy diagnosis were evaluated only within cows that were determined as pregnant by the specialist veterinarian. A generalized linear model approach was used with the outcome being the dichotomous diagnosis (pregnant/non-pregnant) of the student. Random effect terms were included in these models for student and cow to account for the study design in which a single student examined multiple cows and each cow was examined by multiple students. The effects of student factors on the pregnancy diagnosis were evaluated by screening each possible predictor one-by-one in univariate analyses that included these variables as fixed effects in the model. All variables in which $P < 0.20$ in these screening models were subsequently evaluated using a multivariable approach that included all variables identified in the screening models. Multivariable models were fit using a manual backwards stepwise procedure. Variables were removed from the multivariable model when the Student t statistic for the variable's coefficient was $P > 0.05$. The variable with the largest P-value was removed first and the model was re-run again. The removal of variables continued until all remaining factors were $P < 0.05$. Confounding was assessed by calculating the per cent change in the odds ratio for the treatment group variable (primary exposure of interest) between the model with the factor and the model after factor removal. If removal of a variable caused a > 20% change in the odds ratio then the variable was classified as an important confounder and added back into the multivariable model. Models evaluating the factors associated with student specificity were fit using the same procedures as described for sensitivity but within the subset of cows identified as non-pregnant by the specialist veterinarian. Commercial software was used for all statistical analyses (IBM SPSS Statistics Version 24, International Business Machines Corp., Armonk, NY, USA) and significance was set as $P < 0.05$.

Ethical considerations

This study was approved by the Animal Ethics and Research Committee of the University of Pretoria (Protocol V122-15). No cow was palpated more than three times in one session during the experiment.

Results

Study participants

The study population consisted of 128 fifth-year veterinary students of which 96 students were female and 32 male (75% and 25%, respectively). All 128 students had passed the Veterinary Reproduction module during their fourth-year of study in 2015. During the fourth-year training, students performed an average of five non-pregnant TRPs (live cows and BBs) and an average of 16 pregnant TRPs (live cows and BBs) during the training module.

Analysis of correctly completed questionnaires B (n = 126) showed that 39%, 33%, 17% and 9% of students indicated a career interest in small animal practice, mixed animal practice, other (specialized production animal practice, wildlife, state veterinary services, research, industry) and equine practice respectively. Only a very small proportion (2.4%) of students did not have a stated career interest. Students' palpation exposure and experience during fourth and fifth-year is summarized in Table 2.

Table 2 Fourth- and fifth-year student TRP exposure

		4th-year TRP exposure		
	Only exposed to TRPs within the veterinary course	**Some additional exposure with a veterinarian**	**Some additional exposure without a veterinarian**	
Number of students	84 (67%)[1]	16 (13%)[2]	26 (21%)[3]	
		Number of bovine TRPs performed by the end of 4th-year		
	< 10	**10-25**	**25-50**	**> 50 (range 50-300)**
Number of students	84 (67%)	27 (21%)	13 (10%)	3 (2%)
		5th-year TRP exposure		
	Only exposed to TRPs within the veterinary course	**Some additional exposure with a veterinarian**	**Some additional exposure without a veterinarian**	
Number of students (G1)	26 (74%)	3 (9%)	6 (17%)	
Number of students (G2)	33 (77%)	4 (9%)	6 (14%)	
Number of students (G3)	37 (82%)	4 (9%)	5 (11%)	
Number of students (total)[4]	96 (78%)	10 (8%)	16 (13%)	
		Number of bovine TRPs performed by the end of 5th-year TRP training		
	< 10	**10-25**	**25-50**	**> 50 (range 50-300)**
Number of students	93 (74%)	30 (24%)	2 (1.6%)	1 (< 1%)

[1]of the 84 students, 22 were in G1, 31 were in G2 and 31 were in G3
[2]of the 16 students, 4 were in G1, 3 were in G2 and 9 were in G3
[3]of the 26 students, 9 were in G1, 9 were in G2 and 8 were in G3
[4]Five students had missing data

Of the 78 students who volunteered for the initial testing (arm length measurements, grip and arm strength testing, proprioception testing) in January 2016, 69 (88%) were female and 9 (12%) male.

Sixty-nine students (88%) of the 78 who volunteered for the initial testing participated in the second testing in April 2016. Out of the 40 students allocated to the six-week exercise program, 35 students participated in and completed the program. Two students allocated to the exercise group (G1) did not attend any sessions and three students were excluded from the exercise group after the first two weeks due to inconsistent and irregular attendance. The five students who did not participate in and did not complete the exercise program were removed from G1 and analyzed with G2 participants. All 35 students who completed the exercise program participated in the second testing session in April 2016.

Allocation of students into the pre-determined strength categories is shown in Table 3.

Table 3 Allocation of students into pre-determined stratified strength categories based on initial arm strength (Nm/kg BW) for the best repetition shoulder extension (speed: 60° /sec for 5 repetitions)

	Strength categories				
	1 (> 80%)	**2 (71-80%)**	**3 (61-70%)**	**4 (51-60%)**	**5 < 50%)**
Number of students	13	17	18	18	13

Seventy-five out of 78 students (96%) who volunteered for the initial testing were right handed.

Arm length and proprioception results

Arm length (n = 79) ranged from 49.5-64.0 cm (mean +/- standard deviation: 54.7 +/- 3.2 cm). Proprioception scores (n = 70) were recorded as 2/5 for two, 3/5 for 19, 4/5 for 33 and 5/5 for 25 students (median: 4/5).

Grip strength results for the initial testing

Right hand grip strength (kg) ranged from 17.1-52.4 kg (mean: 29.2 +/- 7.4 kg), with a significant gender difference (mean 26.9 kg and 43.0 kg for female and male students respectively, $P < 0.001$).

Left hand grip strength did not differ from right hand ($P = 0.206$), ranged from 16.6-50.7 kg (mean: 28.6 +/- 8.1 kg), and also differed by gender (mean 26.0 kg and 44.0 kg for female and male students respectively, $P < 0.001$).

Exercise Theraband® allocation

The initial Theraband® allocation for the 40 exercise group students were beginner (n = 10, yellow), beginner to intermediate (n = 7, red), intermediate (n = 17, green), advanced (n = 6, blue).

After two weeks of training with the initially allocated TheraBands® (Table 1), all participating students progressed to the next level of resistance bands. After week four students progressed again to the next level of resistance bands for the last two weeks of the exercise program.

Effect of the exercise program on arm and grip strength

While participation in the six-week exercise program did not increase shoulder extension and flexion strength, it did increase right grip strength ($P = 0.025$). The change of grip strength values for G1 (students who volunteered for the strength testing and participated in the exercise program) and G2 (students who volunteered for the strength testing but did not participate in the exercise program) reported as means (95% CI) were 2.31 (0.46, 4.16) and -0.38 (-1.86, 1.10) for right grip strength ($p = 0.025$), and 1.00 (-0.38, 2.38) and 0.24 (-1.03, 1.50) for left grip strength ($p = 0.413$), respectively.

PD assessment, accuracy, sensitivity and specificity results

On the day of the PD assessment, 374/771 (49%) student palpations were performed on pregnant cows, of which 262 were on cows < 6 months (70%) pregnant and 112 were on cows ≥ 6 months (30%) pregnant. One hundred and twenty-five students each palpated six cows in the 12-minute time limit. One student did not finish on time and only palpated five cows. Two students only examined non-pregnant cows initially and were subsequently assigned two pregnant cow palpations. This occurred because the order that cows entered the crush was haphazard without consideration of pregnancy status. Compared to the diagnoses provided by the experienced veterinarian, the mean overall student accuracy of PD was 61% (95% CI 55-65%) for pregnancy status alone and 31% (95% CI 27-36%) for pregnancy status with correct stage. The mean sensitivity (correctly identify pregnant cows) was 79% (95% CI 73-83%). The mean specificity (correctly identify non-pregnant cows) was 42% (95% CI 35-49%).

Sensitivity and specificity estimates for the different experimental groups (G1, G2 and G3) are presented in Table 4.

Table 4 Estimates for overall sensitivity, stage-corrected sensitivity and specificity (95% CI) for different experimental groups of students

	Testing and Exercise (G1, n = 35)	Testing and no exercise (G2, n = 43)	No testing and no exercise (G3, n = 50)
Overall sensitivity	88% (80-94%)	70% (60-79%)	79% (71-85%)
Stage-corrected sensitivity	30% (20-41%)	18% (12-28%)	20% (14-27%)
Specificity	48% (35-61%)	39% (27-53%)	39% (29-50%)

Correlation between PD accuracy, arm length, proprioception and strength measurements

Left shoulder extension and flexion strength, arm length and proprioception based on the initial strength testing results (n = 78 students) did not correlate with the students' overall palpation accuracy, sensitivity or specificity (Table 5). However, higher left grip strength was associated with higher student specificity (P = 0.039, Table 5).

Table 5 Spearman's rho correlation (P value) between measures of rectal palpation accuracy and left* biometric arm strength measures obtained from 78 fifth-year veterinary students in South Africa. Significant positive correlations are presented in bolded font.

Biometric measure	Accuracy measure			
	Accuracy	Sensitivity	Sensitivity-stage	Specificity
Ext_5 rep-L	0.057 (0.639)	0.026 (0.830)	-0.022 (0.856)	0.063 (0.607)
Ext_5 rep-L % BW	-0.044 (0.717)	-0.015 (0.904)	0.003 (0.983)	0.055 (0.655)
Ext_10 rep-L	0.111 (0.365)	0.079 (0.519)	-0.024 (0.848)	0.066 (0.595)
Ext_10 rep-L % BW	0.036 (0.767)	0.063 (0.607)	0.061 (0.619)	0.067 (0.589)
Flex_5 rep-L	0.092 (0.454)	0.060 (0.623)	0.001 (0.991)	0.055 (0.656)
Flex_5 rep-L % BW	-0.015 (0.902)	0.033 (0.791)	0.038 (0.754)	0.075 (0.545)
Flex_10 rep-L	0.097 (0.426)	0.011 (0.930)	0.037 (0.761)	0.066 (0.593)
Flex_10 rep-L % BW	0.015 (0.900)	0.022 (0.860)	0.167 (0.169)	0.135 (0.272)
GS-L	0.171 (0.161)	0.112 (0.360)	0.163 (0.181)	0.252 (0.039)
Arm length (cm)	0.071 (0.543)	-0.005 (0.964)	0.162 (0.166)	0.010 (0.934)
Proprioception	0.017 (0.886)	-0.090 (0.436)	-0.002 (0.985)	0.041 (0.727)

*only left arm strength measures were included as all palpations were done left handed by all students

Accuracy = total proportion correctly identified per student
Sensitivity = proportion of pregnant cows correctly identified by each student
Sensitivity-stage = proportion of pregnant cows in which pregnancy stage was correctly identified by the student
Specificity = proportion of non-pregnant cows correctly identified by each student
Ext_5rep_L in Torque (NM): first test shoulder extension 5 repetitions peak torque (Newton Meters) left arm
Ext_5rep_L % BW: first test shoulder extension 5 repetitions peak torque left arm in % body weight
Ext_10rep_L in Torque (NM): first test shoulder extension 10 repetitions peak torque (Newton Meters) left arm
Ext_10rep_L % BW: first test shoulder extension 10 repetitions peak torque left arm in % body weight
Flex_5rep_L in Torque (NM): first test shoulder flexion 5 repetitions peak torque (Newton Meters) left arm
Flex_5rep_L % BW: first test shoulder flexion 5 repetitions peak torque left arm in % body weight
Flex_10rep_L in Torque (NM): first test shoulder flexion 10 repetitions peak torque (Newton Meters) left arm
Flex_10rep_L % BW: first test shoulder flexion 10 repetitions peak torque left arm in % body weight
GS-L: grip strength left

Associations between student level variables and PD sensitivity

Within the univariate analysis that investigated each variable independently, student sensitivity was higher when palpating cows > 6 months pregnant but no other variables were significant (Table 6). Students were 3.2 times more likely to correctly identify pregnant cows when six or more months pregnant compared to cows that were only two to three months pregnant (reference category).

The multivariable analysis investigates the combined effects of multiple variables and these results (Table 7) showed that students who participated in the exercise program (G1) had higher PD sensitivity compared to non-participating students (G3). Students participating in the exercise program were 2.5 times more likely to correctly identify a pregnant cow compared to students that did not participate in the biometric screening or exercise programs (reference category). Furthermore, male students and students who did not indicate mixed practice as a career interest had higher PD sensitivity.

Table 6 Univariate associations between student level variables and pregnancy diagnosis sensitivity for 128 fourth-year veterinary students in South Africa

Variable	Level	Parameter estimate ($\hat{\beta}$)	Odds ratio (95% CI)	P value
Exercise program	Yes[1]	0.718	2.05 (0.97, 4.35)	0.062
	No[2]	-0.455	0.64 (0.35, 1.14)	0.129
	Non-participant[3]	Referent		
Gender	Female	-0.590	0.56 (0.28, 1.09)	0.086
	Male	Referent		
Background	Farm	-0.529	0.59 (0.29, 1.20)	0.146
	Mixed	0.084	1.09 (0.53, 2.22)	0.817
	City	Referent		
Previous experience	None	Referent		
	Non-veterinarian	-0.407	0.67 (0.34, 1.31)	0.235
	With veterinarian	0.123	1.13 (0.44, 2.92)	0.799
Additional experience	Yes	0.168	1.18 (0.59, 2.40)	0.641
	No	Referent		
Career choice	Mixed practice*	-0.553	0.58 (0.28, 1.17)	0.126
	Other	-0.116	0.89 (0.44, 1.80)	0.891
	Small animal	Referent		
Grip strength-L	< 25	Referent		
	25-30	-0.366	0.69 (0.28, 1.74)	0.433
	> 30	-0.021	0.98 (0.35, 2.72)	0.968
Pregnancy stage	2-3 months	Referent		
	4 months	-0.054	0.95 (0.35, 2.55)	0.914
	5 months	0.698	2.01 (0.86, 4.72)	0.109
	6 months	1.179	3.25 (1.36, 7.76)	0.008
	7-9 months	1.174	3.24 (1.36, 7.71)	0.008

CI = confidence interval
*Includes specialized production animal and state veterinary medicine
[1]G1 = Students who participated in testing and the exercise program (n = 35)
[2]G2 = Students who participated in testing but not the exercise program (n = 43)
[3]G3 = Students who did not participate in testing or the exercise program (n = 50)

Table 7 Multivariable associations between student level variables and pregnancy diagnosis sensitivity for 128 fourth-year veterinary students in South Africa

Variable	Level	Parameter estimate ($\hat{\beta}$)	Odds ratio (95% CI)	P value
Exercise program	Yes[1]	0.908	2.48 (1.13, 5.44)	0.024
	No[2]	-0.155	0.87 (0.45, 1.64)	0.637
	Non-participant[3]	Referent		
Gender	Female	-0.856	0.43 (0.20, 0.92)	0.030
	Male	Referent		
Career choice	Mixed practice*	-0.643	0.53 (0.29, 0.95)	0.033
	Other career	Referent		

CI = confidence interval

*Includes specialized production animal and state veterinary medicine

[1]G1 = Students who participated in testing and the exercise program (n = 35)

[2]G2 = Students who participated in testing but not the exercise program (n = 43)

[3]G3 = Students who did not participate in testing or the exercise program (n = 50)

Associations between student level variables and PD specificity

Within the univariate analysis, students with a grip strength of > 30 kg had higher PD specificity. Students with a left-handed grip strength > 30 kg were 4 times more likely to correctly identify non-pregnant cows compared to students with a grip strength < 25 kg (reference category). Furthermore, male gender, previous TRP experience with a non-veterinarian and additional experience were associated with higher PD specificity (Table 8). Male students were twice as likely to correctly identify non-pregnant cows compared to female students. Student participation in the exercise program did not have an effect on PD specificity.

Table 8 Univariate associations[#] between student level variables and pregnancy diagnosis specificity for 128 fourth-year veterinary students in South Africa

Variable	Level	Parameter estimate ($\hat{\beta}$)	Odds ratio (95% CI)	P value
Exercise program	Yes[1]	0.345	1.41 (0.72, 2.77)	0.315
	No[2]	0.013	1.01 (0.72, 2.77)	0.972
	No – participant[3]	Referent		
Gender	Female	-0.688	0.50 (0.26, 0.96)	0.037
	Male	Referent		
Background	Farm	0.201	1.22 (0.55, 2.71)	0.621
	Mixed	-0.156	0.86 (0.40, 1.82)	0.683
	City	Referent		
Previous experience	None	Referent		
	Non-vet	0.953	2.60 (1.27, 5.29)	0.009
	With vet	0.470	1.60 (0.68, 3.75)	0.278
Additional experience	Yes	0.838	2.31 (1.15, 4.63)	0.018
	No	Referent		
Career choice	Mixed practice*	0.581	1.79 (0.82, 3.89)	0.143
	Other	0.724	2.06 (0.99, 4.31)	0.054
	Small animal	Referent		
Grip strength-L	< 25	Referent		
	25-30	0.542	1.72 (0.62, 4.73)	0.293
	> 30	1.392	4.02 (1.40, 11.5)	0.010

CI = confidence interval
*Includes specialized production animal and state veterinary medicine
[#]No multivariable model significantly fit these data
[1]G1 = Students who participated in testing and the exercise program (n = 35)
[2]G2 = Students who participated in testing but not the exercise program (n = 43)
[3]G3 = Students who did not participate in testing or the exercise program (n = 50)

Student feedback on the six-week exercise program

The response rate to questionnaire A was 77%. Analysis of correctly completed questionnaires A (n = 27) showed that 93% (n = 25) enjoyed participating in the exercise program. Eighty-two per cent (n = 22) thought that their muscle strength had improved through participation in the exercise program. Fourteen students (52%) said they could feel a difference while performing rectal examinations after the exercise program, while 13 students (48%) said they could not. All 14 students who said they could feel a difference while performing rectal examinations, stated that they could do more TRPs more comfortably without becoming tired. Additional benefits other than increased arm strength and endurance mentioned by students were experiencing fun while exercising, socializing, comradery, exercising was relaxing and a stress release in between classes/studying, free and regular exercises, and learning of new exercises. What students did not enjoy was that the exercise program was offered during lunch time and on Friday afternoons. More time flexibility, a better venue and inclusion of more students was mentioned as improvement suggestions to such a program. Seventy per cent of students (n = 19) thought an exercise DVD or a mobile application (app) would be useful and utilized by students. Seven students (n = 26%) did not think that it would be useful or utilized by students, and one student was not sure. One reason given on why an exercise DVD or app would not be useful or utilized by students was that students are not inclined to do additional things in their free time.

Discussion

The attempt to improve student bovine TRP training, follows a world-wide trend to optimize TRP training and to investigate alternatives to live cow palpation training.[10, 12, 14, 16-18, 20, 27]

The main findings of this study are that participation in the six-week exercise program was correlated to a higher PD sensitivity compared to students not participating, and that a left-handed grip strength of > 30 kg was linked to higher PD specificity. This is interesting since participation in the exercise program increased only right grip strength but not whole arm strength. A possible explanation for this could be that the exercise program increased bilateral arm muscle endurance rather than total muscle strength. While strength is defined as the ability of specific muscle groups producing maximum force to overcome a resistance within a single exertion, endurance is defined as a group of muscles that can generate sub-maximal force over a sustained amount of time or through repeated movements.[28] Or in other words, 'strength endurance is the specific form of strength displayed in activities that require a relatively long duration of muscle tension with minimal decrease in efficiency'[29] Since the isokinetic strength measurements using the Humac®/Norm™ Testing System are used to measure total muscle strength in torque (Newton-Meters) and not endurance, an increase in endurance amongst the participants might not have been noticed. This could also explain why none of the shoulder extension and flexion strength measurements were correlated to PD accuracy. The fact that only right grip strength improved through participation in the exercise program might be explained by the fact that 34 out of 35 exercise group students (97%) were right handed. This is in conformance with estimates that 90% of the general human population are right handed,[25] and that the dominant hand in right-handed people is consistently stronger than the non-dominant left hand.[30] Executing exercises using the dominant hand is generally easier and might have resulted in more improvement compared to the left non-dominant hand. We hypothesize that in right-handed participants, the exercise program would not have restored the strength balance between left and right hand and forearm. Grip strength includes hand (finger and thumb muscles), wrist and forearm (forearm flexors and extensors) muscle strength and is an important indicator for upper limb strength and endurance.[31, 32] The fact that a left-handed grip strength of > 30 kg was correlated to higher PD specificity suggests that strength of forearm flexors and extensors as well as hand muscles are more important for TRPs than total strength of upper arm, shoulder and trunk muscles (deltoid, infraspinatus, latissimus dorsi, teres major and triceps brachii, pectoralis major, biceps brachii). It could further indicate that the generally higher upper limb strength and endurance that is linked to higher grip strength,[31, 32] has a positive effect on PD accuracy. The application of this would be to modify the exercise program to concentrate on upper arm, shoulder and trunk muscle endurance training and include more specific exercises targeting grip strength. Grip strength testing is executed using hand-held, readily available dynamometers that could be used by veterinary training institutions for grip strength testing. This might motivate students to exercise in order to improve grip strength and to track progress during an exercise program. The finding that left-handed grip strength of > 30 kg is only linked to increased PD specificity but not sensitivity suggested that palpating non-pregnant uteri not only require more practice, but also more strength, and might play an important role in the general lack in specificity, compared to sensitivity of PD of veterinary students.[10, 21]

Students' overall PD accuracy (pregnancy status alone) and PD accuracy including pregnancy stage was lower than what is considered acceptable accuracy for veterinarians,[7, 8, 9, 11] and is in agreement with previous findings.[10, 21] Overall PD accuracy for experienced large animal practitioners has been reported as high as 99.7% for TRPs performed from day 35 of pregnancy, with a sensitivity of 100% and a specificity of 99.4%.[8] While students at this stage in their studies are not expected to perform at these accuracy levels, the reported 31% overall accuracy (including pregnancy stage) is very low compared to the reported values of large animal practitioners. The additional palpation sessions (TRPs on non-pregnant and pregnant BBs and non-pregnant live cows) offered to the students as 'refresher' training during their fifth-year was not sufficient to ensure acceptable palpation skills. This is in accordance with previous studies,[10, 12] and highlights that additional TRP exposure is essential. Student specificity was similarly low as described in a previous report.[10] This confirms the importance of using non-pregnant cow TRPs to obtain PD skills and that TRP training should focus on non-pregnant cow palpations to improve PD skills and student PD specificity as previously described.[10] This approach is further supported by the findings of this study that students' previous and additional palpation experience was associated with higher PD specificity (Table 8). The lower sensitivity of pregnancy detection for cows in early stages of pregnancy is in agreement with previous findings.[9, 10]

Arm length and proprioception were not significantly associated with students' overall palpation accuracy, sensitivity or specificity. Therefore, smaller students or veterinarians with relatively shorter arms are not necessarily at a disadvantage when performing bovine TRPs. The reason that proprioception did not have an effect on PD accuracy could be explained by the fact that the median proprioception score was 4/5, which indicates that the majority of students have a good perception of joint movement and positioning in space in the absence of visual feedback.[25] If more students had low initial proprioception scores then an association with palpation ability might have been apparent, therefore further research into this using a more diverse population in terms of proprioceptive ability is warranted.

Other student-level variables that were associated with PD accuracy were gender, career choice as well as previous and additional experience. PD sensitivity and specificity were higher for male students. It is well described that grip strength for men is higher than women,[33-36] and shown in our data as well. However, our data could not confirm or rule out the hypothesis that gender differences in grip strength is an important explanation of gender differences in PD accuracy reported here and elsewhere. Further studies are warranted to investigate these gender differences, in order to target PD by TRP training of veterinary students, especially in light of the fact that female students are over-represented in veterinary student populations.

A career choice other than mixed practice was associated with higher PD sensitivity. This is interesting as a previous study found that students from a farming background with an interest in mixed practice had higher PD sensitivity.[10] That study hypothesized that previous animal exposure and experience by growing up on a farm and interest in large animals seems to be positively correlated with large animal clinical skills including bovine PD via TRP[10] The fact that this study showed the opposite might indicate that career interests and large animal skills might be influenced by additional factors in different student cohorts. It might also be influenced by the fact that the previous study investigated a fourth-year and this study at a fifth-year student cohort (out of a six-year course). Background and initial experience might be overcome by additional exposures related to advancement within the veterinary course.

Interestingly, previous and additional TRP experience was only significantly associated with student PD specificity but not sensitivity. This suggests the importance of additional TRP exposure to improve PD skills by improving PD specificity, since specificity is a particular weakness amongst veterinary students.[10] Only 34% of students had previous TRP exposure outside the formal veterinary training, which is similar to a previous report.[10] The fact that the majority of students did not have any additional TRP exposure outside of what they were exposed to during the fourth-year training, confirms that despite being very important, bovine PD opportunities outside veterinary training programs are limited and not easily accessible to students.[10, 14]

Limitations of the current study include the evaluation of only a single cohort of students, self-selection into the initial muscle testing program, and the multiple independent statistical tests performed on collected data. The first two aspects could lead to selection bias and generalizability of the findings cannot be guaranteed for this reason. The alpha error rate of 5% (statistical significance level) implies that 5% of all statistical tests performed would be expected to be significant even when no true association exists within the data. It is not possible to differentiate false-positive findings from valid mathematical associations. The positive results presented in the manuscript should therefore be interpreted in combination with these potential limitations.

It was encouraging that almost all students enjoyed participating in the exercise program, that 52% of students reported that they could feel an improvement while performing rectal examinations, and that they could do more TRPs more comfortably without becoming tired. The fact that many students mentioned additional benefits such as experiencing fun, relaxation and stress relief through participation in the exercise program is an interesting 'side effect' since stress-related disorders are common amongst veterinary students world-wide.[37-45] The Center for Disease Control (CDC) declares exercise to be one of the most important activities to improve physiological as well as psychological health.[46, 47] Psychological benefits of exercising include a reduced risk for depression and anxiety, improved mood, better sleep quality, and better cognitive functioning.[37, 46, 47] However, veterinary students generally have a heavy workload in- and outside the classroom combined with stress of academic performance, which can cause other life goals such as physical activity to become less of a priority.[37] It has been identified previously that students have different motivators to exercise.[37, 48] Therefore, if participation in an exercise program not only benefits arm strength and indirectly palpation accuracy but also general student well-being, then these benefits might be sufficient motivators to include exercise programs into veterinary curricula in future. It is currently planned to modify the exercise program and make it available through an online platform (via a mobile application) to all students interested in participating. Students will then be able to exercise on their own time and choose a venue of their convenience as indicated in the student feedback.

Conclusion

Hand grip strength and participation in an exercise program are significant predictors of veterinary students' PD accuracy, while our data did not support an association between arm length or proprioception and PD accuracy. Implementation of an exercise program aimed at improving grip strength in the veterinary curriculum is a novel approach to improve bovine TRP training, with possible additional benefits to general student well-being related to exercising.

Acknowledgements

We acknowledge David and Susan Hill of Hall's Hill Farm, Doornpoort, South Africa, The *Health and Welfare Sector Education and Training Authority* (*HWSETA*), South Africa and Zoetis South Africa for their support of this study.

References

1. Morin DE, Constable PD, Troutt HF, Johnson AL. Individual animal medicine and animal production skills expected of entry-level veterinarians in bovine practice. *Journal of the American Veterinary Medical Association* 221(7):959-68, 2002.

2. Luby CD, McIntyre K, Jelinski MD. Skills required of dairy veterinarians in western Canada: A survey of practicing veterinarians. *The Canadian Veterinary Journal* 54(3):267-70, 2013.

3. Alexander BM, Johnson MS, Guardia RO, Van de Graaf WL, Senger PL, Sasser RG. Embryonic loss from 30 to 60 days post breeding and the effect of palpation per rectum on pregnancy. *Theriogenology* 43:551-6, 1995.

4. Romano JE, Thompson JA, Kraemer DC, Westhusin ME, Forrest DW, Tomaszweski Ma. Early pregnancy diagnosis by palpation per rectum: Influence on embryo/fetal viability in dairy cattle. *Theriogenology* 67:486-93, 2007.

5. Romano JE, Thompson JA, Kraemer DC, Westhusin ME, Tomaszweski MA, Forrest DW. Effects of early pregnancy diagnosis by palpation per rectum on pregnancy loss in dairy cattle. *Journal of the American Veterinary Medical Association* 239:668-73, 2011.

6. Romano JE, Fahning ML. Effects of early pregnancy diagnosis by per rectal palpation of the amniotic sac on pregnancy loss in dairy cattle. *Journal of the American Veterinary Medical Association* 243:1462-7, 2013.

7. Alonso-Alanusa L, Galina-Hidalgo C, Romero-Zuniga JJ, Estrada-Konig S, Galindo-Badilla J. Usefulness of rectal palpation and transrectal ultrasonography in the diagnosis of gestation of the Zebu cattle in the humid tropical in Costa Rica Utilidad de la palpacion rectal y la ecografia transrectal en el diagnostico de gestacion del ganado cebu en el tropico humedo de Costa Rica. Revista Cientifica, Facultad de Ciencias Veterinarias, Universidad del Zulia 22(1):9-16, 2012.

8. Romano JE, Fahning ML. Accuracy of per rectum palpation for pregnancy diagnosis in cattle. Proceedings of the XXVIII World Buiatrics Congress. Cairns, Australia2014. p 129.

9. Warnick LD, Mohammed HO, White ME, Erb HN. The relationship of the interval from breeding to uterine palpation for pregnancy diagnosis with calving outcomes in holstein cows. *Theriogenology* 44:811-25, 1995.

10. Annandale A, Annandale CH, Fosgate GT, Holm DE. Training method and other factors affecting student accuracy in bovine pregnancy diagnosis. *Journal of Veterinary Medical Education* 45(2):224-31, 2018.

11. Oltenacu PA, Ferguson JD, Lednor AJ. Economic evaluation of pregnancy diagnosis in dairy cattle: a decision analysis approach. *Journal of Dairy Science* 73:2826-31, 1990.

12. Bossaert P, Leterme L, Caluwaerts T, Cools S, Hostens M, Kolkman I, De Kruif A. Teaching transrectal palpation of the internal genital organs in cattle. *Journal of Veterinary Medical Education* 36:451-60, 2009.

13. French HM, Dascanio JJ, Gilbert GE, Robinson JQ. Bovine reproductive palpation training: does the cow make a difference? *Journal of Veterinary Medical Education* 45(2):219-23, 2018.

14. Lopes G, Rocha A. Teaching bovine rectal palpation with live cows in the slaughterhouse: Is it worthwhile? *Reproduction in Domestic Animal*s 41:510-3, 2006.

15. Penny CD. Education - a university view. *Cattle Practice* 10(4):255-6, 2002.

16. Baillie S, Crossan A, Brewster S, Mellor D, Reid S. Validation of a bovine rectal palpation simulator for training veterinary students. *Studies in Health Technology and Informatics* 111:33-6, 2005.

17. Baillie S, Mellor DJ, Brewster SA, Reid SWJ. Integrating a bovine rectal palpation simulator into an undergraduate veterinary curriculum. *Journal of Veterinary Medical Education* 32:79-85, 2005.

18. Baillie S, Crossan A, Brewster SA, May SA, Mellor DJ. Evaluating an automated haptic simulator designed for veterinary students to learn bovine rectal palpation. Simulation in Healthcare: *Journal of the Society for Simulation in Healthcare* 5:261-6, 2010.

19. Giese H, Gundelach Y, Dilly M. Simulationsbasiertes Training der transrektalen gynäkologischen Untersuchung beim Rind. Jahrestagung der Gesellschaft für Medizinische Ausbildung (GMA). Hamburg: Düsseldorf: *German Medical Science GMS Publishing House*; 2014.

20. Giese H, Gundelach Y, Geuenich K, Ehlers JP, Dilly M. Effects of training methods for rectal palpation in cattle on student's performance and self-evaluation. AMEE. Glasgow 2015.

21. Annandale A, Fosgate GT, Bok H, Holm DE. Ability of a bovine transrectal palpation objective structured clinical examination to predict veterinary students' pregnancy diagnosis accuracy. *The Veterinary Record* 185(6):171-180, 2019.

22. Youngquist RS, Threlfall WR. Current therapy in large animal theriogenology. 2nd edition, St Louis, Missouri, *Saunders Elsevier* 294-303, 1997.

23. Ager AL, Roy J-S, Roos M, Belley AF, Cools A, Hébert LJ. Shoulder proprioception: How is it measured and is it reliable? A systematic review. *Journal of Hand Therapy* 30(2):221-31, 2017.

24. Goble DJ, Noble BC, Brown SH. Where was my arm again? Memory-based matching of proprioceptive targets is enhanced by increased target presentation time. *Neuroscience letters* 481(1):54-8, 2010.

25. Goble DJ. Proprioceptive acuity assessment via joint position matching: from basic science to general practice. *Physical therapy* 90(8):1176-84, 2010.

26. Irons PC, Holm DE, Annandale CH. Curricular renewal at the southern tip of Africa: the 2016 veterinary curriculum at the University of Pretoria. *Journal of Veterinary Medical Education* 44(3):440-9, 2017.

27. Norman ST, Dall'Alba G. Computer Assisted Learning for Improving Cattle Palpation Skills of Veterinary Students. *Open Journal of Veterinary Medicine* 3(08):9, 2013.

28. O'Dell D. Strength endurance [WWW] Available from: https://www.brianmac.co.uk/ articles/scni16a7.htm [Accessed 31/1/2019]. 2004.

29. Siff MC. Supertraining. Supertraining Institute, Denver, CO. 2000.

30. Yang F, Liu Z-L, Lam W-K, Ma R-Y. Hand grip and pinch strength in young and middle-aged Chinese adults. 8th World Congress of Biomechanics, DOI:10.13140/RG.2.2.25833.548802018.

31. Trosclair D, Bellar D, Judge LW, Smith J, Mazerat N, Brignac A. Hand-grip strength as a predictor of muscular strength and endurance. *The Journal of Strength & Conditioning Research* 25, 2011.

32. Ruprai R, Tajpuriya S, Mishra N. Handgrip strength as determinant of upper body strength/physical fitness: a comparative study among individuals performing gymnastics (ring athletes) and gymnasium (powerlifters). *International Journal of Medical Science and Public Health* 5:1167-1172, 2015

33. Angst F, Drerup S, Werle S, Herren DB, Simmen BR, Goldhahn J. Prediction of grip and key pinch strength in 978 healthy subjects. *BMC musculoskeletal disorders* 11:94-100, 2010.

34. Hogrel J-Y. Grip strength measured by high precision dynamometry in healthy subjects from 5 to 80 years. *BMC Musculoskeletal Disorders* 16(1):139, 2015.

35. Cuesta-Vargas A, Hilgenkamp T. Reference values of grip strength measured with a jamar dynamometer in 1526 adults with intellectual disabilities and compared to adults without intellectual disability. *Plos One* 10(6):e0129585-e, 2015.

36. Massy-Westropp NM, Gill TK, Taylor AW, Bohannon RW, Hill CL. Hand grip strength: age and gender stratified normative data in a population-based study. *BMC Research Notes* 4(1):127, 2011.

37. Royal KD, Hunt SA, Gonzalez LM, Lewbart GA, Bailey KM. Veterinary medical students' motivations for exercise. *Journal of Veterinary Medical Education* (JVME) (Preprints):1-7, 2018.

38. Killinger SL, Flanagan S, Castine E, Howard KAS. Stress and depression among veterinary medical students. *Journal of Veterinary Medical Education* 44(1):3-8, 2017.

39. Bakker DJ, Lyons ST, Conlon PD. An Exploration of the relationship between psychological capital and depression among first-year doctor of veterinary medicine students. *Journal of Veterinary Medical Education* 44(1):50-62, 2017.

40. Cardwell JM, Lewis EG. Vocation, Belongingness, and Balance: A qualitative study of veterinary student well-being. *Journal of Veterinary Medical Education* 44(1):29-37, 2017.

41. Drake AAS, Hafen M, Jr., Rush BR, Reisbig AMJ. Predictors of anxiety and depression in veterinary medicine students: a four-year cohort examination. *Journal of Veterinary Medical Education* 39(4):322-30, 2012.

42. Drake AS, Hafen M, Jr., Rush BR. Promoting well-being among veterinary medical students: protocol and preliminary findings. *Journal of Veterinary Medical Education* 41(3):294-300, 2014.

43. Drake AAS, Hafen M, Rush BR. A decade of counseling services in one college of veterinary medicine: veterinary medical students' psychological distress and help-seeking trends. *Journal of Veterinary Medical Education* 44(1):157-65, 2017.

44. Weston JF, Gardner D, Yeung P. Stressors and protective factors among veterinary students in New Zealand. *Journal of Veterinary Medical Education* 44(1):22-8, 2017.

45. Bartram DJ, Baldwin DS. Veterinary surgeons and suicide: a structured review of possible influences on increased risk. *The Veterinary Record* 166(13):388-97, 2010.

46. Centers for Disease Control (CDC). Physical activity and health. Atlanta, GA: CDC 2015. Available from: https://www.cdc.gov/physicalactivity/basics/pa-health/index.htm.

47. President's Council on Fitness, Sports & Nutrition. Physical activity guidelines for Americans. Washington, DC: US Department of Health and Human Services. 2017. Available from: https://www.hhs.gov/fitness/be-active/physical-activity-guidelines-for-americans/.

48. Kulavic K, Hultquist CN, McLester JR. A comparison of motivational factors and barriers to physical activity among traditional versus nontraditional college students. *Journal of American college health* 61(2):60-6, 2013.

Appendix 1:
2016 PD Challenge exercise program questionnaire

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Faculty of Veterinary Science

2016 PD Challenge exercise program questionnaire

Date:
Name
Student number
Gender
Did you enjoy the exercise programme?
Which aspects did you not enjoy?
How could such a programme be improved?
What benefits did you get out of the exercise programme?
Do you think your muscle strength has improved through participation in the exercise programme?
If yes, could you specify which aspect/ aspects (whole arm strength, endurance, grip strength, etc.)?
Do you feel a difference while performing rectal examinations after the exercise programme?
If yes, please specify (less tired during rectal palpations, can do more rectal exams comfortably, etc.)
Do you think an exercise DVD/APP would be useful and utilized by students?
Additional comments/ suggestions

Author information

Annett Annandale, DrMedVet, MSc, Diplomate ACT, is Senior Lecturer and Skills Laboratory Manager, Faculty of Veterinary Science, University of Pretoria, Private Bag X04, Onderstepoort, 0110, South Africa. Email: annett.annandale@up.ac.za. Her research interests include veterinary education and equine reproduction.

Geoffrey T Fosgate, DVM, PhD, Diplomate ACVPM, is a Professor of Veterinary Epidemiology in the Department of Production Animal Studies, Faculty of Veterinary Science, University of Pretoria, Private Bag X04, Onderstepoort 0110, South Africa. Email: geoffrey.fosgate@up.ac.za. His area of research is analytical epidemiology and the study of diseases at the wildlife-livestock interface.

Carina A Eksteen, BSc Physiotherapy, MEd, PhD is a Professor in Physiotherapy and research fellow in the Physiotherapy department, School of Health Care Sciences at the Sefako Magatho Health sciences University, Garankuwa Pretoria, South Africa. Email: carina.eksteen@smu.ac.za.

Wim D J Kremer, Professor, Diplomate ECHM is Vice Dean of Education and Head of School of the Faculty of Veterinary Medicine, Utrecht University, The Netherlands. He is professor of Farm Animal Health and currently heading the Centre of Quality Improvement in Veterinary Education. Email: w.d.j.kremer@uu.nl. His research interests include educational research.

Harold G J Bok, PhD DVM, is an assistant professor at the Centre of Quality Improvement in Veterinary Education, Faculty of Veterinary Medicine, Utrecht University, Utrecht, The Netherlands. Email: g.j.bok@uu.nl. His research interests include work-based learning and assessment, programmatic assessment, feedback, and expertise development.

Dietmar E Holm, BVSc, MSc, PhD, Associate Professor, is Deputy Dean, Teaching and Learning, Faculty of Veterinary Science, University of Pretoria, Private Bag X04, Onderstepoort, 0110, South Africa. Email: dietmar.holm@up.ac.za. His research interests include bovine herd health and veterinary education.

Chapter 5

Electromyographic analysis of muscle activation patterns and muscle activity levels during bovine transrectal palpation

Annett Annandale, Geoffrey T Fosgate, Carina A Eksteen,
Wim D J Kremer, Harold G J Bok, Dietmar E Holm

Under review in:

Journal of Veterinary Medical Education

Abstract

The unusual and tiring physical activity of bovine transrectal palpation (TRP) requires a novel approach to improve students' TRP and pregnancy diagnosis (PD) skills. It has been shown that students who participated in an exercise programme, and students who had a grip strength (GS) of more than 30 kg performed better in bovine PDs. Participation in the exercise programme increased students' sensitivity (ability to identify pregnant cows) but did not increase total arm muscle strength. In order to identify which muscles are used during TRPs and to improve the exercise programme, an electromyographic (EMG) analysis was used to identify muscle activation patterns and muscle activity levels during bovine TRPs. Eight subject matter experts (SMEs) each palpated two live cows and one Breed'n Betsy® rectal examination simulator while an EMG Triggered Stimulator recorded muscle activity. Muscle activation was higher for forearm muscles compared to all other examined muscle groups ($P < 0.001$), was higher during retraction of the uterus, palpation of left and right uterine horn, compared to palpation of cervix, uterine body, left and right ovary ($P < 0.001$), was higher for antagonistic than agonistic muscles ($P < 0.001$) and showed an endurance pattern. Findings have been used to modify the previously developed exercise programme in effort to improve students' TRP and PD skills. 'The bovine PD improvement exercise programme' is available to students through an online application (http://icarus.up.ac.za/vetmlp/), and aims to not only improve GS and TRP accuracy but also stamina and wellbeing while adding fun to busy study schedules.

Key words: Veterinary education, bovine pregnancy diagnosis, transrectal palpation training, veterinary students, EMG, exercise programme, student wellbeing

Introduction

Training methods, rectal examination simulator use, and factors influencing students' TRP and pregnancy diagnosis (PD) performance have been previously studied in effort to improve bovine trans rectal palpation (TRP) student training.[1-10] A recent study evaluated if arm strength has an effect on PD accuracy, and if a six-week exercise programme aimed at improving arm muscle strength could improve PD accuracy amongst students.[11] This investigation was based on the assumption that the bovine TRP procedure[12] requires an unusual physical effort that can cause fatigue, especially in examiners not used to TRPs, which might be a factor influencing PD accuracy. It was shown that participation in the exercise programme and a grip strength of more than 30 kg are significant predictors of veterinary students' PD accuracy.[11] Students' PD accuracy was described as sensitivity (ability to correctly identify pregnant cows) and specificity (ability to correctly identify non-pregnant cows). Students participating in the exercise programme were 2.5 times more likely to correctly identify a pregnant cow compared to students not participating.[11] Students with a grip strength > 30 kg had a higher PD specificity and were four times more likely to correctly identify non-pregnant cows compared to students with a grip strength < 25 kg (reference category). However, total arm strength (shoulder extension and flexion strength), did not correlate with students' overall palpation accuracy, sensitivity or specificity.[11] Participation in the six-week exercise programme also did not increase total arm strength. A possible explanation for this could be that the exercise programme increased arm muscle endurance rather than total muscle strength.[11] Since isokinetic strength measurements were done using the Humac®/Norm™ Testing System that measures total muscle strength in torque (Newton-Meters) and not endurance, an increase in endurance amongst the participants might not have been detected.[11] This would also explain why none of the whole arm strength measurements were correlated to PD accuracy. These findings warrant further investigation into which muscle groups are used during bovine TRPs and to describe muscle activation patterns during TRPs. Electromyographic (EMG) analysis has been used to describe other movements including pedaling.[13] Muscle activation pattern and muscle activity levels provide information on a specific movement technique.[13] Since no EMG information is available on bovine TRP, an investigation using this technique is warranted to follow up on the recent grip strength and exercise programme data related to students' PD accuracy.[11]

Student PD sensitivity for early pregnancy stages is lower for students trained on BB rectal examination simulators compared to students trained on live cows even though the live cow training did not include early pregnancy stages.[3] This is counterintuitive since the BB simulators are specifically designed to improve early pregnancy detection. A possible explanation for this apparent contradiction could be that overcoming the unusual experience of TRP may be more difficult than the actual ability to palpate.[3] Another possible explanation could be that rectal examination simulators do not imitate the same movements and muscle activations during TRPs as the same procedure on live animals. This could be due to the absence of rectal peristalsis, anal sphincter tone, and other internal organs such as a bladder and rumen. A difference in muscle activation could be a potential reason for the variation in training outcomes for BB and live cow trained students. An investigation into this phenomenon could give insights into why simulator training does not have the same outcome as live cow training.

Endurance is described as 'the specific form of strength displayed in activities that require a relatively long duration of muscle tension with minimal decrease in efficiency'.[14] The performance of TRPs might require endurance due to the necessary repetitive motions. Differentiation of total muscle strength (defined as the ability of specific muscle groups producing maximum force to overcome a resistance within a single exertion), and muscle endurance (defined as a group of muscles that can generate sub-maximal force over a sustained amount of time or through repeated movements),[15] during TRPs could be useful information to modify the previously described exercise programme in order to optimize the positive benefits on TRP performance.

This study aims to use EMG analysis to evaluate which muscle groups are activated during TRPs and to identify muscle group contraction patterns during the same movement (TRP). Another objective was to compare muscle activation between live cow and BB TRPs.

Based on the previously reported positive predictive value of GS for PD accuracy,[11] and the fact that GS is a measure of hand and forearm strength, it was hypothesized that forearm muscles (extensors and flexors) would be the most and strongest activated muscle group during TRPs. It was also hypothesized that muscle activation for BB palpations would be less compared to live cow palpations and that the EMG patterns would show that muscle endurance rather than total strength was more important during TRPs.

Materials and Methods

EMG study

Participants in the EMG data collection

Study participants were veterinarians experienced in bovine TRP and PD [subject matter experts (SMEs)].

Study design and EMG recordings

For purposes of this observational study, SMEs (n = 8) were asked to volunteer for TRP of two non-pregnant life cows (LC) and one Breed'n Betsy® rectal examination simulator (BB, set up as a non-pregnant cow with ovaries) for EMG recording purposes. A NeuroTrac® Myo Plus 2 (MYO220A) dual channel EMG ETS (EMG Triggered Stimulator) was used to record muscle activity (Verity Medical LTD Romsey, Hampshire, UK) (Figure 1 A). Each dual conductor lead wire (one per channel) ends in a negative black-pin and positive red-pin that are connected to the electrodes. SMEs were prepared for the TRP EMG recording by placing self-adhesive round (32 mm ∅) electrodes onto the skin over the major parts of the muscles to be recorded. Skin areas were wiped using Neosafe alcohol swabs (Neomedic Limited, Hertfordshire, UK) prior to each application of electrodes to ensure correct adherence. Two electrodes were placed on the skin over each muscle body in line with the muscle fibre about 1-2 cm apart as per Neurotrac® Electrode Placement Manual. Electrode placement was done by a physiotherapist [CAE] (Figure 1 C). The electrode connected to the negative black-pin was placed near the proximal insertion of the muscle. The electrode connected to the positive red-pin was placed at the motor point of the muscle closest to the centre of the muscle mass.

Figure 1 EMG recording set up and data collection

A. NeuroTrac®Myo Plus 2 (MYO220A) dual channel EMG ETS (EMG Triggered Stimulator, Verity Medical LTD Romsey, Hampshire, UK)

B. NeuroTrac®Myo Plus 2 (MYO220A) dual channel EMG ETS: technical information and channel 1 (red) and 2 (green) EMG electrode wire plug ins

C. SME preparation for the TRP EMG recording. Placement of self-adhesive round (32 mm ∅) electrodes onto the skin over the major parts of the muscles to be recorded. Two electrodes were placed on the skin over each muscle body in line with the muscle fibre about 1-2 cm apart as per Neurotrac® Electrode Placement Manual. Electrode placement was done by a physiotherapist [CAE].
D. Connection of the dual conductor lead wire (one per channel) to the electrodes
E. EMG data collection for a BB palpation: SME is palpating while EMG data is transferred instantly via Bluetooth to a laptop using NeuroTrac Software (Verity Medical LTD Romsey, Hampshire, UK) to create the database. The assistant operates the laptop to ensure correct data capture.
F. EMG data collection for a live cow palpation
G. EMG data collection for a BB palpation
H. View of the electrode placement for triceps, posterior deltoid and rhomboid muscle

Electrodes were placed on four antagonistic muscle groups: (1) forearm muscles (forearm extensors and flexors), (2) upper arm muscles (biceps and triceps), (3) shoulder muscles (anterior and posterior deltoid muscle) and (4) shoulder girdle supportive muscles (pectoralis and rhomboid muscle) (Figure 1 D, F, H). The pins of the lead wire from the EMG device were then inserted into the electrode wire connectors (Figure 1 D). The NeuroTrac® Myo Plus 2 was placed in a moon bag secured around the waist of the SME. The EMG data were transferred instantly via Bluetooth to a laptop using NeuroTrac Software (Verity Medical LTD Romsey, Hampshire, UK) to create the database (Figure 1 E-H). Muscle activation was set at a minimum 25 μV.

Since a dual channel EMG machine was used, each muscle group had to be recorded individually. Therefore, each SME had to repeat the TRP four times per cow/BB, one palpation per one of the four muscle groups. After recording for one muscle group, lead wires were re-connected to the electrodes for the next muscle group. The TRP was subdivided into seven steps: palpation of the cervix (1), palpation of the uterine body (2), retraction of the uterus (3), palpation of the left uterine horn (4), palpation of the left ovary (5), palpation of the right uterine horn (6) and palpation of the right ovary (7). SMEs were asked to relax the arm for 2-3 sec in-between each step to enable visualization of individual steps. The SMEs could use their preferred arm for the palpations. During the palpations, one assistant operated the laptop to ensure correct data recording and saving. A second assistant ensured that the SMEs followed the palpation steps in the correct order and that SMEs relaxed arm muscles between steps. Each SME first palpated two LCs and then one BB. For each SME, 12 data sheets were recorded: (1) LC forearm flexors and extensors (cow 1 and 2), (2) LC biceps and triceps (cow 1 and 2), (3) LC anterior and posterior deltoid (cow 1 and 2), (4) LC pectoralis and rhomboid (cow 1 and 2), (5) BB forearm flexors and extensors, (6) BB biceps and triceps, (7) BB anterior and posterior deltoid and (8) BB pectoralis and rhomboid. EMG data were initially saved as graphic displays (Figures 2-4) and later exported as excel files for data analysis using a conversion function within the NeuroTrac Software.

Statistical analysis of EMG data

Continuous EMG recordings were manually categorized into the seven steps of the bovine rectal palpation examination. Area under each EMG recording was estimated using an approximate integration method as the average of adjacent EMG values multiplied by the time interval between successive recording points (trapezoid method). Total area was calculated as the sum of individual areas and categorized by step, operator, cow, and Breed'n Betsy® simulator. The time necessary to complete each step was manually determined from EMG recordings and a total muscle activation rate was calculated as the total area under the EMG curve divided by the time required to complete each examination step. Quantitative data were assessed for normality using commercial software (MINITAB Statistical Software, Release 13.32, Minitab Inc, State College, Pennsylvania, USA) by calculating descriptive statistics, plotting histograms, and performing the Anderson-Darling test. Data were descriptively presented as the median and interquartile range and transformed using the natural logarithm prior to statistical analysis. Total muscle activation rate was compared among examination steps, muscle groups, antagonists/agonists, and cow/palpation simulator using linear mixed models. Linear mixed models included a random effect term for SME and fixed effect terms for cow versus palpation simulator, examination step, muscle group, and flexor/extensor. Post-hoc comparisons were adjusted using Bonferroni correction. Similar mixed models were fit independently for each step of the examination. Commercial software (IBM SPSS Statistics Version 25, International Business Machines Corp., Armonk, NY, USA) was used to fit statistical models and significance was set as $\alpha = 0.05$.

Subjective evaluation of EMG data graphic displays

An experienced physiotherapist [CAE] subjectively evaluated the EMG data graphic display files to determine whether each muscle activation pattern indicated use of total muscle strength or endurance. Muscle activation was evaluated for each TRP step based on duration (longer/sustained activation periods indicated endurance compared to short activation periods for total muscle strength) and force of muscle activation (sub-maximal force over a sustained time period/ TRP step indicates muscle endurance and maximum force within a single exertion indicates total muscle strength).

Ethical considerations

This study was approved by the Animal Ethics and Research Committee of the University of Pretoria (Protocol V122-15).

Results

Study participants

The study population consisted of eight SMEs of which three were female and five male. Five of the SMEs (three males and two females) used their left arm for palpations while three (two males and one female) used the right arm.

The median and interquartile range for area under the EMG curve (μV) for palpation steps and muscles groups of live cow and BB TRPs are listed in Table 1.

Table 1 Median and interquartile range in micro-Volts (μV) for area under the EMG curve for individual live cow and BB TRP steps for all muscle groups listed as agonists and antagonists

Step/muscle group	Live cows		Breed'n Betsy®	
	Agonists[1] μV	Antagonists[2] μV	Agonists[1] μV	Antagonists[2] μV
Cervix palpation (1)				
Forearm	421 (266, 1087)	605 (355, 1485)	364 (208, 524)	413 (257, 673)
Arm	108 (70, 166)	235 (178, 379)	69 (45, 102)	85 (69, 240)
Shoulder	91 (39, 144)	158 (97, 253)	85 (43, 331)	115 (65, 155)
Chest	63 (24, 103)	115 (71, 144)	76 (53, 127)	84 (63, 145)
Uterine body palpation (2)				
Forearm	441 (162, 637)	314 (271, 810)	381 (143, 465)	319 (235, 449)
Arm	116 (58, 164)	240 (162, 386)	103 (78, 137)	142 (87, 317)
Shoulder	197 (102, 297)	218 (185, 346)	184 (141, 272)	131 (75, 269)
Chest	63 (28, 87)	123 (90, 148)	48 (35, 135)	50 (42, 101)
Uterus retraction (3)				
Forearm	657 (434, 1283)	941 (662, 1408)	650 (367, 1148)	496 (337, 1171)
Arm	257 (147, 415)	306 (231, 541)	259 (76, 424)	183 (145, 505)
Shoulder	234 (127, 314)	289 (247, 509)	243 (117, 405)	213 (57, 504)
Chest	82 (49, 135)	163 (109, 295)	157 (95, 211)	163 (68, 331)
L horn palpation (4)				
Forearm	942 (615, 1441)	1364 (734, 2520)	760 (366, 1200)	647 (497, 777)
Arm	346 (186, 436)	415 (360, 639)	322 (127, 417)	281 (196, 454)
Shoulder	267 (143, 480)	453 (164, 994)	526 (221, 640)	507 (143, 627)
Chest	105 (68, 141)	298 (197, 479)	158 (93, 207)	201 (173, 272)
L ovary palpation (5)				
Forearm	784 (315, 1178)	758 (537, 1094)	332 (313, 1215)	581 (494, 742)
Arm	171 (108, 222)	170 (135, 293)	112 (64, 169)	140 (78, 192)
Shoulder	196 (118, 349)	255 (131, 528)	171 (99, 312)	111 (74, 222)
Chest	76 (39, 111)	230 (125, 276)	125 (53, 281)	91 (79, 142)
R horn palpation (6)				
Forearm	824 (485, 1246)	999 (806, 1369)	964 (515, 1593)	665 (584, 773)
Arm	197 (114, 283)	267 (152, 372)	624 (188, 729)	298 (108, 374)
Shoulder	196 (123, 271)	285 (199, 442)	401 (323, 707)	238 (120, 494)
Chest	55 (45, 78)	134 (91, 235)	161 (66, 196)	181 (118, 277)
R ovary palpation (7)				
Forearm	520 (288, 720)	679 (515, 744)	387 (207, 531)	277 (126, 637)
Arm	99 (69, 394)	232 (122, 372)	142 (115, 166)	91 (54, 120)
Shoulder	133 (78, 195)	157 (82, 300)	223 (101, 321)	102 (41, 157)
Chest	69 (55, 94)	159 (88, 260)	38 (31, 84)	82 (41, 110)

[1]Agonists: Forearm extensor, biceps, anterior deltoid and pectoralis muscle

[2]Antagonists: Forearm flexor, triceps, posterior deltoid and rhomboid muscle

The median and interquartile range for rate of muscle activation (μV/s) for palpation steps and muscles groups of live cow and BB palpations are listed in Table 2.

Table 2 Median and interquartile range in micro-Volts per seconds (μV/s) for rate of muscle activation for individual live cow and BB TRP steps for all muscle groups listed as agonists and antagonists

Step/muscle group	Live cows		Breed'n Betsy®	
	Agonists[1] μV/s	Antagonists[2] μV/s	Agonists[1] μV/s	Antagonists[2] μV/s
Cervix palpation (1)				
Forearm	84 (60, 112)	119 (87, 173)	78 (68, 86)	97 (76, 129)
Arm	26 (14, 36)	50 (36, 62)	14 (11, 20)	30 (21, 36)
Shoulder	15 (11, 30)	37 (28, 59)	26 (15, 51)	28 (14, 39)
Chest	14 (10, 19)	23 (17, 31)	17 (12, 19)	17 (14, 29)
Uterine body palpation (2)				
Forearm	56 (46, 76)	80 (57, 133)	63 (55, 92)	76 (45, 123)
Arm	21 (16, 27)	46 (34, 64)	22 (15, 25)	33 (19, 55)
Shoulder	44 (22, 54)	50 (30, 64)	30 (25, 36)	33 (14, 63)
Chest	16 (9, 21)	29 (21, 40)	17 (9, 21)	17 (14, 30)
Uterus retraction (3)				
Forearm	93 (72, 101)	132 (90, 153)	83 (62, 152)	96 (47, 184)
Arm	34 (25, 58)	54 (41, 82)	40 (26, 51)	44 (31, 59)
Shoulder	34 (22, 45)	44 (34, 89)	33 (23, 61)	43 (16, 93)
Chest	16 (10, 18)	37 (24, 51)	24 (20, 38)	24 (16, 54)
L horn palpation (4)				
Forearm	104 (74, 134)	183 (92, 209)	117 (89, 165)	81 (68, 124)
Arm	35 (27, 55)	64 (46, 73)	38 (27, 54)	42 (38, 49)
Shoulder	49 (30, 62)	97 (25, 142)	69 (41, 93)	52 (22, 109)
Chest	14 (12, 21)	48 (38, 73)	20 (15, 23)	40 (19, 57)
L ovary palpation (5)				
Forearm	95 (77, 129)	109 (69, 134)	93 (54, 117)	104 (70, 152)
Arm	30 (24, 45)	44 (26, 61)	26 (12, 32)	26 (18, 31)
Shoulder	38 (25, 69)	45 (27, 99)	35 (24, 59)	30 (13, 39)
Chest	11 (8, 20)	43 (26, 51)	17 (10, 29)	18 (14, 27)
R horn palpation (6)				
Forearm	85 (70, 127)	130 (94, 185)	152 (103, 178)	94 (80, 118)
Arm	30 (26, 59)	49 (40, 59)	74 (32, 174)	43 (35, 52)
Shoulder	41 (24, 62)	46 (28, 85)	63 (40, 92)	37 (25, 64)
Chest	14 (8, 19)	34 (23, 45)	17 (11, 25)	26 (22, 34)
R ovary palpation (7)				
Forearm	68 (53, 96)	81 (54, 129)	68 (57, 91)	69 (49, 85)
Arm	21 (17, 47)	40 (28, 51)	33 (12, 52)	20 (16, 24)
Shoulder	28 (22, 36)	31 (16, 79)	32 (32, 41)	15 (11, 17)
Chest	12 (8, 16)	21 (16, 54)	10 (8, 19)	17 (13, 22)

[1]Agonists: Forearm extensor, biceps, anterior deltoid and pectoralis muscle
[2]Antagonists: Forearm flexor, triceps, posterior deltoid and rhomboid muscle

Examples of the graphic EMG data sheets are shown in Figures 2-4.

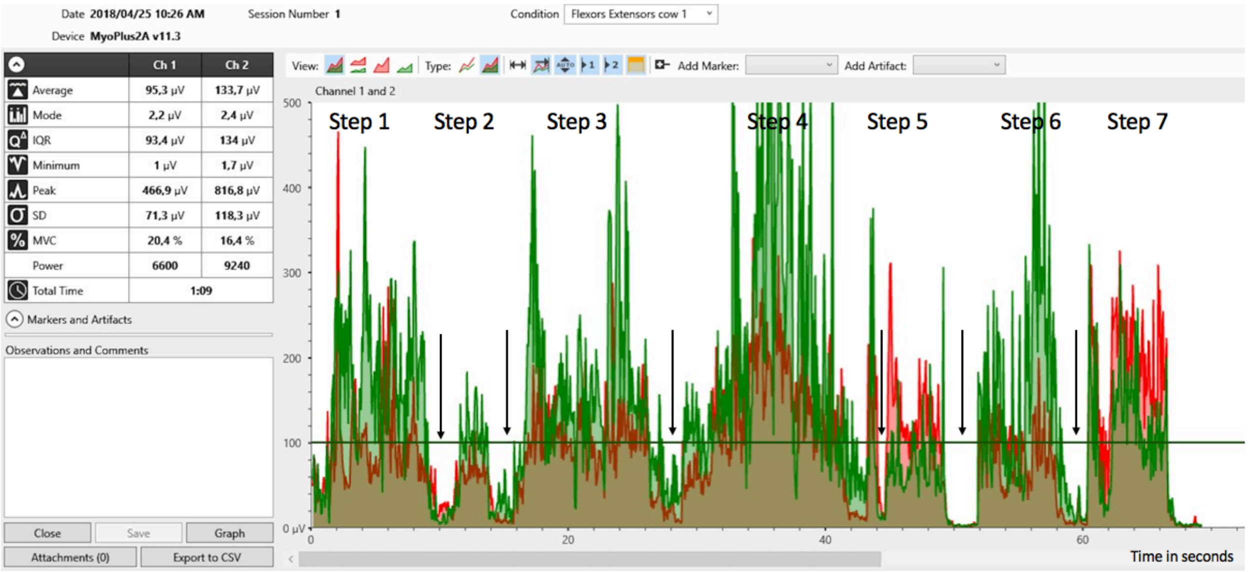


Figure 2 Example of a graphic EMG data capture file for forearm muscles (extensors and flexors) for a live cow palpation

Ch1: Channel one (red) EMG recordings for forearm extensors during a live cow palpation
Ch2: Channel two (green) EMG recordings for forearm flexors during a live cow palpation
Step 1: palpation of the cervix
Step 2: palpation of the uterine body
Step 3: retraction of the uterus
Step 4: palpation of the left uterine horn
Step 5: palpation of the left ovary
Step 6: palpation of the right uterine horn
Step 7: and palpation of the right ovary
↓ black arrows indicate areas of muscle relaxation between TRP steps

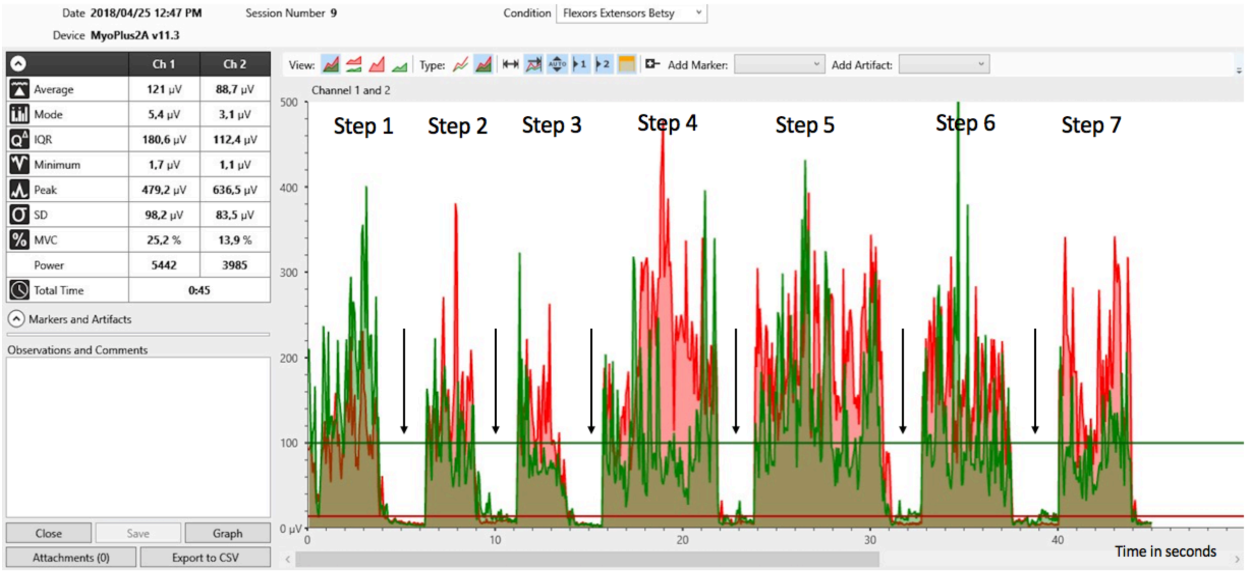


Figure 3 Example of a graphic EMG data capture file for forearm muscles (extensors and flexors) for a Breed'n Betsy® palpation

Ch1: Channel one (red) EMG recordings for forearm extensors during a live cow palpation
Ch2: Channel two (green) EMG recordings for forearm flexors during a live cow palpation
Step 1: palpation of the cervix
Step 2: palpation of the uterine body
Step 3: retraction of the uterus
Step 4: palpation of the left uterine horn
Step 5: palpation of the left ovary
Step 6: palpation of the right uterine horn
Step 7: and palpation of the right ovary
↓ black arrows indicate areas of muscle relaxation between TRP steps

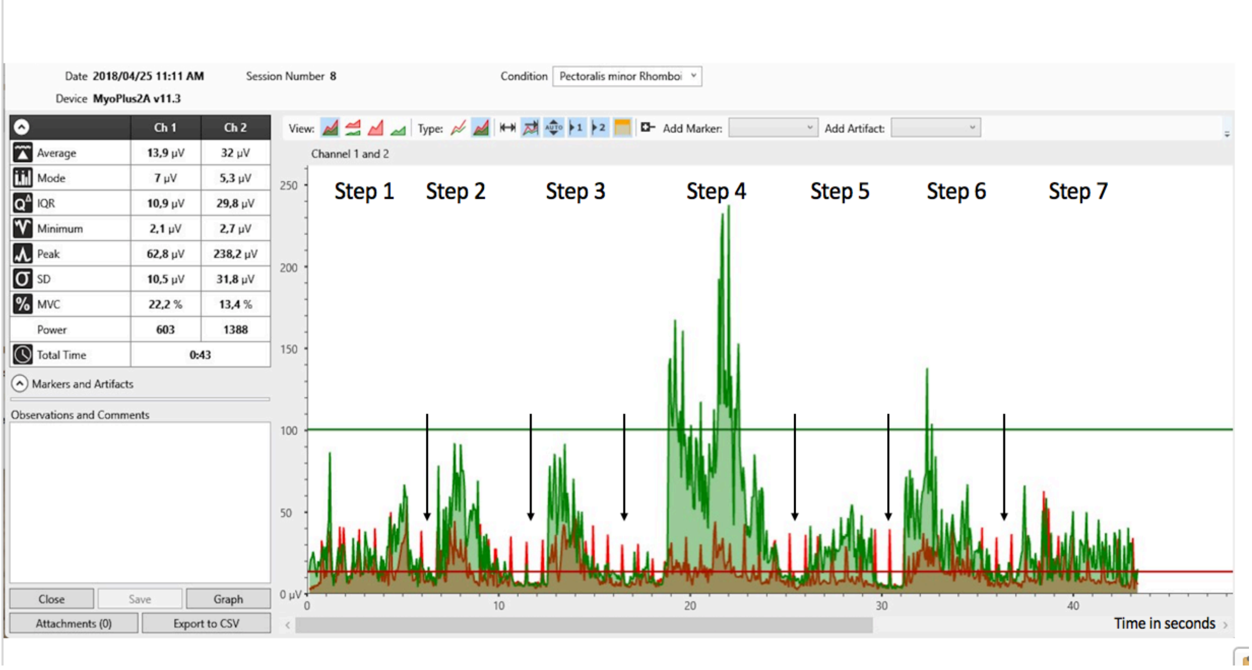


Figure 4 Example of a graphic EMG data capture file for shoulder girdle supportive muscles (pectoralis and rhomboid muscle) for a live cow palpation

Ch1: Channel one (red) EMG recordings for the pectoralis minor muscle during a live cow palpation
Ch2: Channel two (green) EMG recordings for the rhomboid muscle during a live cow palpation
Step 1: palpation of the cervix
Step 2: palpation of the uterine body
Step 3: retraction of the uterus
Step 4: palpation of the left uterine horn
Step 5: palpation of the left ovary
Step 6: palpation of the right uterine horn
Step 7: and palpation of the right ovary
↓ black arrows indicate areas of muscle relaxation between TRP steps

Pairwise comparisons of total muscle activation rate for individual muscle groups

Overall total muscle activation rate (µV/s) for all steps of the TRP was significantly higher for forearm muscles (forearm extensors and flexors) compared to upper arm muscles (biceps and triceps), shoulder muscles (anterior and posterior deltoid muscle) and shoulder girdle supportive muscles (pectoralis and rhomboid muscle), ($P < 0.001$).

Overall total muscle activation rate for upper arm muscles (biceps and triceps) was not different than shoulder muscles (anterior and posterior deltoid muscle, $P = 1.000$), but higher than the muscle activation rate for shoulder girdle supportive muscles (pectoralis and rhomboid muscle, $P < 0.001$). Overall total muscle activation rate for shoulder muscles (anterior and posterior deltoid muscle) was higher than for shoulder girdle supportive muscles (pectoralis and rhomboid muscle, $P < 0.001$). Overall total muscle activation rate for shoulder girdle supportive muscles (pectoralis and rhomboid muscle) was significantly less than for all other muscle groups ($P < 0.001$).

Pairwise comparisons of total muscle activation rate for individual TRP steps

Compared to cervix palpation (step 1), total muscle activation rate was higher for steps 3, 4 and 6 (retraction of the uterus, palpation of left and right uterine horn, $P < 0.001$), but not different for steps 2 (palpation of uterine body, $P = 1.000$), 5 (palpation of left ovary, $P = 0.171$) and 7 (palpation of right ovary, $P = 1.000$).

Comparison of muscle activation rate for live cow and BB palpations

Total muscle activation rate (all TRP steps combined) was not different for cow 1 and 2 palpations ($P = 0.294$).

Total muscle activation rate for BB palpations overall for all steps was not different than cow 1 palpations ($P = 0.053$) but lower than cow 2 palpations ($P < 0.001$). Within individual steps, palpations performed on cow 2 resulted in a higher muscle activation rate for steps 1 ($P = 0.028$), 2 ($P = 0.030$), 5 ($P = 0.002$) and 7 ($P = 0.030$) compared to BB palpations. There was no difference in muscle activation between cow 2 and BB palpations for steps 3 ($P = 0.518$), 4 ($P = 0.152$) and 6 ($P = 0.358$).

Comparison of muscle activation rate for muscle agonists and antagonists

Overall muscle activation rate was higher for antagonists (forearm flexor, triceps, posterior deltoid and rhomboid muscle) compared to agonists (forearm extensor, biceps, anterior deltoid and pectoralis muscle) for all steps ($P < 0.001$). Within individual steps, antagonistic muscle activation was higher for TRP steps 1-6 ($P < 0.001$ for steps 1-4, $P = 0.005$ for step 5 and $P = 0.008$ for step 6) compared to agonistic muscle activation but activation was not different for step 7 ($P = 1.000$).

Subjective evaluation of EMG data graphic displays

Subjective evaluation of the EMG data graphic display files suggested an endurance muscle activation pattern with sub-maximal muscle force over a sustained amount of time rather than single exertion maximum muscle force that would be expected with total muscle strength.

Discussion

The electromyographic analysis of muscle activation pattern and muscle activity levels during bovine TRP improved the understanding of the TRP movement technique.

The finding that muscle activation of the forearm (flexors and extensors) during TRPs is higher than muscle activation of any other muscle group, is consistent with the previously described predictive value of grip strength (= combined hand and forearm muscle strength) for students' PD accuracy.[11] The method of bovine TRP and PD,[12, 16] where palpation of the female reproductive tract is done through the rectal wall to feel for positive signs of pregnancy as well as gestational age, or non-pregnancy, suggests that the whole arm is used equally in the procedure. However, locating and thorough palpation of the reproductive structures moving from the cervix to uterine horns, palpating uterine horns up to the ovary, fixing of the ovaries to enable palpation of ovarian structures mostly uses fingers and forearm movements as confirmed by the results of this study.

Total muscle activation within individual steps was consistent with the hypothesis that retraction of the uterus and palpation of left and right uterine horn require higher muscle activation compared to all other steps of the TRP. These results and the finding that muscle antagonists (forearm flexor, triceps, posterior deltoid and rhomboid muscle) are more strongly activated compared to agonists (forearm extensor, biceps, anterior deltoid and pectoralis muscle), could be explained by the technique used to perform these steps of the TRP procedure. In order to retract the uterus, using the intercornual ligament technique, the middle finger is hooked under the ventral intercornual ligament before a simultaneous dorsal and caudal movement of the hand and forearm draws the uterus into the pelvic cavity. This movement often reflects the uterus back on itself and allows for complete and thorough examination of both horns. Palpation of uterine horns starts at the base of the uterine horn at the bifurcation with the index, middle and ring finger on the ventral side of the horn and the thumb on the dorsal side. Keeping the fingers in that same position the hand now moves up from the base of the horn towards the tip while uterine horn size, tone, contents and consistency are examined. This movement pattern would explain why these parts of the TRP require more muscle activation than for example the downward and lateral movements required to locate cervix and uterine body. The same can be expected for ovarian palpation compared to uterine body retraction or horn palpation. Once the ovary is fixed in the hand by placing the mesovarium between middle and ring finger with the ventral 'free' ovarian border dorsally, only the thumb is used to examine ovarian size and structures while no further arm movement is involved in this step.

The fact that there was only a difference in muscle activation between cow 2 and BB palpations but not between cow 1 and BB palpations while the muscle activation for cow 1 and 2 palpations was similar, is interesting. While the latter finding was expected, this study hypothesized that muscle activation for TRPs in live cows would be higher than for TRPs in BBs. This hypothesis could be used to explain the difference in training outcomes for BB and live cow trained students.[3] It was based on the reasoning that rectal examination simulators might not require the same movements and muscle activations during TRPs as what is required for live animals.[3] However, the absence of rectal peristalsis, anal sphincter tone, and other internal organs such as a bladder and rumen did not cause a significant difference in muscle activation between BB and cow 1 palpations. The fact that cow 2 palpations required higher overall muscle activation for all steps combined compared to BB palpations might be due to more intense straining during cow 2 palpations. It is interesting that within individual steps, the steps requiring the most muscle activation (retraction of the uterus and palpation of uterine horns) was still similar for cow 2 and BB palpations. Based on these findings, a difference in muscle activation for BB and live cow palpations as a potential reason for the difference in training outcome for BB and live cow trained students as hypothesized previously,[3] is less likely to be true.

However, it seems easier to relax between individual TRP steps for BB palpations as seen in Figures 2 and 3. Figures 2 and 3 show forearm muscle activation for a live cow and a BB palpation, respectively. The areas of muscle relaxation between TRP steps as indicated by arrows in these figures are more distinct for BB palpations. This was a finding consistently seen for all muscle groups during BB palpations.

The fact that evaluation of the graphic EMG recordings suggested an endurance pattern of muscle activation, supports a previous hypothesis that endurance is more important rather than total muscle strength during TRPs.[11] Students who participated in a previously described exercise programme were better at identifying pregnant cows while an increase in total muscle strength was not measurable on completion of the programme.[11] The attempt to explain this finding was that the exercise programme increased muscle endurance rather than total muscle strength.[11] The increased endurance as a hypothesized reason for better PD performance was supported by the results of the current study. This finding was subsequently used to modify the previously described exercise programme,[11] and design a three-month exercise programme aimed at GS and improving arm muscle strength and endurance. The finding that muscle antagonists (forearm flexor, triceps, posterior deltoid and rhomboid muscle) were more strongly activated compared to agonists (forearm extensor, biceps, anterior deltoid and pectoralis muscle) was also taken into consideration for the exercise programme outline.

Design of 'The bovine PD improvement exercise programme'

The practical application of the analysis and interpretation of EMG data in this study in combination with previous GS data,[11] was the design of a three-month exercise programme with the help of an experienced biokineticist.

The programme specifically targets grip strength (forearm extensors and flexors, and hand muscles), upper arm and shoulder as well as core muscle strength and endurance. It is divided into three levels starting with easier entry-level exercises, and building up to more advanced exercises. Participation in the program takes 30 minutes three times a week. The programme was designed in a way that allows students to exercise in the relatively short time period with any comfortable clothes (no changing of clothes required) and with readily available exercise equipment. The exercise equipment used is GS specific equipment: Powerballs (Mantality, Canero Business Park, Johannesburg, South Africa), egg exercisers, hand exercise webs (both from the Physio and Wellness Warehouse, Willow Park Manor, Pretoria, South Africa) and dumbbells; as well as general exercise equipment: Yoga mats, Powercore Exercise balls (65 cm, 150 kg carrying capacity) and different strengths of TheraBand® latex exercise bands (Hitech Therapy CC, Bryanston, South Africa) (Figure 5). Each day of the exercise programme starts with a warm-up, and is followed by one powerball, two egg exerciser and two hand exercise web exercises. These exercises are then followed by an additional two exercises per day that vary from day 1 to day 3 of the programme and concentrate on whole arm, shoulder, back, core or abdominal and leg muscle strength. The combination of exercises ensures a variety of training routines and a balanced work-out concentrating on the muscle groups listed above.

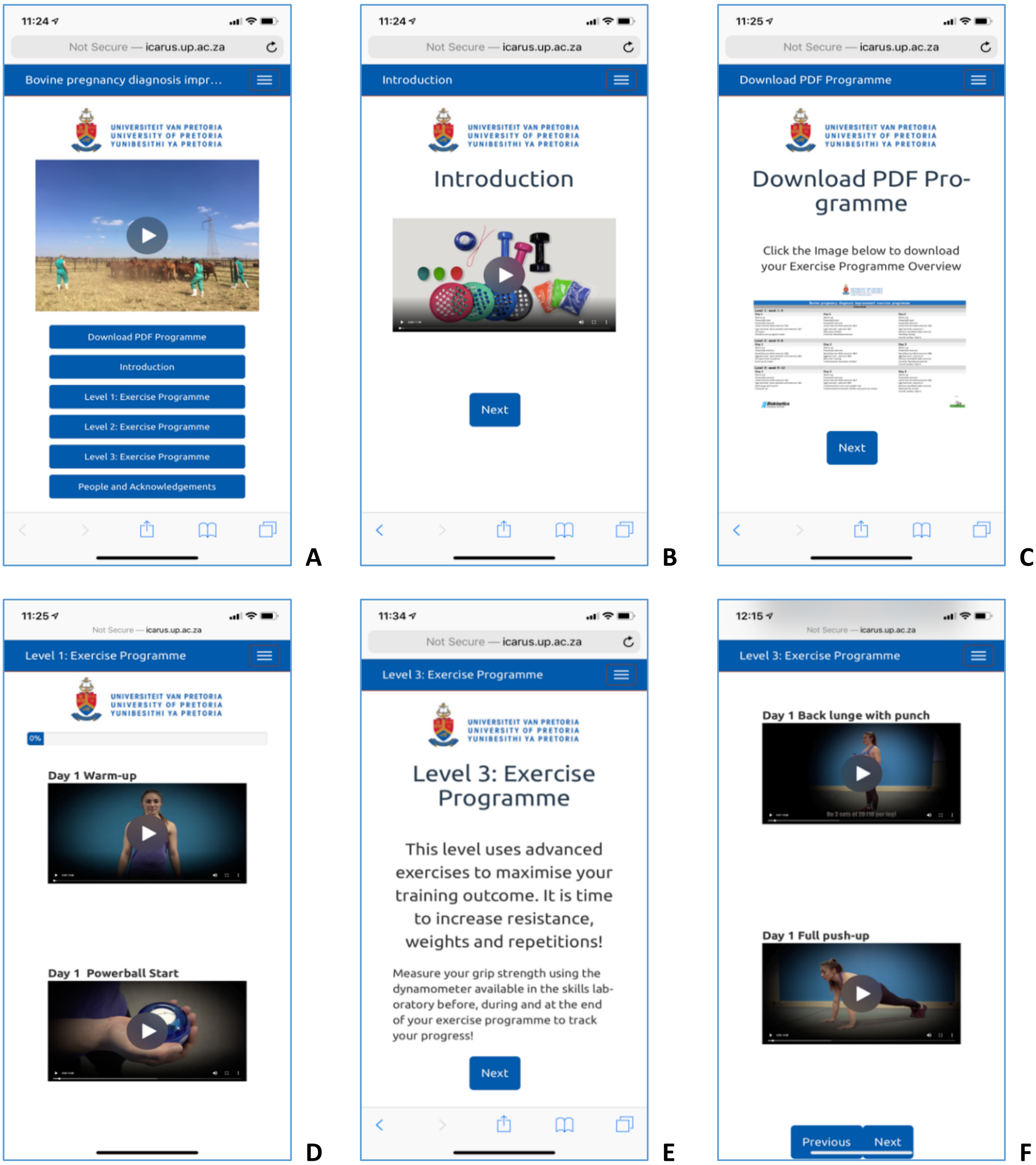


Figure 5 Screenshots of the 'Bovine pregnancy diagnosis improvement exercise programme App' as seen on smartphone accessed through: http://icarus.up.ac.za/vetmlp/

A. A Homepage with the welcome video and all links of the exercise programme.

B. B Link with the introduction video to the exercise equipment.

C. C Link to download the exercise programme overview.

D. D Link to exercise Level 1: videos demonstrating the exercises.

E. E Links to the different exercise levels give additional information and remind users to track their progress via grip strength measurements.

F. F Examples of two Level 3 exercises.

All exercises were demonstrated by a former female gymnast and video recorded by a University of Pretoria employed video producer during the development phase of the programme. The videos are narrated and explain how the exercises should be executed. All video clips were edited and uploaded with all the necessary information on the University of Pretoria's Mobile Online Learning Platform. The exercise programme is called 'The bovine PD improvement exercise programme' and can be accessed through the following link: http://icarus.up.ac.za/vetmlp/ on smartphones, tablets, PCs and laptops. A two-minute welcome video message gives students information on the background of the exercise programme, on muscle groups that are targeted, the time commitment and the expected outcome. There is a link to download the programme, to a short introduction video on the exercise equipment, to level 1-3 of the programme and to acknowledgements (Figure 5). The exercise programme videos per individual day can be accessed through links to Level 1, 2 and 3 of the exercise programme.

All necessary exercise equipment as well as a handheld digital Grip Strength Dynamometer CAMRY Model EH 101 (Camry Scale USA, South El Monte, California) were purchased by the teaching institution and made available to students within the veterinary skills laboratory. The skills laboratory has tablets available for students to use who do not have a smartphone or tablet.

The exercise programme availability through the user-friendly online application considers previous student improvement suggestions to make such a programme widely available to more students with added time and location flexibility.[11]

Feedback on the previously described exercise programme showed that students not only experienced physical benefits but also fun and relaxation while exercising, socializing, comradery, and stress release. Exercise has been described to be one of the most important pursuits to improve physiological as well as psychological health.[17, 18] A reduced risk for depression and anxiety, improved mood, better sleep quality, and better cognitive functioning are known psychological benefits of exercising.[17-19] Since stress-related disorders are common amongst veterinary students world-wide,[19-27] implementation of an exercise programme not only benefitting arm strength and indirectly TRP accuracy but also improving general student well-being could be a positive addition to veterinary curricula.

However, physical activity can become less of a priority for veterinary students due to heavy workload within the veterinary programme combined with stress of academic performance,[19] and that students require motivators to exercise.[19, 28] Increased grip strength and arm muscle endurance through participation in this programme will not only have positive effects on veterinary hands-on skills (bovine TRP and PD) but potentially also on other aspects of student activities. It is speculated that for example, rock climbers, tennis and badminton players and musicians playing guitar, piano or violin will benefit from increased grip strength.

Therefore, if participation in an exercise programme not only increases arm strength and indirectly palpation accuracy but also general student well-being, these additional physiological and psychological benefits are hoped to be motivators for students to exercise and use the 'The bovine PD improvement exercise programme'.

A study limitation was the technical restriction because of limited EMG ETS (EMG Triggered Stimulator) availability and logistics around using EMG ETS technology (small portable versus a fixed larger machines) in a bovine examination crush set up. Due to the fact that the only portable EMG ETS machines available for use in the experiment were 2-channel machines restricted the number of muscle groups that could be examined simultaneously. If for example, an 8-channel EMG machine would have been available, it would have been possible to include further muscle groups, such as back and core muscles. Inclusion of these muscle groups would have been advantageous since musculoskeletal disorders (MSDs) related to the veterinary profession and especially large animal procedures and rectal examination in specific have been widely described,[29-33] Future EMG studies should investigate additional muscle activation patterns with a view of MSD prevention through posture improvement for example.

Conclusions

The electromyographic analysis of muscle activation pattern and activity during bovine TRP adds novel information to the existing literature concerning bovine TRP and PD. In conclusion, muscle activation was highest for forearm muscles, was higher during retraction of the uterus, palpation of left and right uterine horn, compared to palpation of cervix, uterine body, left and right ovary ($P < 0.001$), was higher for antagonistic than agonistic muscles ($P < 0.001$) and showed an endurance pattern. These results have been used to modify a previously developed exercise programme to improve students' TRP and PD skills. 'The bovine PD improvement exercise programme' is available to students through an online application (http://icarus.up.ac.za/vetmlp/), and aims to not only improve GS and TRP accuracy but also stamina and wellbeing while adding fun to busy study schedules. This use of technology can complement traditional training in effort to maximize training outcomes for programmes with limited live animal exposure.

Acknowledgements

This study was funded through a *Health and Welfare Sector Education and Training Authority* (*HWSETA)* research grant and a *University of Pretoria's Research Development Programme (RDP)* grant. The authors would like to thank Drs C E May, I Salles Martins, C H Annandale, M van der Leek, T Tshuma and K Pettey for participating in this study. The authors would also like to thank Candice Attree from Attree Biokineticists for her enthusiasm to develop the exercise programme, Kayla Haasbroek for being the exercise model, Mr Andre du Plessis for the video recording and editing, and Mr Isak van der Walt for designing and uploading the online content of 'The bovine PD improvement exercise programme'.

References

1. Bossaert P, Leterme L, Caluwaerts T, Cools S, Hostens M, Kolkman I, De Kruif A. Teaching transrectal palpation of the internal genital organs in cattle. *Journal of Veterinary Medical Education* 36:451-60, 2009.

2. Lopes G, Rocha A. Teaching bovine rectal palpation with live cows in the slaughterhouse: Is it worthwhile? *Reproduction in Domestic Animals* 41:510-3, 2006.

3. Annandale A, Annandale CH, Fosgate GT, Holm DE. Training method and other factors affecting student accuracy in bovine pregnancy diagnosis. *Journal of Veterinary Medical Education* 45(2):224-31, 2018.

4. Annandale A, Fosgate GT, Bok H, Holm DE. Ability of a bovine transrectal palpation objective structured clinical examination to predict veterinary students' pregnancy diagnosis accuracy. *The Veterinary Record* 185(6):171-180, 2019.

5. Baillie S, Crossan A, Brewster S, Mellor D, Reid S. Validation of a bovine rectal palpation simulator for training veterinary students. *Studies in Health Technology and Informatics* 111:33-6, 2005.

6. Baillie S, Mellor DJ, Brewster SA, Reid SWJ. Integrating a bovine rectal palpation simulator into an undergraduate veterinary curriculum. *Journal of Veterinary Medical Education* 32:79-85, 2005.

7. Baillie S, Crossan A, Brewster SA, May SA, Mellor DJ. Evaluating an automated haptic simulator designed for veterinary students to learn bovine rectal palpation. *Simulation in Healthcare: Journal of the Society for Simulation in Healthcare* 5:261-6, 2010.

8. Giese H, Gundelach Y, Dilly M. Simulationsbasiertes Training der transrektalen gynäkologischen Untersuchung beim Rind. Jahrestagung der Gesellschaft für Medizinische Ausbildung (GMA). Hamburg, Düsseldorf: *German Medical Science GMS Publishing House*; 2014.

9. Giese H, Gundelach Y, Geuenich K, Ehlers JP, Dilly M. Effects of training methods for rectal palpation in cattle on student's performance and self-evaluation. AMEE. Glasgow 2015.

10. French HM, Dascanio JJ, Gilbert GE, Robinson JQ. Bovine reproductive palpation training: does the cow make a difference? *Journal of Veterinary Medical Education* 45(2):219-23, 2018.

11. Annandale A, Fosgate GT, Eksteen CA, Kremer WDJ, Bok HGJ, Holm DE. Influence of an exercise program, muscle strength, proprioception and arm length on veterinary students' bovine pregnancy diagnosis accuracy. Accepted for publication in *The Journal of Veterinary Medical Education*.

12. Youngquist RS, Threlfall WR. Current therapy in large animal theriogenology. 2nd edition, St Louis, Missouri, *Saunders Elsevier* 294-303, 1997.

13. Hug F, Dorel S. Electromyographic analysis of pedaling: a review. *Journal of electromyography and kinesiology: official journal of the International Society of Electrophysiological Kinesiology* 19(2):182-98, 2009.

14. Siff MC. Supertraining. Supertraining Institute, Denver, CO. 2000.

15. O'Dell D. Strength endurance [WWW] Available from: https://www.brianmac.co.uk/ articles/scni16a7.htm [Accessed 31/1/2019]. 2004.

16. Sheldon M, Noakes D. Pregnancy diagnosis in cattle. *In Practice* 24:310-7, 2002.

17. Centers for Disease Control (CDC). Physical activity and health. Atlanta, GA: CDC 2015. Available from: https://www.cdc.gov/physicalactivity/basics/pa-health/index.htm.

18. President's Council on Fitness, Sports & Nutrition. Physical activity guidelines for Americans. Washington, DC: US Department of Health and Human Services. 2017. Available from: https://www.hhs.gov/fitness/be-active/physical-activity-guidelines-for-americans/.

19. Royal KD, Hunt SA, Gonzalez LM, Lewbart GA, Bailey KM. Veterinary medical students' motivations for exercise. *Journal of Veterinary Medical Education* (Preprints):1-7, 2018.

20. Killinger SL, Flanagan S, Castine E, Howard KAS. Stress and depression among veterinary medical students. *Journal of Veterinary Medical Education* 44(1):3-8, 2017.

21. Bakker DJ, Lyons ST, Conlon PD. An exploration of the relationship between psychological capital and depression among first-year doctor of veterinary medicine students. *Journal of Veterinary Medical Education* 44(1):50-62, 2017.

22. Cardwell JM, Lewis EG. Vocation, belongingness, and balance: a qualitative study of veterinary student well-being. *Journal of Veterinary Medical Education* 44(1):29-37, 2017.

23. Drake AAS, Hafen M, Jr., Rush BR, Reisbig AMJ. Predictors of anxiety and depression in veterinary medicine students: a four-year cohort examination. *Journal of Veterinary Medical Education* 39(4):322-30, 2012.

24. Drake AS, Hafen M, Jr., Rush BR. Promoting well-being among veterinary medical students: protocol and preliminary findings. *Journal of Veterinary Medical Education* 41(3):294-300, 2014.

25. Drake AAS, Hafen M, Rush BR. A decade of counseling services in one college of veterinary medicine: veterinary medical students' psychological distress and help-seeking trends. *Journal of Veterinary Medical Education* 44(1):157-65, 2017.

26. Weston JF, Gardner D, Yeung P. Stressors and protective factors among veterinary students in New Zealand. *Journal of Veterinary Medical Education* 44(1):22-8, 2017.

27. Bartram DJ, Baldwin DS. Veterinary surgeons and suicide: a structured review of possible influences on increased risk. *The Veterinary Record* 166(13):388-97, 2010.

28. Kulavic K, Hultquist CN, McLester JR. A comparison of motivational factors and barriers to physical activity among traditional versus nontraditional college students. *Journal of American College Health* 61(2):60-6, 2013.

29. Scuffham AM, Legg SJ, Firth EC, Stevenson MA. Prevalence and risk factors associated with musculoskeletal discomfort in New Zealand veterinarians. *Applied Ergonomics* 41(3):444-53, 2010.

30. Scuffham AM, Firth EC, Stevenson MA, Legg SJ. Tasks considered by veterinarians to cause them musculoskeletal discomfort, and suggested solutions. *New Zealand Veterinary Journal* 58(1):37-44, 2010.

31. Smith DR, Leggat PA, Speare R. Musculoskeletal disorders and psychosocial risk factors among veterinarians in Queensland, Australia. *Australian Veterinary Journal* 87(7):260-5, 2009.

32. Kozak A, Schedlbauer G, Peters C, Nienhaus A. Self-reported musculoskeletal disorders of the distal upper extremities and the neck in German Veterinarians: A cross-sectional study. *Plos One* 9(2), 2014.

33. Berry SL, Susitaival PI, Ahmadi A, Schenker MB. Cumulative trauma disorders among California veterinarians. *American Journal of Industrial Medicine* 55(9):855-61, 2012.

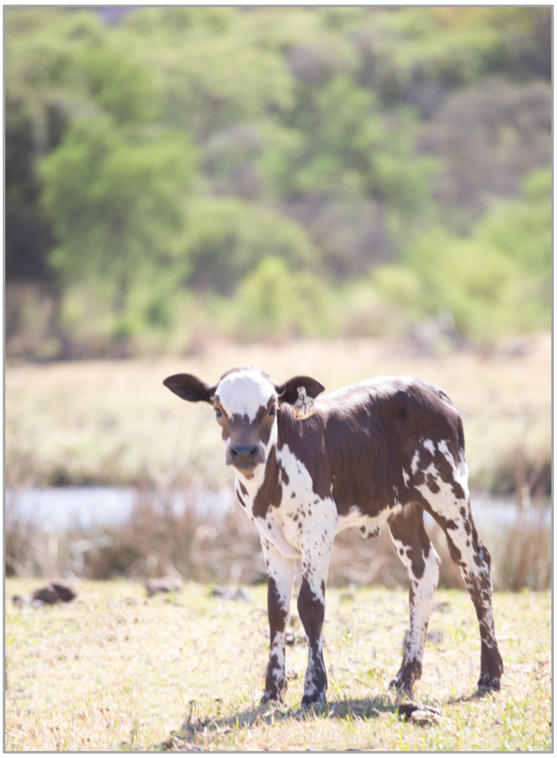
Chapter 6

Effect of a high-intensity one-week training programme and student level variables on the bovine transrectal palpation and pregnancy diagnosis skills of final-year veterinary students

Annett Annandale, Catherine E May, Martin L van der Leek, Geoffrey T Fosgate, Wim D J Kremer, Harold G J Bok, Dietmar E Holm

Under review in:

Veterinary Record



Abstract

In an attempt to improve transrectal palpation (TRP) and pregnancy diagnosis (PD) training, the effect of a high intensity one-week training programme for veterinary elective students (n = 59) with an interest in production animal practice was evaluated. The training consisted of student exposure to rectal examination simulators, reproductive tract abattoir organs, theory training materials and live cow PDs supervised by experienced large animal practitioners. Palpation skills were assessed before and after training using a validated TRP OSCE in non-pregnant cows. Students' scores improved from the first to the second OSCE (P = 0.03), mostly as a result of improved ability to identify uterine symmetry (or asymmetry) and the presence (or absence) of a corpus luteum on the right ovary (P < 0.01 and P = 0.03, respectively). Each student then performed PDs (n = 12) on cows of known pregnancy status. Students' PD accuracy was measured as sensitivity and specificity, being respectively defined as the proportion of pregnant or non-pregnant cows correctly identified. Overall student sensitivity and specificity were 81.6% (95% CI 77.7-84.9%), 89.1% (95% CI 78.1-92.2%) and 67.7% (95% CI 60.1-74.5%), respectively. Previous student TRP exposure under veterinary supervision was positively correlated with higher student specificity (P = 0.043). In conclusion, this study further validates the TRP OSCE and describes a strategy to improve students' TRP skills. It has the potential to reduce training time and animal use at teaching institutions by outsourcing student training to private practitioners with access to real patients.

Key words: Veterinary education, bovine pregnancy diagnosis, transrectal palpation training, veterinary students

Introduction

Bovine transrectal palpation (TRP) and pregnancy diagnosis (PD) are complex skills that require extensive training and exposure to TRP in live cows.[1-3] Transrectal palpation and PD are economically important,[4-7] and frequently performed procedures in bovine practice,[8] and are therefore important skills for veterinary graduates.[9] Student training is challenging due to limited teaching animal availability, welfare concerns and the costs associated with farm visits for student training purposes. Furthermore, student training opportunities for bovine TRP and PD are not easily accessible outside the veterinary course.[3, 10, 11] It has recently been shown that the overall PD accuracy (pregnancy status and stage) of fourth- and fifth-year students (of a six-year course) was lower than what is considered acceptable for large animal veterinarians.[3, 11-16] Their PD specificity (ability to correctly identify non-pregnant cows) was lower than sensitivity (ability to correctly identify pregnant cows), and the majority of students had insufficient palpation skills after TRP and PD training.[3, 11, 16] In an effort to overcome training constraints due to limited live cow access and to improve bovine TRP training, several studies have investigated various training methods,[3, 10, 17] rectal examination simulator use,[1, 3, 11, 16, 18-20] and factors influencing students' TRP and PD performance.[2, 3, 11, 16] While rectal examination simulator training was shown to be superior to theoretical instruction only,[18, 21] live cow training resulted in better student TRP skills and PD accuracy for cows <6 months pregnant.[1, 3] It is recommended to combine rectal examination simulator training with live cow palpations to optimise learning outcomes.[1, 3, 11, 16] Providing additional rectal examination simulator and live cow training sessions for a fifth-year student cohort was not sufficient to reach an overall competent student palpation level.[16] Implementation of live cow palpation access, limited to students interested in a career in food animal practice during the later stages of the curriculum was proposed as an approach to improve students' palpation abilities.[16] This approach and the effect on students' TRP and PD skills has not been investigated yet. A TRP Objective Structured Clinical Examination (OSCE) has the ability to predict students' PD accuracy.[16] Student categorisation into having 'competent palpation skills' was associated with higher PD specificity.[16] The TRP OSCE was a valid assessment with good reliability for all items within the station (Cronbach's alpha = 0.78).[16, 22, 23] The described TRP OSCE could be used to track students' progress during or after TRP and PD training sessions.

Other factors affecting students' PD accuracy such as career interest, student background (city, farm, mixed), previous bovine TRP and PD experience, gender and grip strength have also been described.[3, 11] Since previous investigations have involved fourth-and fifth-year veterinary student cohorts (of a six-year course),[24] the effect of these factors on a final-year student cohort was regarded worth evaluating. While a grip strength of more than 30 kg has previously been associated with a higher student ability to identify pregnant cows,[11] the effect of grip strength on live cow TRP OSCE results has not yet been reported. Veterinary students follow the general population trend where approximately 90% of people are right-handed.[11, 25] Due to on-farm examination crush set-up it is often not possible to choose which arm to use for bovine PDs and there is no student data on arm preference for bovine TRPs available. Being able to use the preferred arm for bovine TRP might have an effect on palpation accuracy, but has not yet been investigated.

The main aim of the study was to evaluate the effect of a one-week intense training programme on bovine TRP skills of final-year (of a six-year programme) veterinary students interested in production animal practice as assessed via TRP OSCEs, and if this approach could potentially reduce training time and teaching animal use at teaching institutions by outsourcing student training to private practitioners with access to real patients.

The study also evaluated if post-training TRP OSCE scores were predictors of student PD accuracy. Furthermore, the study evaluated if career interest, student background (city, farm, mixed), gender, previous bovine TRP experience, the number of PDs performed during the training programme, grip strength and being able to use the preferred arm for TRPs were predictors for TRP OSCE and PD accuracy results.

It was hypothesised that a one-week intense training programme was an appropriate strategy to improve students' TRP OSCE scores and palpation abilities and furthermore, could overcome training limitations at teaching institutions. It was additionally hypothesised that TRP OSCE scores were predictive of PD accuracy and that this study would further validate the TRP OSCE.

Materials and Methods

Participants and setting

Study participants were final-year (of a six-year program)[24] veterinary students (n = 59) at the Faculty of Veterinary Science, University of Pretoria, South Africa. The six-year Bachelor of Veterinary Science (BVSc) program includes nine semesters of didactic pre-clinical training and three semesters of clinical work-integrated learning during the last 18 months of study.[24]

During the last three semesters of clinical work-integrated learning, all students are exposed to both Veterinary Core Practice (VCP) and Veterinary Elective Practice (VEP) clinical rotations within and outside of the Onderstepoort Veterinary Academic Hospital (OVAH). Within the VCP clinical rotations, species exposure is similar for all students. Within the VEP clinical rotations, students choose additional clinical exposure based on their specific interests. Only students in those electives indicative of an interest in large animal practice were able to enrol for the one-week intense bovine PD training ('The Onderstepoort PD Challenge'). The training programme took place in July 2018 after students had completed the first two semesters of clinical work-integration.

Student TRP and PD training prior to the experiment

During the fourth-year of didactic training, theoretical and practical aspects of bovine TRP and PD are taught within the veterinary reproduction module.[24] This includes hands-on training on reproductive tract abattoir organs, rectal examination simulators and live cows as previously described.[3, 16] Students are furthermore exposed to additional bovine TRP opportunities later in the curriculum within the mandatory reproduction and/or herd health clinical rotations during the first two semesters of clinical work-integration at the teaching institution, and optionally during private practice rotations.

Pre-and post-training assessment of students' TRP skills

All participants' pre- and post-training TRP skills were assessed by means of a TRP OSCE on non-pregnant cows with no reproductive tract pathology.[16] The TRP findings for each cow were pre-determined and documented by two experienced specialist veterinarians. The pre-training TRP OSCE was done at the beginning of the one-week training programme prior to any additional training. The post-training TRP OSCE was done exactly one week later after completion of the intense TRP and PD training. During both OSCE assessments, each student palpated one live cow and wrote down their findings on an OSCE marking sheet.[16] Prior to the pre-training TRP OSCE, student information on dominant hand and preferred arm for TRPs was documented. Students could choose which arm they preferred to use and were instructed to use the same arm for both OSCEs. Examination time was restricted to 10 minutes per student. No cow was palpated more than three times. The nine scores used to evaluate palpation skills (size and position of the cervix; size, tone and symmetry of uterine horns; size and presence of pertinent structures on the ovaries) were ordinally transformed: no palpation skills (0-1/9), deficient palpation skills (2 or 3/9), some palpation skills (4 or 5/9), good palpation skills (6 or 7/9 and competent in palpation (8 or 9/9), as described previously.[16]

Grip strength measurement

Prior to the pre-training TRP OSCE, grip strength was measured in kilogram using the handheld digital Grip Strength Dynamometer CAMRY Model EH 101 (Camry Scale USA, South El Monte, California). Students stood upright with feet hip-width apart and toes pointing forward with arms held loosely next to the body with palms facing towards the body. The dynamometer was grasped between the fingers and the palm at the base of the thumb. Students were then asked to squeeze the hand grip with maximal effort for three to five seconds. Right and left hand grip strength was measured individually and recorded.[11]

TRP and PD at the teaching institution

The following day, all 59 final-year veterinary students received a mandatory day of additional supervised bovine TRP and PD training at the teaching institution, supervised and executed by experienced faculty. The training included inspection and palpation of abattoir specimens of bovine female reproductive organs, skills laboratory exposure to rectal examination simulators (Breed'n Betsy® (BB) and Haptic Cow) and exposure to theoretical information on bovine TRP and PD for self-study. Students (n = 59) were randomly divided into six groups of 9-10 students and each group rotated through all training stations. Two groups were at one of the three training stations simultaneously and two-hour training periods were allocated to each station. The abattoir specimens included non-pregnant uteri as well as uteri at various stages of gestation. Separate BB simulators were set up using non-pregnant uteri and a variety of pregnant uteri models from 6-11 weeks and 4-5 months of gestation.[3] The Haptic cow training allowed students to palpate non-pregnant uteri and a range of pregnancy stages from 7-7.5 weeks, 8-8.5 weeks, 4-5 months and 6-7 months.

Private practice placements

Students then spent two days at private practices performing bovine PDs under the supervision of experienced large animal veterinarians. Private practitioners were asked to participate in the project via a call on a national large animal practitioners email list serve. A total of 24 practices chose to participate and accommodated all students. An average of 2.5 students were allocated per practice (range 1-7). Students received a travel allowance to cover the costs associated with the private practice placements.

PD accuracy assessment

Students' bovine PD accuracy via TRP was assessed as described previously.[3, 16] All students (n = 59) visited a commercial Nguni beef cattle herd one (student groups 1, 2 and 3) or two (student groups 4, 5 and 6) days after the second TRP OSCE assessment. Each student completed a questionnaire on student background, previous bovine TRP and PD experience and career interest.[3] The questionnaire also contained questions concerning the one-week training programme. Each student was then allowed a total of 15 minutes to perform PDs via TRP on 12 cows. The pregnancy status and stage of these cows were determined by a veterinarian with more than ten years' experience in bovine TRP and PD. For cows <6 months pregnant, a student's stage of pregnancy estimation was considered to be correct if it was within one month of the predetermined findings and for cows >6 months pregnant, if it was within two months of the predetermined findings. Due to the examination crush set-up on the farm, all student palpations were performed left-handed. Each student's pregnancy diagnoses (pregnancy status and stage) were recorded on an individual data capture sheet against the appropriate cow number, and students who examined the same cow were blinded to each other's diagnoses.[3, 16] Cows were not formally randomised but taken into the crush in a convenient manner out of a group of available cows. Each cow was only palpated on one of the two assessment days.

Statistical analysis

Quantitative data were assessed for normality by evaluating histograms, calculating descriptive statistics and performing the Anderson-Darling test using commercial software (MINITAB Statistical Software, Release 13.32, Minitab Inc, State College, Pennsylvania, USA). Quantitative data that violated the normality assumption were analysed using nonparametric procedures. Quantitative data were compared between levels of categorical predictors using Mann-Whitney U or Kruskal-Wallis tests for variables with two and three levels, respectively. Paired quantitative data were compared using Wilcoxon signed-rank tests. Bivariate correlation between quantitative variables was estimated using Spearman's rho. Paired dichotomous data were compared using McNemar's chi-square tests.

Statistical analysis of factors affecting PD accuracy

Sensitivity (Se) was defined as the proportion of cows determined to be pregnant by the veterinarian that were correctly identified by the student. Stage corrected sensitivity was defined as the proportion of pregnant cows in which pregnancy stage was correctly identified by the student. Specificity (Sp) was defined as the proportion of non-pregnant cows as determined by the veterinarian correctly identified by the student. Overall accuracy was calculated as the proportion of cows in which the student determination of pregnancy was the same as the veterinarian's. Sensitivity is the probability that the student correctly recognised a pregnancy and therefore factors associated with the sensitivity of student pregnancy diagnosis were evaluated only within cows that were determined as pregnant by the veterinarian. A generalised linear model approach was used with the outcome being the dichotomous diagnosis (pregnant/non-pregnant) of the student. Random effect terms were included in these models for student and cow to account for the study design in which a single student examined multiple cows and each cow was examined by multiple students. The effects of student factors on the pregnancy diagnosis were evaluated by screening each possible predictor one-by-one in univariate analyses that included these variables as fixed effects in the model. All variables in which $P < 0.20$ in these screening models were subsequently evaluated using a multivariable approach that included all variables identified in the screening models. Multivariable models were fit using a manual backwards stepwise procedure. Variables were removed from the multivariable model when the statistical test of the variable's coefficient was $P > 0.05$. The variable with the largest P-value was removed first and the model was re-run again. The removal of variables continued until all remaining factors were $P < 0.05$. Confounding was assessed by calculating the per cent change in the odds ratio for the treatment group variable (primary exposure of interest) between the model with the factor and the model after factor removal. If removal of a variable caused a > 20% change in the odds ratio then the variable was classified as an important confounder and added back into the multivariable model. Models evaluating the factors associated with student specificity were fit using the same procedures as described for sensitivity but within the subset of cows identified as non-pregnant by the veterinarian. Commercial software was used for all statistical analyses (IBM SPSS Statistics Version 24, International Business Machines Corp., Armonk, NY, USA) and significance was set as $P < 0.05$.

Ethical considerations

This study was approved by the Animal Ethics and Research Committee of the University of Pretoria (Project number SOP038-18). No cow was palpated more than three times in one session at any stage during the experiment.

Results

Study participants

The study population consisted of 59 final-year veterinary students of which 33 students were female and 26 male (56% and 44%, respectively).

Of the 59 students, 41 had chosen Rural and Wildlife Practice (RVP) and 18 Intensive Animal Production (IAP) as their VEP elective.

The majority of student participants had been exposed to bovine TRPs and PDs during the first 12 months of the clinical work-integrated learning prior to the onset of the project either during reproduction (RR) and herd health clinical rotations (HHR) within the training institution and or during private practice placements. Fifty-six (97%) of the 59 students were right handed and two (3.4%) were left handed. One student indicated equal preference for left and right hand. Forty-six (78%) and 13 (22%) students indicated their preferred hand for TRPs was left and right, respectively.

Right hand grip strength (kg) ranged from 22.2-75.6 kg (mean: 46.6 +/- 15.6kg), with a significant gender difference (mean 34.6 kg and 61.5 kg for female and male students respectively, $P < 0.001$).

Left hand grip strength was different from the right hand ($P < 0.001$), ranged from 22.4-76 kg (mean: 43.2 +/- 14.5 kg), and also differed by gender (mean 32.6 kg and 56.4 kg for female and male students respectively, $P < 0.001$).

One student was sick on the day of the PD assessment and did not participate. The same student also did not complete the questionnaire. Analysis of completed questionnaires (n = 58) showed that 50 (86%), four (7%), two (3.5%) and two (3.5%) students indicated a career interest in rural mixed animal practice, specialized production animal practice, small animal practice and specialized wildlife practice, respectively. Twenty-eight (48%), 21 (36%) and nine (16%) students were from a city, mixed and farm background, respectively. Fifteen students (26%) indicated that their bovine TRP experience was limited to what they had been exposed to during the formal training at the teaching institution. Thirty-seven (64%) and six (10%) of the 58 students had additional TRP exposure outside the veterinary course with and without supervision of a veterinarian, respectively. Students' palpation experience prior to and during the one-week training program is summarised in Table 1. The average number of PDs performed by students during private practice placements within the one-week training programme was 159 (median 110; min 20; max 600; Table 1).

Table 1 Pregnancy diagnosis experience by 58 final-year veterinary students prior to and during the training programme

Number of PDs performed prior to the one-week training program						
	< 50	**50-100**	**100-200**	**200-500**	**500-700**	**1000-1500**
Number of students	13 (22%)	23 (40%)	9 (16%)	3 (5%)	2 (3%)	8 (14%)
Number of PDs performed during the one-week training program						
	< 50	**50-100**	**100-200**	**200-500**	**500-700**	**1000-1500**
Number of students	5 (9%)	24 (41%)	15 (26%)	12 (21%)	2 (3%)	0

Comparison of pre-and post-training live cow TRP OSCE results

Total live cow TRP OSCE scores were significantly higher for the second post-training OSCE (P = 0.03). Individual OSCE components that students were more likely to correctly identify post-compared to pre-training were uterine symmetry/asymmetry (P < 0.001), and presence/absence of a corpus luteum on the right ovary (P = 0.030). Post-training OSCE scores improved for 7/7, 16/19 and 19/30 students with deficient, some and good initial TRP skills respectively (Figure 1). Student distribution within the different palpation skills categories for the pre-and post-training TRP OSCE is summarised in Figure 1.

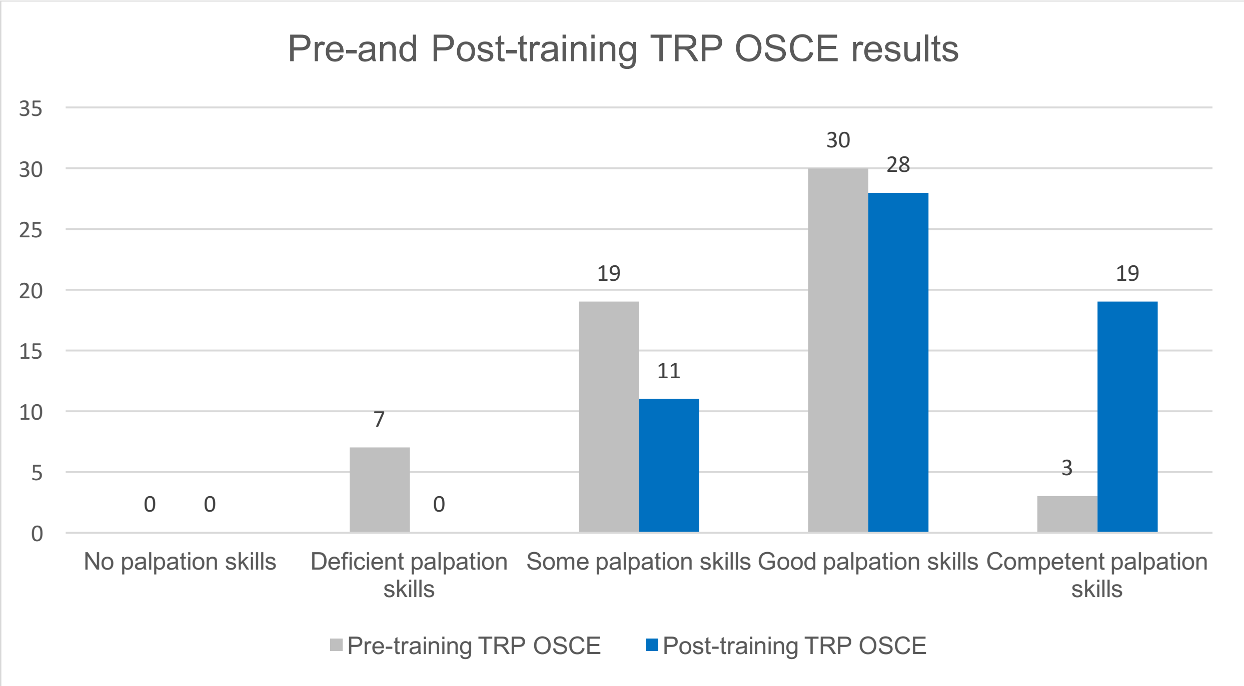


Figure 1 Schematic display of student allocation into palpation skills categories based on pre- and post-training TRP OSCE scores of final-year veterinary students (n = 59)

Correlation between pre-training total TRP OSCE scores and student background, gender, previous palpation experience and grip strength

Median total pre-training TRP OSCE scores were significantly higher for male students (P = 0.039). Grip strength of the preferred hand was positively correlated with the total TRP OSCE score at the initial pre-training assessment (Spearman's rho = 0.400, P = 0.002). Students' pre-training

TRP OSCE scores did not vary by student background (P = 0.095) or previous experience (P = 0.223).

Correlation between post-training total TRP OSCE scores and student background, gender, previous palpation experience, number of live cow PDs done during the one-week training and grip strength

Total TRP OSCE scores for the post-training assessment did not vary by gender (P = 0.520) or previous palpation experience (P = 0.243). Also, total post-training TRP OSCE scores were not significantly correlated to the number of live cows palpated during the training (P = 0.486) or grip strength (P = 0.641). However, the total post-training TRP OSCE scores did vary by student background categories (P = 0.022). Students from a mixed background had the highest post-training TRP OSCE scores, followed by students from a city background. Students from a farm background had the lowest total post-training TRP OSCE scores.

PD assessment, accuracy, sensitivity and specificity results

On the day of the PD assessment, 697 student palpations were performed of which 444 (64%) were on pregnant cows. Of these, 305 (69%) were on cows <6 months pregnant and 139 (31%) on cows >6 months pregnant. Fifty-eight students each palpated 12 cows in the 15-minute time limit. Compared to the diagnoses provided by the experienced veterinarian, the mean overall student accuracy of PD was 81.6% (95% CI 77.7-84.9%) for pregnancy status alone and 43.3% (95% CI 38.4-48.3%) for pregnancy status with correct stage. The mean sensitivity (correctly identify pregnant cows) was 89.1% (95% CI 78.1-92.2%). Student sensitivity for cows < 6 and ≥ 6 months pregnant were 86.4% (95% CI 80.9-90.5%) and 92.1% (95% CI 86.4-95.5%), respectively. Stage corrected mean sensitivity was 30.0% (95% CI 25.4-35.1%).

The mean specificity (correctly identify non-pregnant cows) was 67.7% (95% CI 60.1-74.5%).

Correlation between PD accuracy and grip strength

Higher grip strength (> 35 kg) was associated with higher student PD sensitivity. (P = 0.011, Tables 2 and 3). Students with a grip strength of > 35 kg were 2.5 times more likely to identify pregnant cows correctly. Grip strength was not associated with PD specificity (Table 4).

Table 2 Univariate associations between student level variables and pregnancy diagnosis sensitivity for 58 final-year veterinary students in South Africa

Variable	Level	Parameter estimate ($\hat{\beta}$)	Odds ratio (95% CI)	P value
Gender	Male	0.668	1.95 (0.92, 4.12)	0.080
	Female	Referent		
Background	Farm	0.884	2.42 (0.71, 8.31)	0.160
	Mixed	-0.001	1.00 (0.47, 2.10)	0.998
	City	Referent		
Previous experience	None	Referent		
	With non-veterinarian	-0.290	0.75 (0.20, 2.84)	0.669
	With veterinarian	-0.219	0.80 (0.34, 1.89)	0.614
Additional PDs	Yes	-0.091	0.91 (0.44, 1.89)	0.805
	No	Referent		
Career interest	Mixed practice	0.525	1.69 (0.31, 9.17)	0.542
	Other	0.106	1.11 (0.16, 7.67)	0.914
	Small animal	Referent		
Grip strength	< 34.5	Referent		
	34.5-49.5	1.154	3.17 (1.39, 7.25)	**0.006**
	≥ 50	0.792	2.21 (0.97, 5.02)	0.059
Grip strength	≤ 35	Referent		
	> 35	0.907	2.48 (1.23, 4.97)	**0.011**
PD number*	< 100	Referent		
	≥ 100	0.274	1.32 (0.64, 2.70)	0.453
Preferred hand	Left	-0.299	0.74 (0.30, 1.84)	0.518
	Right	Referent		

CI = confidence interval

PD* = number of live cow PDs done during the one-week training programme

Table 3 Multivariable associations between student level variables and pregnancy diagnosis sensitivity for 58 final-year veterinary students in South Africa

Variable	Level	Parameter estimate ($\hat{\beta}$)	Odds ratio (95% CI)	P value
Grip strength	≤ 35	Referent		
	> 35	0.888	2.43 (1.23, 4.81)	**0.011**
Left horn diameter	Correct	0.962	2.62 (1.32, 5.20)	**0.006**
	Incorrect	Referent		
Corpus luteum right	Correct	-0.887	0.41 (0.17, 1.00)	**0.050**
	Incorrect	Referent		

CI = confidence interval

Table 4 Univariate associations between student level variables and pregnancy diagnosis specificity for 58 final-year veterinary students in South Africa

Variable	Level	Parameter estimate ($\hat{\beta}$)	Odds ratio (95% CI)	P value
Gender	Male	0.696	2.01 (1.09, 3.68)	**0.025**
	Female	Referent		
Background	Farm	0.993	2.70 (1.05, 6.92)	0.039
	Mixed	-0.140	0.87 (0.46, 1.66)	0.670
	City	Referent		
Previous experience	None	Referent		
	With non-veterinarian	-0.383	0.68 (0.26, 1.82)	0.443
	With veterinarian	0.694	2.00 (1.02, 3.92)	**0.043**
Additional PDs	Yes	0.439	1.55 (0.86, 2.78)	0.141
	No	Referent		
Career interest	Mixed practice	0.243	1.28 (0.24, 6.76)	0.774
	Other	0.938	2.55 (0.33, 19.5)	0.365
	Small animal	Referent		
Grip strength	< 34.5	Referent		
	34.5-49.5	0.325	1.38 (0.65, 2.94)	0.847
	≥ 50	0.691	2.00 (0.95, 4.18)	0.067
Grip strength	< 50	Referent		
	≥ 50	0.527	1.70 (0.90, 3.20)	0.103
PD number*	< 100	Referent		
	≥ 100	0.393	1.48 (0.80, 2.73)	0.208
Preferred hand	Left	-0.480	0.62 (0.29, 1.33)	0.216
	Right	Referent		

CI = confidence interval
PD* = number of live cow PDs done during the one-week training programme.

Associations between student level variables and PD sensitivity

Within the univariate analysis that investigated each variable independently, none of the student level variables (background, career interest, previous experience, number of PDs done during the one-week training program and use of the preferred hand for TRPs during the PD assessment) were significant predictors of students' PD sensitivity (Table 2).

Associations between student level variables and PD specificity

Within the univariate analysis, male students (P = 0.025), students from a farm background (P = 0.039) and students who had previous TRP experience with a veterinarian (P = 0.043) were more likely to correctly identify non-pregnant cows (i.e. had higher PD specificity) (Table 4). Career interest and number of PDs performed during the one-week training program were not associated with student PD specificity.

Within the multivariable analysis adjusted for other factors, male students and students from a farm background were twice and 2.8 times more likely to correctly identify a non-pregnant cow compared to female students and students from a city or mixed background, respectively (Table 5).

Table 5 Multivariable associations between student level variables and pregnancy diagnosis specificity for 58 final-year veterinary students in South Africa

Variable	Level	Parameter estimate ($\hat{\beta}$)	Odds ratio (95% CI)	P value
Gender	Male	0.773	2.08 (1.18, 3.65)	**0.011**
	Female	Referent		
Farm background	Yes	1.016	2.76 (1.08, 7.06)	**0.034**
	No	Referent		
Follicle right	Correct	-0.751	0.47 (0.25, 0.89)	**0.021**
	Incorrect	Referent		

CI = confidence interval

Associations between post-training TRP OSCE scores and PD sensitivity

Within the univariate analysis, students' ability to correctly estimate left uterine horn diameter and to correctly diagnose presence or absence of a corpus luteum on the right ovary were associated with higher student PD sensitivity (P = 0.022 and P = 0.017, respectively) (Table 6). None of the other individual OSCE items were predictors of students' PD sensitivity.

The multivariable analysis investigates that combined effects of multiple variables (Table 3) showed that students who correctly estimated left uterine horn diameter were 2.6 times more likely to correctly identify a pregnant cow compared to students that did not correctly estimate left uterine horn diameter. Furthermore, students who correctly diagnosed presence or absence of a corpus luteum on the right ovary were 1.6 times more likely to correctly identify a pregnant cow compared to students that did not.

Table 6 Univariate associations between student post-training TRP OSCE scores and pregnancy diagnosis sensitivity for 58 final-year veterinary students in South Africa

Variable	Parameter estimate ($\hat{\beta}$)	Odds ratio (95% CI)	P value
Left horn diameter	0.838	2.31 (1.13, 4.73)	**0.022**
Right horn diameter	0.331	1.39 (0.63, 3.07)	0.410
Cervix diameter	0.383	1.47 (0.69, 3.14)	0.322
Uterine symmetry	0.345	1.41 (0.67, 2.99)	0.367
Intra-uterine fluid	-0.046	0.96 (0.44, 2.09)	0.908
Left ovary size	0.172	1.19 (0.55, 2.58)	0.663
Right ovary size	-0.017	0.98 (0.47, 2.08)	0.964
Corpus luteum left	-0.064	0.94 (0.43, 2.06)	0.873
Corpus luteum right	-1.102	0.33 (0.13, 0.82)	**0.017**
Follicle left	-0.325	0.72 (0.35, 1.48)	0.375
Follicle right	0.188	1.21 (0.58, 2.50)	0.611
Total*	**0.051**	**1.05 (0.88, 1.27)**	**0.583**

*Sum of the 11 individual assessment components and modelled as a continuous predictor

Associations between post-training TRP OSCE scores and PD specificity

Within the univariate analysis, none of the individual OSCE items or overall OSCE score were associated with student PD specificity (Table 7).

However, the multivariable results suggested that students who correctly diagnosed presence or absence of a follicle on the right ovary were twice as likely to correctly identify a non-pregnant cow compared to students that did not (Table 5).

Table 7 Univariate associations between student post-training TRP OSCE scores and pregnancy diagnosis specificity for 58 final-year veterinary students in South Africa

Variable	Parameter estimate ($\hat{\beta}$)	Odds ratio (95% CI)	P value
Left horn diameter	-0.061	0.94 (0.48, 1.85)	0.859
Right horn diameter	0.008	1.01 (0.50, 2.03)	0.982
Cervix diameter	0.197	1.22 (0.61, 2.42)	0.573
Uterine symmetry	-0.419	0.66 (0.32, 1.36)	0.257
Intra-uterine fluid	0.041	1.04 (0.54, 2.01)	0.903
Left ovary	-0.123	0.88 (0.45, 1.74)	0.720
Right ovary	-0.053	0.95 (0.51, 1.75)	0.863
Corpus luteum left	-0.113	0.89 (0.48, 1.67)	0.721
Corpus luteum right	0.345	1.41 (0.76, 2.62)	0.273
Follicle left	-0.009	0.99 (0.55, 1.80)	0.977
Follicle right	-0.598	0.55 (0.30, 1.01)	0.053
Total*	**-0.048**	**0.95 (0.81, 1.12)**	**0.555**

*Sum of the 11 individual assessment components and modelled as a continuous predictor

Student feedback on the one-week intense TRP and PD training programme

The response rate to feedback on the one-week training programme was 95% (56/59). Ninety-one per cent of students (51/56) either agreed or strongly agreed that they enjoyed the one-week training programme and 80% (45/56) agreed that the programme should be implemented as an annual event within the VEP work-place based student training. Sixty per cent of students (33/55) indicated that the one-week training programme increased their interest in production animal practice.

Seventy-seven (43/56) and 18% (10/56) of students strongly agreed or agreed that the live cow PD exposure in private practice was beneficial. Student feedback on the skills laboratory (rectal examination simulator exposure) and abattoir obtained reproductive organ training suggested that students found the latter more beneficial (Table 8).

Table 8 Student feedback on the 2018 one-week intense TRP and PD training programme

Statements (number of student responses)	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Overall, I think the one-week training programme improved my bovine TRP and PD skills. (n = 55)	**1** (1.8%)	**4** (7%)	**14** (26%)	**29** (53%)	**7** (13%)
I think my post-training TRP OSCE scores have improved from the pre-training TRP OSCE. (n = 56)	**1** (1.8%)	**9** (16%)	**21** (37.5%)	**23** (41%)	**2** (3.5%)
I found the skills laboratory training (Breed'n Betsy®, Haptic cow, theory material) beneficial. (n = 56)	**5** (9%)	**17** (30%)	**17** (30%)	**14** (25%)	**3** (5%)
I found exposure to the abattoir obtained reproductive organs beneficial. (n = 56)	**2** (3.5%)	**3** (5%)	**7** (12.5%)	**33** (59%)	**11** (20%)
I found the additional live cow PD exposure in private practice beneficial. (n = 56)	**0**	**2** (3.5%)	**1** (1.8%)	**10** (18%)	**43** (77%)
The one-week training programme increased my interest in production animal practice. (n = 55)	**0**	**2** (3.6%)	**20** (36%)	**25** (45%)	**8** (15%)
I recommend implementation of the one-week training programme as an annual event within VEP. (n = 56)	**1** (1.8%)	**0**	**10** (18%)	**26** (46%)	**19** (34%)
I consider the PD assessment as fair. (n = 55)	**0**	**3** (5.5%)	**10** (18%)	**39** (71%)	**3** (5.5%)
Overall, I enjoyed the 2018 PD challenge. (n = 56)	**0**	**0**	**5** (9%)	32 (57%)	**19** (34%)

Discussion

The significantly higher post-training TRP OSCE scores (P = 0.030) indicate the value of a one-week, high intensity bovine TRP training programme. Post-training OSCE scores improved for students with deficient, some and good initial TRP skills respectively (Figure 1) and the number of students in the competent palpation skills category increased from three to 19. Based on the post-training OSCE, 47/59 (80%) students were now in the 'good or competent palpation skills category', showing that the majority of students had developed sufficient palpation skills during the one week training period.

Overall PD accuracy via TRP in cows > 35 days pregnant has been reported as high as 99.7% for experienced large animal practitioners, with a sensitivity of 100% and a specificity of 99.4%.[13] Students' overall PD accuracy (82%), sensitivity (88%) and especially specificity (67%) in this study were higher than previously reported for fourth- and fifth-year veterinary students.[3, 11, 16] This finding supports the approach to implement focused live cow TRP and PD training during the later stages of the curriculum for selected students with an interest in food animal practice.[16] Focusing on non-pregnant cow palpations and specificity was highlighted as an area of TRP and PD training improvement.[3] A student specificity of 67% means that two out of three cows were correctly identified as non-pregnant by the students in this study, while it would have only been one out of three cows previously (41%[3] and 42%[16]). Since the ability to identify non-pregnant cows has direct financial implications for the farmer,[14, 26, 27] the higher student specificity in this study is an important and valuable finding. Stage-corrected sensitivity (defined as the proportion of pregnant cows in which pregnancy stage was correctly identified by the student) in this study was also higher (43%) than previously reported (31%),[16] but is an area that requires further improvement and additional student training.

The individual post-training OSCE components associated with higher student sensitivity were students' ability to correctly estimate left uterine horn diameter and to correctly diagnose the presence or absence of a corpus luteum on the right ovary, both of which improved post-training. Students were more likely to correctly identify uterine symmetry/asymmetry ($P < 0.001$) and presence/absence of a corpus luteum on the right ovary ($P = 0.03$) post-training. The individual OSCE component associated with higher student specificity was students' ability to correctly diagnose presence or absence of a follicle on the right ovary. One commonality these OSCE components share is that they are considered more advanced TRP skills.[16] Correctly diagnosing structures on the ovaries requires students to be able to follow the uterine horns to find the ovaries, stabilise them and feel for ovarian structures. This skill is more advanced than locating the cervix and uterus,[16] and therefore supports the positive association shown to PD accuracy. The same holds true for students' ability to correctly estimate uterine horn diameter, which would enable them to recognise uterine asymmetry as one of the important signs of pregnancy. An association between PD accuracy and a student's ability to give quantitative measurements is in accordance with a previous study where higher student PD sensitivity was shown to be associated with students' ability to correctly estimate ovary dimensions.[16] The ability to estimate quantitative measurements of reproductive organs during bovine TRPs has a positive effect on student TRP training.[2] The fact that a previous study validated the presence of a CL and presence/absence of fluid as independent predictors of PD accuracy,[16] while the current study validated two other OSCE components strengthens the evidence that the OSCE as a whole is a valid assessment of TRP skills.[28] None of the more subjective measures such as tone of the uterus were predictors of PD accuracy. These findings could be used to modify the OSCE components and concentrate exclusively on objective measures. The reason for the correlation between students' ability to correctly identify structures on the right but not the left ovary is unclear. A practical recommendation from these findings would be to concentrate on more advanced TRP skills (ability to give quantitative measurements of reproductive structures and to correctly identify ovarian structures) during the initial TRP training before advancing to live cow PDs.

There was a high variation in the number of live cow palpations performed by students (range 20-600) during the private practice placements within the one-week training program with half of the students palpating fewer than 100 cows in total (Table 1). Despite a previously reported positive correlation between number of cows palpated and students' TRP skills,[1] in this study, there was no correlation between the number of cows palpated during the private practice placements and post-training OSCE scores, student PD sensitivity or specificity. This might be explained through the concept of 'deliberate practice',[29] which refers to 'intense, repetitive performance, in a controlled setting, of intended cognitive or psychomotor skills within a focused domain; rigorous skills assessment to identify deficiencies and errors; specific, informative feedback on how to correct them; and ongoing practice, with progressive increases in level of difficulty, yielding gradual, continuous improvement in skills performance'.[29-31] The effect of deliberate practice on expert status in many professional disciplines, including chess, athletics, music, and medicine has been shown,[29, 32] and its importance for veterinary education has been highlighted.[30, 33] Therefore, it may well be that the level of supervision and feedback provided by specific veterinarians is more important than the overall number of cows palpated. The effect of private practice could not be statistically evaluated in this study as there were too many practices (n = 24) and on average only 2.5 students per practice. However, feedback from students indicated that in practices where students palpated more than 300 cows during the two-day practice placements, there was often little feedback or supervision from the veterinarian due to time pressure. Other students highlighted the time and effort individual veterinarians took to teach them even though fewer cows were palpated. This reasoning could be further substantiated by the fact that only previous TRP experience with a veterinarian was associated with a higher student PD specificity, highlighting the effect of expert supervision. A practical application of this finding would be to identify veterinarians with an interest in student TPR training who are able to set aside time for sufficient feedback and supervision.

The fact that gender and grip strength were associated with higher pre- but not post-training TRP OSCE scores might be explained by a previous finding where higher palpation accuracy for male students was thought to be linked to grip strength.[11] Grip strength is generally higher for men compared to women in the general population.[25] The same has been shown in this study and in a recently published study where male students' grip strength was higher than that of female students.[11] It is possible that a higher grip strength led to better gender performance in the pre-training OSCE in this study. However, palpation experience gained during the one-week training program appeared to overcome the initial grip strength advantage of male students. The live cow palpation experience gained could have led to easier and faster reproductive tract finding and palpation. More efficient and competent palpation execution and technique might require less muscle activation and therefore less grip strength during palpations. The hypothesis that increased live cow palpation experience leads to decreased effort during non-pregnant cow palpations is supported by the associations of grip strength and PD sensitivity and specificity identified in this study. While grip strength was associated with students' PD specificity in a previous study,[11] this was not the case in this study. The cohort in the previous study was fifth-year students (of a six-year program) as compared to final-year students in this study. The lower palpation experience level might therefore have required greater effort to correctly identify non-pregnant cows. Grip strength in this study was correlated with PD sensitivity while there was no association in the previous study. One possible explanation is that while in general it seems easier for students to correctly identify pregnant compared to non-pregnant cows,[3, 16] the fact that students palpated 12 cows instead of six as described previously could have influenced muscle fatigue and required endurance, previously shown to be linked to grip strength.[34, 35] This could be the reason why students with a grip strength of > 35 kg were more likely to correctly identify pregnant cows than students with a grip strength of < 35 kg.

The finding that students' use of their preferred hand for TRPs was not associated with PD sensitivity or specificity, could be explained by the fact that the majority of students (78%) preferred the left hand while the on-farm examination crush used during the student PD assessment required left hand palpation. If a higher percentage of students would have had to palpate with their non-preferred hand, an association might have been detected.

The majority of students enjoyed the one-week training program (91%), recommended implementation thereof as an annual event within the VEP work-place based student training (80%) and found the live cow PD exposure in private practice beneficial (60%). This supports the initiative to incorporate this programme for production animal elective students as an annual event. Interestingly, 39% of students did not find the rectal examination simulator (BB and Haptic Cow) training beneficial, which suggests that simulator training at this stage in the students' career might be too late as previous live cow experience outweighs the simulator training benefits. This is in accordance with a previous study reporting that students with previous live cow PD experience had negative opinions concerning BB training while students without any prior live cow PD experience were exclusively positive.[3] This underpins a previous recommendation of simulator training earlier in the curriculum prior to live cow palpations,[3] and can be used to adjust the one-week training programme to make simulator training a voluntary exercise for interested students.

Another positive aspect of formative in-training TRP assessments aimed at tracking students' progress, could be based on 'the forward testing effect'.[36, 37] 'The forward testing effect describes the finding that testing of previously studied information potentiates learning and retention of new information'.[38] Forward testing is a new technique using interim tests to improve learning.[36-38] The pre-training TRP OSCE in this study would be the interim test that may have positively influenced the training outcome during this programme. Apart from a potentiated learning period after the pre-training test,[36-38] students may have realised the gaps in their current knowledge compared to the desired status and adjusted their learning accordingly.[37] Even though the current available literature describing the forward testing effect is based on theoretical knowledge, the effect may be transferrable to hands-on skills based on Miller's framework of clinical skills assessment.[39] Knowledge (knows) and competence (knows how) are prerequisites for performance (shows how) and action (does).[39] This is supported by a previous report on student TRP training showing that even though students were able to locate cervix, uterus and ovaries during bovine TRPs, they had difficulty in interpreting these findings.[1] Being able to combine theoretical knowledge ('knows' and 'knows how') with basic skills ('shows how' level in a simulated testing environment using a TRP OSCE) should prepare students for the final 'does' level where skills and knowledge are combined to come to a diagnosis (PD assessment or stage of the oestrous cycle in this case).

One limitation of this study is that only students interested in production animal practice were included in this study. Career interest and student background can influence PD accuracy,[3] and this may have influenced the results of this study. Therefore, these findings may not be applicable to students with other career interests.

Conclusion

In conclusion, a one-week intense training programme is an appropriate strategy to improve students' TRP OSCE scores and palpation abilities through implementation of focused live cow access via private practice placements during later stages of the curriculum for selected students intending to follow a career in food animal practice. This approach has the potential to overcome training limitations including animal use constraints at teaching institutions.

Acknowledgements

The authors thank Mr and Mrs David and Susan Hill of Hall's Hill Farm, Doornpoort, South Africa, for their generosity in making their Nguni cattle herd and their facilities available in support of veterinary education research. The *Health and Welfare Sector Education and Training Authority* (*HWSETA*), South Africa, and Zoetis South Africa are acknowledged for their financial support of this study. This study was further funded through a *University of Pretoria's Research Development Programme (RDP)* grant.

References

1. Bossaert P, Leterme L, Caluwaerts T, Cools S, Hostens M, Kolkman I, De Kruif A. Teaching transrectal palpation of the internal genital organs in cattle. *Journal of Veterinary Medical Education* 36:451-60, 2009.

2. French HM, Dascanio JJ, Gilbert GE, Robinson JQ. Bovine reproductive palpation training: does the cow make a difference? *Journal of Veterinary Medical Education* 45(2):219-23, 2018.

3. Annandale A, Annandale CH, Fosgate GT, Holm DE. Training method and other factors affecting student accuracy in bovine pregnancy diagnosis. *Journal of Veterinary Medical Education* 45(2):224-31, 2018.

4. Alexander BM, Johnson MS, Guardia RO, Van de Graaf WL, Senger PL, Sasser RG. Embryonic loss from 30 to 60 days post breeding and the effect of palpation per rectum on pregnancy. *Theriogenology* 43:551-6, 1995.

5. Romano JE, Thompson JA, Kraemer DC, Westhusin ME, Forrest DW, Tomaszweski Ma. Early pregnancy diagnosis by palpation per rectum: Influence on embryo/fetal viability in dairy cattle. *Theriogenology* 67:486-93, 2007.

6. Romano JE, Thompson JA, Kraemer DC, Westhusin ME, Tomaszweski MA, Forrest DW. Effects of early pregnancy diagnosis by palpation per rectum on pregnancy loss in dairy cattle. *Journal of the American Veterinary Medical Association* 239:668-73, 2011.

7. Romano JE, Fahning ML. Effects of early pregnancy diagnosis by per rectal palpation of the amniotic sac on pregnancy loss in dairy cattle. *Journal of the American Veterinary Medical Association* 243:1462-7, 2013.

8. Morin DE, Constable PD, Troutt HF, Johnson AL. Individual animal medicine and animal production skills expected of entry-level veterinarians in bovine practice. *Journal of the American Veterinary Medical Association* 221(7):959-68, 2002.

9. Luby CD, McIntyre K, Jelinski MD. Skills required of dairy veterinarians in western Canada: A survey of practicing veterinarians. *The Canadian Veterinary Journal* 54(3):267-70, 2013.

10. Lopes G, Rocha A. Teaching bovine rectal palpation with live cows in the slaughterhouse: Is it worthwhile? *Reproduction in Domestic Animals* 41:510-3, 2006.

11. Annandale A, Fosgate GT, Eksteen CA, Kremer WDJ, Bok HGJ, Holm DE. Influence of an exercise program, muscle strength, proprioception and arm length on veterinary students' bovine pregnancy diagnosis accuracy. Accepted for publication in *The Journal of Veterinary Medical Education*.

12. Alonso-Alanusa L, Galina-Hidalgo C, Romero-Zuniga JJ, Estrada-Konig S, Galindo-Badilla J. Usefulness of rectal palpation and transrectal ultrasonography in the diagnosis of gestation of the Zebu cattle in the humid tropical in Costa Rica Utilidad de la palpacion rectal y la ecografia transrectal en el diagnostico de gestacion del ganado cebu en el tropico humedo de Costa Rica. *Revista Cientifica*, Facultad de Ciencias Veterinarias, Universidad del Zulia 22(1):9-16, 2012.

13. Romano JE, Fahning ML. Accuracy of per rectum palpation for pregnancy diagnosis in cattle. Proceedings of the XXVIII World Buiatrics Congress. Cairns, Australia p. 129, 2014.

14. Warnick LD, Mohammed HO, White ME, Erb HN. The relationship of the interval from breeding to uterine palpation for pregnancy diagnosis with calving outcomes in holstein cows. *Theriogenology* 44:811-25, 1995.

15. Oltenacu PA, Ferguson JD, Lednor AJ. Economic evaluation of pregnancy diagnosis in dairy cattle: a decision analysis approach. *Journal of Dairy Science* 73:2826-31, 1990.

16. Annandale A, Fosgate GT, Bok H, Holm DE. Ability of a bovine transrectal palpation objective structured clinical examination to predict veterinary students' pregnancy diagnosis accuracy. *The Veterinary Record* 185(6):171-180, 2019.

17. Norman ST, Dall'Alba G. Computer assisted learning for improving cattle palpation skills of veterinary students. *Open Journal of Veterinary Medicine* 3(8):9, 2013.

18. Baillie S, Crossan A, Brewster S, Mellor D, Reid S. Validation of a bovine rectal palpation simulator for training veterinary students. *Studies in Health Technology and Informatics* 111:33-6, 2005.

19. Baillie S, Mellor DJ, Brewster SA, Reid SWJ. Integrating a bovine rectal palpation simulator into an undergraduate veterinary curriculum. *Journal of Veterinary Medical Education* 32:79-85, 2005.

20. Baillie S, Crossan A, Brewster SA, May SA, Mellor DJ. Evaluating an automated haptic simulator designed for veterinary students to learn bovine rectal palpation. *Simulation in Healthcare: Journal of the Society for Simulation in Healthcare* 5:261-6, 2010.

21. Giese H, Gundelach Y, Geuenich K, Ehlers JP, Dilly M. Effects of training methods for rectal palpation in cattle on student's performance and self-evaluation. AMEE. Glasgow, 2015.

22. Brannick MT, Erol-Korkmaz HT, Prewett M. A systematic review of the reliability of objective structured clinical examination scores. *Medical Education* 45(12):1181-9, 2011.

23. Hecker K, Read EK, Vallevand A, Krebs G, Donszelmann D, Muelling CKW, Freeman SL. Assessment of first-year veterinary students' clinical skills using objective structured clinical examinations. *Journal of Veterinary Medical Education* 37(4):395-402, 2010.

24. Irons PC, Holm DE, Annandale CH. Curricular renewal at the southern tip of Africa: the 2016 veterinary curriculum at the University of Pretoria. *Journal of Veterinary Medical Education* 44(3):440-9, 2017.

25. Goble DJ. Proprioceptive acuity assessment via joint position matching: from basic science to general practice. *Physical therapy* 90(8):1176-84, 2010.

26. De Vries A. Economic value of pregnancy in dairy cattle. *Journal of dairy science* 89:3876-85, 2006.

27. Bridges A, Lake S, Lemenager R, Claeys M. Non-pregnant cows are non-productive cows. Purdue University Department od Animal Sciences Ext Pub AS-586-W, 2008.

28. Van der Vleuten CPM. The assessment of professional competence: Developments, research and practical implications. *Advances in Health Sciences Education* 1(1):41-67, 1996.

29. Ericsson KA, Charness N. Expert performance: Its structure and acquisition. *American Psychologist* 49(8):725-47, 1994.

30. Scalese RJ, Issenberg SB. Effective use of simulations for the teaching and acquisition of veterinary professional and clinical skills. *Journal of Veterinary Medical Education* 32(4):461-7, 2005.

31. George JH, Doto FX. A simple five-step method for teaching clinical skills. *Family Medicine* 33(8):577-8, 2001.

32. McGaghie WC, Issenberg SB, Cohen ER, Barsuk JH, Wayne DB. Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. *Academic medicine: Journal of the Association of American Medical Colleges* 86(6):706-11, 2011.

33. Annandale A, Scheepers E, Fosgate GT. The effect of ovariohysterectomy model practice on surgical times for final-year veterinary students' first live-animal ovariohysterectomies. *Journal of Veterinary Medical Education* 1-12, 2019.

34. Trosclair D, Bellar D, Judge LW, Smith J, Mazerat N, Brignac A. Hand-grip strength as a predictor of muscular strength and endurance. *The Journal of Strength and Conditioning Research* 25, 2011.

35. Ruprai R, Tajpuriya S, Mishra N. Handgrip strength as determinant of upper body strength/physical fitness: a comparative study among individuals performing gymnastics (ring athletes) and gymnasium (powerlifters). *International Journal of Medical Science and Public Helath* 5(6):1167-1172, 2016.

36. Yang C, Potts R, Shanks DR. Enhancing learning and retrieval of new information: a review of the forward testing effect. *NPJ Science of Learning* 3:8, 2018.

37. Yang C, Potts R, Shanks DR. The forward testing effect on self-regulated study time allocation and metamemory monitoring. *Journal of Experimental Psychology Applied* 23(3):263-77, 2017.

38. Yang C, Shanks DR. The forward testing effect: Interim testing enhances inductive learning. *Journal of Experimental Psychology Learning, Memory, and Cognition* 44(3):485-92, 2018.

39. Miller GE. The assessment of clinical skills competence performance. *Academic Medicine* 65(9):S63-S7, 1990.

Chapter 7
General discussion

Discussion

The aim of this thesis was to investigate alternative and improved undergraduate veterinary training methods for bovine transrectal palpation (TRP) and pregnancy diagnosis (PD) skills. The second aspiration of this thesis was that thinking differently about clinical skills training for bovine TRP and PD as an example might lead to an alternative approach to traditional skills training in general that has the potential to overcome some of the training constraints at teaching institutions. As explained in Chapter 1, this led to a number of studies describing and evaluating TRP and PD assessment methods, identifying predictors and factors affecting students' TRP and PD accuracy, developing and implementing research-based innovative teaching ideas, including optimised simulator training, in-training assessment methods, additional training opportunities linked to or not directly linked to the TRP skill itself and the use of technology to improve skills training. The series of studies described in this thesis aimed at demonstrating how training innovations can be combined with traditional training to improve overall TRP and PD training and to optimise limited live animal exposure to practice these skills. In Chapters 2 and 3 we described a method to measure students' PD accuracy on live cows and an OSCE to assess students' TRP skills. The study described in Chapter 3 further evaluated if students' TRP OSCE scores are predictors for students' future PD accuracy. The same study also resulted in the development of the 'Mini Cow Palpation Box'. The study described in Chapter 2 moreover evaluated the effectiveness of rectal examination simulator training compared to live animal training, and investigated factors influencing students' PD accuracy. Chapter 4 reports on a study based on the unusual physical activity involved in bovine TRPs and investigated the effects of arm muscle strength, grip strength, proprioception and an exercise program on students' PD accuracy. Results from this study led to the investigation presented in Chapter 5 where an electromyographic (EMG) analysis study took the results of the previous study a step further and led to the development of the 'Bovine PD Improvement Exercise Programme'. Chapter 6 describes a study based on the findings of the studies outlined in Chapters 2, 3 and 4 and investigates the effect of a one-week intense training program on final-year veterinary students' PD accuracy. The discussion is divided into three parts: Part one describes how each of these chapters contributed to the understanding of bovine TRP and PD training and assessment, and how the results presented in these chapters have led to training innovations and improvements. Part two of the discussion describes a new concept to teach clinical hands-on skills (The 'Predictor Micro-Skills Concept') which is based on the TRP and PD skills training investigations done as part of this PhD thesis and which might be applicable to many other clinical skills. Part three of the discussion describes the approach to blending of a fun student project and research while teaching, which as part of the PhD investigations has led to an annual PD training intervention at our institution.

Part one: Alternative and improved undergraduate veterinary training methods for bovine transrectal palpation (TRP) and pregnancy diagnosis (PD) skills

Students' TRP and PD skills assessments and accuracy

The studies reported on in Chapters 2 and 3 describe a new method for PD accuracy assessment and a TRP OSCE which has been shown to be valid and reliable. Something that has not been described previously for students' TRP and PD skills evaluations and is described in this thesis are two separate assessment methods which have been shown to bridge the gap between practical competence (evaluated via TRP OSCE assessment under simulated examination conditions) and clinical performance (PD assessment in a real-life farm situation) of the same skill (TRP skills in this case).[1] This is an important result since OSCE assessments are conducted under simulated examination conditions, and they do not necessarily provide valid information on the candidate's ability to perform the skill in real-life situations as shown previously.[1, 2] For example, the performance level of Dutch general practitioners was lower than their competence level based on OSCE assessments.[2] Comparing students' TRP performances and training outcomes between studies has proven difficult as different evaluation criteria and methods were used in each study.[3-6] While Baillie *et al*. evaluated if students were able to find the uterus,[3] Lopes *et al*. used a scoring system with grades from 0-2.5 points based on the diagnosis reached by the students rather than describing the actual findings.[4] A potential problem associated with this approach has been identified by a later study which found that even when students were able to localise cervix, uterus and ovaries, they had difficulties interpreting these structures and deduce a correct diagnosis.[5] Bossaert *et al.* had students complete a questionnaire after palpations in which questions were asked about the localisation and evaluation of the cervix, uterus, and ovaries. Students were supposed to draw a final conclusion about the presence or absence of pregnancy, the phase of the oestrous cycle, and the presence or absence of pathologies. Points were allocated to each answer, resulting in a test result ranging from zero to 100.[5] The validated TRP OSCE as described in Chapter 3 might prove helpful for future investigations to rather use a standardised test for these student evaluations. The method to assess students' PD accuracy as described in Chapter 2, was later used and optimised in the studies described in Chapters 3, 4 and 6. The TRP OSCE as first described in Chapter 3 was further validated in Chapter 6, highlighting its usefulness. The results of students' TRP abilities and PD accuracy described in Chapters 2 and 3 using these assessments confirm the need to improve PD via TRP training, and highlighted students' specificity (ability to identify non-pregnant cows) as a problem area (Table 1). These two studies furthermore bring to the fore that the training as described for fourth- and fifth-year students is insufficient to reach palpation competency. Results of the PD assessments for the studies presented in Chapters 2, 4 and 6 are summarised in Table 1 and demonstrate how the training interventions and advancing from pre-clinical to clinical student cohorts for TRP and PD training have improved students' PD accuracy. Especially the specificity improvement is encouraging and showing that while in 2014 students would have only recognised one out of three non-pregnant cows correctly, this had advanced to two out of three in 2018. The fact that overall PD accuracy and sensitivity were higher in the first study (Chapter 2) compared to the second study (Chapter 4) can be explained by the fact that the pregnancy rate was 62% in 2014 compared to 49% in 2016 with 46% and 70% of pregnant cows < 6 months pregnant for 2014 and 2016, respectively (Table 1). Since both studies showed that students' PD sensitivity is higher in cows > 6 months pregnant,[7, 8] the higher percentage of cows < 6 months pregnant in combination with the lower pregnancy rate in general in the 2016 study made a correct diagnosis more difficult, and explains the lower student PD accuracy and sensitivity.

Table 1 Overall student PD accuracy, sensitivity and specificity for fourth-, fifth- and final-year student cohorts

	2014 **4th-year student cohort (Chapter 2)**	**2016** **5th-year student cohort (Chapter 4)**	**2018** **Final-year student cohort (Chapter 6)**	**2019** **Final-year student cohort (Chapter 7, part 3)**
Pregnancy rate	62%	49%	64%	66%
Percentage of cows ≤ 6 months pregnant	46%	70%	69%	64%
Overall student PD accuracy	71%	61%	82%	85%
Sensitivity	87%	79%	88%	89%
Specificity	41%	42%	67%	79%

Stage corrected sensitivity (defined as the proportion of pregnant cows in which pregnancy stage was correctly identified by the student) was 43% for final-year students who had received a one-week intense TRP and PD training programme (Chapter 6). This was higher than the reported 31% for a fifth-year student cohort (Chapter 4),[8] but is an area that could be improved and additional student training should focus on stage corrected sensitivity.

Optimised rectal examination simulator training

While simulations are increasingly attractive as a parallel to clinical experience, it is crucially important that simulations be validated to meet the expected training outcomes.[9] Several studies evaluated the use and implementation of rectal examination simulators in veterinary training programs.[3, 5, 10-13] In the case of TRP and PD, simulator training was shown to be superior to theoretical instruction only,[12] and additional simulator training significantly improved students' performance after live cow palpations.[3] It was also shown that students trained on live cows were more skilled evaluating the uterus and ovaries in non-pregnant cows than simulator trained students while there was no difference between the two training groups in recognising pregnant cows by TRP.[5] The study described in Chapter 2 is the first large scale rectal examination simulator study specifically validating the effectiveness of simulator PD training compared to live animal PD training.[7] It was found that student sensitivity for pregnancy detection in cows > 6 months pregnant was similar for training on simulators and live cows. However, PD training on simulators was associated with lower student sensitivity (students' ability to identify pregnant cows) for pregnancy detection in cows < 6 months pregnant. This was interesting since the Breed'n Betsy® simulators are specifically designed for early pregnancy detection and furthermore, because in this study students trained on live cows only palpated cows > 6 months pregnant during training.[7] It was hypothesised that a possible explanation for this contradiction could be that overcoming the unusual experience of TRP may be more difficult than the actual ability to palpate.[7] Another explanation could be that rectal examination simulators do not necessarily imitate the same movements and muscle activations during TRPs as the same procedure on live animals due to the absence of rectal peristalsis, anal sphincter tone, and other internal organs such as a bladder and rumen (Chapter 5). A different muscle activation pattern was hypothesised as a potential reason for the difference in training outcome for simulator and live cow trained students. An investigation to elaborate on this hypothesis described in Chapter 6 concluded that a difference in muscle activation for simulator and live cow palpations as a potential reason for the difference in training outcome for simulator and live cow trained students can be excluded. However, muscle relaxation between individual TRP steps for simulator palpations as seen in Figures 2 and 3 of Chapter 6 indicate that the areas of muscle relaxation between TRP steps are more distinct for simulator palpations. This was a finding consistently seen for all muscle groups during simulator palpations and thought to be due to the absence of rectal peristalsis. Based on these results in combination with a low student specificity identified as a problem area, teaching efforts focusing on specificity of PD and repeated simulator-based training in conjunction with live cow exposure were recommended.[7] These recommendations are in agreement with previous studies advising live cow training in combination with simulator training to optimise learning outcomes.[3, 5, 12]

The findings of the simulator validation (Chapter 2) collectively with the findings of the studies described in Chapter 3 and 6, led to another level of simulator use during training. It was found that students' ability to estimate ovarian size and to confirm presence or absence of a corpus luteum was correlated with higher sensitivity of PD (Chapter 3), while students' ability to confirm presence or absence of a follicle was positively correlated with higher specificity of PD (Chapter 6). Based on these results and the recommended approach to introduce a TRP OSCE as a formative assessment for ongoing feedback throughout the TRP training (Chapter 3),[14] led to the implementation of a compulsory in-training simulator OSCE assessment at our training institution. During this assessment, students have to palpate three simulator cows and fill in an OSCE sheet to indicate size of ovaries and presence or absence of ovarian structures. Students can choose when they want to do the assessment and repeat the assessment as many times as necessary to pass. Passing this 'right of way' assessment is a requirement before students are allowed to advance to live cow palpations. The aim is to verify that students have basic palpation skills before live cow access is granted to ensure more efficient live cow use. Another finding related to the use of simulators is that timing of simulator training in relation to student experience within the veterinary course is important. The study described in Chapter 2 reported that fourth-year students without any prior live cow PD experience were exclusively positive about their simulator experience, while students with previous live cow PD experience made negative remarks about the simulator experience.[7] This finding is supported by final-year student questionnaire feedback described in the study presented in Chapter 6 (Table 8) showing that refresher rectal examination simulator training at that stage of the students' career was not perceived as beneficial by the majority of students. Therefore, rectal examination simulator training should be implemented early on in the curriculum before live cow exposure. Leading these findings back to the initial research question whether rectal examination simulator training is as good as (or could potentially replace) live cow PD training, we conclude that it is not. However, using simulators optimally at the right time in the veterinary course as described above is an effective approach to compensate for a shortage of live animal training opportunities to an extent by having better prepared students maximally utilising limited live cow palpation opportunities after rectal examination simulator exposure and assessments.

To summarise this paragraph, the following conclusions have been drawn to optimise rectal examination simulator training. Repeated rectal examination simulator-based training in conjunction with live cow exposure is advised. Rectal examination simulator training should be implemented early on in the curriculum, and use of the ‘Mini-cow palpation box’ to develop coordination and fine motor skills to estimate object sizes without visualisation is recommended. Furthermore, the introduction of a TRP OSCE (on simulator and/or non-pregnant live cows, depending on availability) as a compulsory formative in-training assessment (‘right of way’ examination) before advancing to PD training on live cows is suggested, while the use of the validated TRP OSCE on live cows can be implemented to ensure training outcomes and track student progress during advanced TRP and PD training sessions.

Predictors and student level variables affecting students’ TRP and PD skills

The studies outlined in Chapters 2, 4 and 6 looked at a variety of predictors and student level variables that were thought to potentially have an effect on students’ TRP and PD skills. These predictors and student level variables can broadly be categorised as *demographic factors* (city, farm or mixed upbringing background, gender and career interest), *previous exposure* (TRP and PD experience), *physical parameters* (arm length and strength, grip strength, proprioception, use of preferred hand for TRPs) and *bovine pregnancy stage*.

Demographic factors

Interestingly, looking at demographic factors, the influence of background, gender and career interest on students’ PD accuracy was different for fourth-, fifth- and final-year student cohorts. The first study (Chapter 2) found that a farming background and an interest in a mixed animal practice career were significantly associated with higher PD sensitivity for fourth-year students. It was hypothesised that previous animal exposure and experience by growing up on a farm and an interest in large animals seems to be positively correlated with large animal clinical skills including bovine PD via TRP.[7] However, the study documented in Chapter 4 found that a career choice other than mixed practice was associated with higher PD sensitivity for a fifth-year student cohort. The fact that this study showed the opposite to the previous study might indicate that career interests and large animal skills might be influenced by additional factors in different student cohorts. It might also be influenced by the fact that the previous study investigated a fourth-year and the subsequent study a fifth-year student cohort (out of a six-year course). Background and initial experience might be overcome by additional exposure related to advancement within the veterinary course.[8] This information is helpful to identify the optimal time within the veterinary course for live cow TRP exposure and supports the approach of focused access to live cow palpations during later stages of the curriculum (Chapter 3).[14] The study presented in Chapter 6 however showed that neither farming background nor career interest had an influence on final-year students' PD sensitivity. Students' PD specificity was higher for students from a farming background. The different findings compared to the studies investigating fourth- and fifth-year student cohorts were likely influenced by the fact that all students participating in the latter study had chosen production animal electives [Rural Veterinary Practice and Wildlife (RVP), Intensive Animal Production (IAP) or State Veterinary Practice and Veterinary Public Health (SVP - VPH)] as their elective component for the clinical work-integrated learning during the last 18 months of study. Furthermore, only 7% of these students indicated a career interest other than rural mixed or specialized production animal practice. It is interesting though that a farming background was only correlated with higher specificity but not sensitivity. This could be explained by the fact that identifying non-pregnant cows (specificity) had been consistently found to be more challenging for students than identifying pregnant cows (sensitivity) within all investigated student cohorts (Chapter 2, 4 and 6).[7, 8] For this more difficult skill a farming background could have been advantageous based on the associated large animal exposure due to growing up on a farm. This had been previously described to be potentially correlated with large animal clinical skills including bovine PD via TRP (Chapter 2).[7]

Gender has been found to be associated with PD accuracy. Male students of a fifth-year cohort had higher PD sensitivity and specificity and were twice as likely to correctly identify pregnant cows than female students (Chapter 4).[8] Another study showed that male final-year students were twice as likely to identify pregnant cows than their female colleagues (Chapter 6). It was hypothesised that this gender difference could be due to a difference in grip strength. Grip strength is higher for men than women in the general population.[15] The same has been shown in veterinary students where male students' grip strength was higher than that of female students (Chapter 4 and 6).[8] Since grip strength is linked to higher PD accuracy as shown in Chapters 4 and 6,[8] it could explain the gender difference. This finding should be used to motivate students to measure their grip strength and exercise to improve it, if applicable. Another possible reason for the gender difference in PD accuracy could be that female students are hesitant to palpate firmly due to higher emotional empathy levels for the cow. This is based on a study reporting significantly higher levels of emotional empathy with animals for female students than male students.[16] The effect of students' emotional empathy levels with animals on TRP and PD accuracy remains to be investigated.

Students' TRP and PD exposure

All three studies described in Chapters 2, 4 and 6 showed that students had limited access to palpation opportunities in addition to the formal training offered at the teaching institution and confirms that bovine PD opportunities outside veterinary training programs are limited and not easily accessible to students. This is in accordance with other publications,[4, 5] and confirms the need to improve the TRP training at teaching institutions and the need of teaching institution staff to create palpation opportunities for students outside of the training institution as described in Chapter 6. Both studies reported on in Chapters 4 and 6 showed that previous TRP exposure was correlated with higher specificity for fifth- and final-year students. The fact that the prior experience only affected specificity but not sensitivity confirms the finding that identifying non-pregnant cows is a skill more difficult than identifying pregnant cows and needs more practice. The positive effect of previous exposure on PD accuracy was not seen in the fourth-year student cohort (Chapter 2) and can probably be attributed to the fact that the majority of students did not have any prior TRP experience.[7]

There was a high variation in numbers of live cow palpations done by students (range n = 20-600) during private practice placements within the one-week training program described in Chapter 6. In total, 50% of students palpated less than 100 cows and the other half palpated more than 100 cows (Chapter 6, Table 1). Interestingly however, there was no correlation between number of cows palpated during the private practice placements within the training program and post-training OSCE scores, student PD sensitivity or specificity, even though a positive correlation had been shown previously between number of cows palpated and students' TRP skills.[5] A possible explanation for this could be based on the concept of 'deliberate practice'.[17] This concept refers to 'intense, repetitive performance, in a controlled setting, of intended cognitive or psychomotor skills within a focused domain; rigorous skills assessment to identify deficiencies and errors; specific, informative feedback on how to correct them; and ongoing practice, with progressive increases in level of difficulty, yielding gradual, continuous improvement in skills performance'.[17-19] The effect of deliberate practice on expert status in many professional disciplines, including chess, athletics, music, and medicine has been shown,[17, 20] and its importance for veterinary education has been highlighted.[18, 21] Therefore, it could be speculated that the level of supervision and feedback provided by the veterinarian might be more important than the number of cows palpated to improve TRP and PD skills. Students who palpated more than 300 cows during private practice placements probably received less feedback and supervision from the veterinarian due to time pressure compared to students who palpated less cows. In support of this statement, students highlighted the time and effort veterinarians took to teach them, which was particularly evident amongst practice placements where less cows were palpated. This reasoning could be further substantiated by the fact that only previous TRP experience with a veterinarian was associated with a higher student PD specificity, underlining the effect of expert supervision compared to previous student TRP experience without veterinary supervision. This highlights the importance of feedback and supervision.

Physical parameters

Physical parameters that have been confirmed to be predictors of students' PD accuracy are arm muscle endurance and grip strength (Chapter 4, 5 and 6).[8] Since specific grip strength values have been linked to students' PD performance it might be worthwhile for teaching institutions to invest in hand-held dynamometers. This would enable instructors to measure grip strength of veterinary students participating in bovine TRP and PD training to motivate students whose grip strength is less than 35 kg to enrol in an exercise programme designed to increase it. The 'Bovine PD improvement exercise programme' was specifically developed to target arm endurance and grip strength, uses readily available exercise equipment, caters for users of any fitness level and can easily be implemented in student routines (Chapter 5). It is therefore a recommended approach to indirectly improve students' palpation abilities by increasing grip strength and upper body endurance. This might be especially valuable in view of the fact that female students are over-represented in veterinary student populations, and that grip strength of male students was shown to be higher than that of female students (Chapter 4 and 6).[8]

Pregnancy stage

Bovine pregnancy stage is one of the factors associated with students' PD accuracy. Students' sensitivity of pregnancy detection was repeatedly higher for cows more than six months pregnant (Chapter 2 and 4).[7, 8] This shows the need to concentrate on early pregnancy palpation training in conjunction with a focus on specificity of PD. This need is further confirmed by the low stage corrected sensitivity of 31% and 43%, as reported on in Chapters 4 and 6, respectively.[8]

Animal welfare

Welfare is an important aspect of veterinary education and maintaining high ethical standards for the use of teaching animals is essential. While rectal examination simulator training has not been found to be an alternative that could replace live animal training, optimising simulator training to implement it at the right time in the veterinary course, to offer repeated simulator training, using additional teaching aids such as the 'Mini-cow Palpation Box' and using in training formative assessments as described above to ensure basic palpation competency before advancing to live cow palpation training is advised. While this approach will not necessarily decrease the numbers of animals needed to teach these skills, it will ensure that better prepared students use the limited palpation opportunities optimally with good learning outcomes. Implementing private practice placements as part of TRP and PD training as described in Chapter 6 is another approach to decrease the use of teaching animals within teaching institutions. The 'outsourcing' of TRP and PD training to private practitioners gives students access to client owned cows which are not palpated on a regular basis and presents a once-off use compared to repeated use of the same teaching animals within a university setting.

Implications for undergraduate bovine TRP and PD skills training methods

In order to summarise the teaching strategies and interventions for bovine TRP and PD training based on the research presented in this PhD thesis, recommended additions to existing bovine TRP and PD training programmes at veterinary teaching institutions are listed below.

1. Repeated rectal examination simulator-based training in conjunction with live cow exposure.
2. Implementation of rectal examination simulator training early on in the curriculum.
3. Teaching efforts focussing on specificity of PD.
4. Teaching efforts focusing on stage corrected sensitivity.
5. Use of the ‘Mini Cow palpation box’ to develop coordination and fine motor skills to estimate object sizes without visualisation.
6. Introduce a TRP OSCE (on simulator and/or non-pregnant live cows, depending on availability) as a compulsory formative in-training assessment (‘right of way’ examination) before advancing to PD training on live cows.
7. Use of the validated TRP OSCE on live cows to ensure training outcomes and track student progress during advanced TRP and PD training sessions.
8. Implementation of focused access to live cow palpations for students with an interest in production animal practice during later stages of the curriculum.
9. Encourage students to use an exercise programme like the ‘Bovine Pregnancy Diagnosis Improvement Exercise programme’ to improve grip strength and indirectly palpation abilities.
10. Use of a hand-held dynamometer to measure students’ grip strength and to track grip strength improvement for students using the exercise programme.

Part two: The predictor and micro-skills concept to teach clinical hands-on skills

The investigation into alternative and improved undergraduate veterinary training methods for bovine TRP and PD skills gave way to a new concept to teach clinical hands-on skills which can be widely applied to a variety of hands-on skills (Figure 1). The idea is to look at potential predictors and student level variables (as done for bovine TRP and PD) that may have an effect on student performance for a specific skill. Once identified, options should be explored how these predictors and factors can help to identify micro-skills. Micro-skills within this concept are part tasks (such as students’ ability to identify object sizes blindly for bovine TRP) which can be trained independently (use of the ‘Mini-cow Palpation box’ for this example), and assessed. Once students have mastered these micro-skills, training of the actual clinical skill is expected to be more efficient.

This approach has the potential to not only foster better student performance but also to decrease the time instructors and teaching staff spend on the actual teaching of the clinical skill. Mastering micro-skills could be students’ responsibility prior to clinical skills training. For example, most clinical skills involve fine motor skills. As per Wikipedia definition, ‘Fine motor skill (or dexterity) is the coordination of small muscles, in movements – usually involving the synchronisation of hands and fingers – with the eyes’. There are many ways to improve fine motor skills which are entirely unrelated to veterinary training and involve grasping, holding, pressing, or using a pincer grip (holding something between the fore-finger and thumb). Fine motor skills can be assessed by a variety of standardised tests, such as the Purdue Pegboard Test,[22] or Strength Dexterity Tests.[23, 24] Testing of veterinary students’ fine motor skills can be done by support staff or fellow students, and does not necessarily have to involve academic staff. Students identified who do not have necessary fine motor skills could be given tasks to practice those skills such as feeding thread through a needle, making a bracelet using small beads, or shooting marbles into a box. A specific clinical skill might involve a range of micro-skills. Upon demonstration of micro-skills competency, students can advance to the specific clinical skill training. Curricular implementation is important to ensure a timeline to be followed and allow students to improve on micro-skills prior to clinical skill training. A prerequisite for this concept to be implemented successfully is the ability to measure outcomes for the actual clinical skill (TRP and PD accuracy as described in this thesis) as well as for the micro-skills (grip strength measurement for example) to ensure that skills training improvements are achieved.

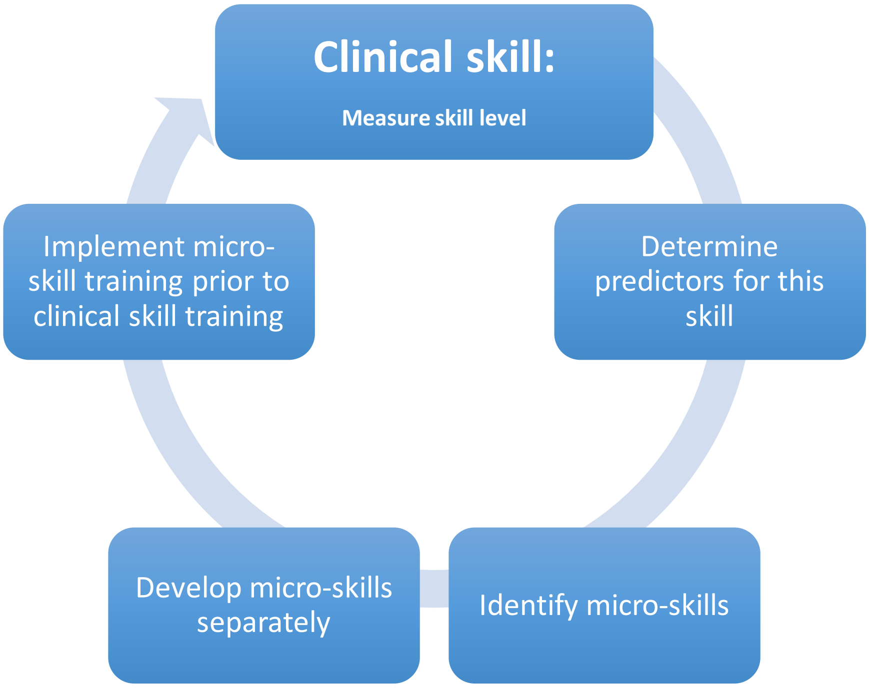


Figure 1 The 'Predictor Micro-Skills Concept' to teach clinical hands-on skills that can be used to think differently about clinical skill training

Part three: Blending a fun student project with research while teaching - 'The Onderstepoort Pregnancy Diagnosis Challenge'

While designing the first project of this study the authors had to consider how to accurately measure the student skill level for PD via TRP after training, how to collect research data while teaching and how to motivate students to perform at their best to gather good and meaningful research data. This is how the idea of the 'Onderstepoort Pregnancy Diagnosis Challenge' (The OP PD Challenge) was developed and implemented. The aim of the PD challenge was to find the 'Student PD champion' who, based on the PD assessments done on live cows, showed the highest PD accuracy, sensitivity and specificity. Through industry partner involvement, student incentivisation by adding prestigious prizes to winning the title of the PD champion, were hoped to increase student motivation to learning and performing at their best. Repeating the PD challenge over four years now while adjusting student cohorts, training methods, student exposure, enabled us to identify the answers as to 'when' the PD challenge should be done (curricular implementation), 'who' (which students should participate) and 'what' in terms of training is best to optimise the learning outcome.

The first PD challenge in 2014 was done within the didactic fourth-year veterinary reproduction module which includes the initial student TRP and PD training. Until then students' post-training TRP skill level and PD accuracy had not been measured and training outcome was unknown. Therefore, the first 'OP PD Challenge' (Chapter 2) gave a good baseline and insight into fourth-year students' PD abilities. While fourth-year student competence is not expected to be at the same level as that of experienced large animal practitioners routinely performing PDs, a specificity of 41% was identified as a concern (Table 1). Moving the following PD challenge in 2016 from a fourth-year to a fifth-year student cohort was an attempt to expose students to additional 'refresher' training on rectal examination simulators and live cows during their fifth-year after the initial fourth-year TRP and PD training (Chapter 3 and 4).[8, 14] However, this approach did not seem to improve student performance (Table 1) and the additional TRP and PD training exposure was insufficient to improve PD accuracy. An additional approach to improve TRP competency was taken when focused access to live cow palpations during later stages of the curriculum was implemented during the 2018 PD Challenge (Chapter 6). The 2018 PD challenge was moved from fifth- to final-year and was made available to students choosing production animals as their elective during the three semesters of workplace-based training. The University of Pretoria's six-year Bachelor of Veterinary Science (BVSc) program includes nine semesters of didactic pre-clinical training and three semesters of clinical work-integrated learning during the last 18 months of study.[25]

During the three semesters of clinical work-integrated learning, all students are exposed to Veterinary Core Practice (VCP) and Veterinary Elective Practice (VEP) clinical rotations within and outside of the Onderstepoort Veterinary Academic Hospital (OVAH) of the teaching institution. Within VCP clinic rotations species exposure is similar for all students. Within VEP, students can choose additional clinical exposure based on their interest. The VEP options students could choose from in 2017 before the start of the clinical work-integrated 18 months period were: Small Animal and Exotics Practice, Equine Practice, Research, Veterinary Public Health/State Veterinary Practice, Rural and Wildlife Practice and Intensive Animal Production. Only students in the latter three options of VEP paths were able to enrol for the one-week intense bovine PD training. The PD Challenge 2018 student cohort (n = 59) was therefore composed of students with an interest in food animal practice and with additional hands-on clinical experience. The majority of student participants had been exposed to bovine TRPs and PDs during clinic rotations in reproduction, herd health as well as private practice placements (Chapter 6). Overall PD accuracy, sensitivity and specificity were higher compared to previous student cohorts (Table 1). Placing the ‘OP PD Challenge’ into the final-year of veterinary training at our institution has subsequently been proven successful (Table 1). The only 2019 PD Challenge change in terms of hands-on training that had been made comparing the one-week training program was that the two-day private practice placements in 2018 had been increased to a three-day period in 2019. Overall PD accuracy, sensitivity and specificity were the highest since the beginning of the PD Challenge in 2014. Especially, the advancement of PD specificity which had been identified as a crucial problem area from 41% in 2014 to 79% in 2019 is a major success and highlights the importance of ‘when’, ‘how’ and ‘what’ for training outcomes. The OP PD Challenge has now been incorporated as an annual elective event within the three semesters of clinical work-integrated learning and promises to be a solution to train students competent in bovine PD via TRP while overcoming the previously reported shortage of live animal exposure.

Strengths and limitations

The strengths of this thesis are strongly associated with its approach using a combination of observational and prospective cohort studies while establishing strong collaborations between Veterinary Science, Health Sciences (physiotherapists and biokineticists), Information Technology and Education Innovation. Using this approach enabled us to look at a veterinary training challenge from a new point of view. The focus of this thesis was to understand more about TRP as a procedure and factors affecting training thereof. This strategy enabled us to explore new training approaches and innovations that can be used to design new or modify existing bovine TRP and PD training programmes at Veterinary schools world-wide. The investigations described in this thesis have also led to new questions around TRP and PD training which have the potential to further improve training options. Another strength to be mentioned is added benefits achieved by some of the innovations described in this thesis. If the benefits of ‘The bovine PD improvement exercise programme’ could motivate students to exercise, not only to increase arm strength and indirectly palpation accuracy but also because of increased general well-being, the additional physiological and psychological benefits are hoped to have a positive effect on students. Another strong point of this thesis is the idea of ‘blending a fun student project with research while teaching’ to efficiently use time and effort to collect research data while teaching and motivating students to perform at their best. This approach could be implemented widely for validation and skills training investigations within veterinary education.

Apart from the limitations of each individual study that were described in more detail in the individual chapters, the overall limitations of this thesis relate to the chosen research approach. As the studies are conducted in the local learning context of South Africa, transferability of the results to other contexts could be discussed. Then again, as the investigation was based on an internationally-described problem associated with TRP and PD training, and our findings were related to existing scholarly evidence, our results may have a broader relevance than the local veterinary teaching institution and environment. Another limitation of this thesis is that prior TRP and PD theory knowledge was not evaluated as one of the potential factors affecting students' TRP and PD performance. However, this can be taken as an opportunity for future investigations to evaluate that aspect.

Implications for further research

The findings described in this thesis reveal a profusion of opportunities for further research. Possible future projects around TRP and PD student training involve the investigation into pre-existing theory knowledge and emotional empathy levels towards animal as predictors for hands-on TRP skill performance. Furthermore, the effect of the modified 'Bovine PD improvement exercise program' on students' grip-strength as described in Chapter 5 and motivators influencing students' choice to exercise can be examined. Moreover, additional simulations and models resembling positive signs of pregnancy such as a fremitus model could be designed, validated and included into TRP and PD training programs. Another subject worth investigating has been identified around the question of how much force/ pressure can be used to execute bovine TRPs, seeing that it is not possible to determine if a student is applying too much, or too little pressure during TRP and PD training. A prototype 'pressure glove' using pressure sensor technology has been developed by the author and is currently undergoing testing and initial data collection.[26] The idea is to use the data collected on pressure used by experienced large animal veterinarians during TRPs, to program the pressure glove and add a feedback mechanism indicating when too much or too little pressure is used. The aim is to implement this additional teaching tool into initial TRP training sessions in order to optimize student palpations on the one hand, and to raise awareness for animal welfare through indicating how much force during rectal examinations is too much and could lead to injuries to the rectum. Another potential research focus could be based on the fact that bovine TRPs and PDs have been described to be related to musculoskeletal disorders (MSDs) amongst large animal veterinarians.[27-32] The findings described in this thesis (Chapter 4 and 5) around the exercise programme and the electromyographic analysis of TRPs, could lead way to investigations avoiding TRP related MSDs. Another research avenue to be explored is based on the ‘predictor and micro-skills concept’ as described in this thesis which could lead to investigations around the applicability of this concept to other hands-on skills. To conclude, future research based on this thesis is not only limited to bovine TRP and PD training, but opens new research possibilities for hands-on clinical skills training in general, for potential physiological as well as psychological health benefits of teaching innovations and lastly might lead to investigations around TRP related MSDs.

Conclusion and implications for educational practice

The overall aim of this thesis was to investigate alternative and improved undergraduate veterinary training methods for bovine transrectal palpation (TRP) and pregnancy diagnosis (PD) skills as a model for clinical skills training in Veterinary Education. The studies described in this thesis aimed at identifying assessment methods for, and predictors and factors affecting students’ TRP and PD accuracy. The data gathered was used to develop and implement research-based innovative teaching ideas, including optimised simulator training, in-training assessment methods, additional training opportunities linked to or not directly linked to the TRP skill itself and the use of technology to improve skills training. Overall, new information around the bovine TRP procedure has been elucidated while approaches and teaching innovations to enhance bovine TRP and PD training have been described to improve training outcomes for TRP and PD training. These approaches have been implemented at our institution and can readily be applied to other veterinary schools world-wide. In addition to the initial aim of this thesis, the described ‘predictor and micro-skills concept’ to teach clinical hands-on skills has the potential of wide application to improve clinical skills training in general. And lastly, the idea of ‘blending a fun student project with research while teaching’ approach could advance validation and skills training investigations within veterinary education to the next level. I hope that this thesis will inspire veterinary educators to improve bovine TRP and PD training programs, consider using the 'predictor and micro-skills concept' and think about 'blending a fun student project with research while teaching' approach when designing veterinary education projects.

References

1. Davis MH, Ponnamperuma GG, McAleer S, Dale VHM. The Objective Structured Clinical Examination (OSCE) as a determinant of veterinary clinical skills. *Journal of Veterinary Medical Education* 33(4):578-87, 2006.
2. Rethans JJ, Sturmans F, Drop R, Van der Vleuten C. Assessment of the performance of general practitioners by the use of standardized (simulated) patients. *British Journal of General Practice* 41(344):97, 1991.
3. Baillie S, Crossan A, Brewster S, Mellor D, Reid S. Validation of a bovine rectal palpation simulator for training veterinary students. *Studies in Health Technology and Informatics* 111:33-6, 2005.
4. Lopes G, Rocha A. Teaching bovine rectal palpation with live cows in the slaughterhouse: Is it worthwhile? *Reproduction in Domestic Animal*s 41:510-3, 2006.
5. Bossaert P, Leterme L, Caluwaerts T, Cools S, Hostens M, Kolkman I, De Kruif A. Teaching transrectal palpation of the internal genital organs in cattle. *Journal of Veterinary Medical Education* 36:451-60, 2009.
6. French HM, Dascanio JJ, Gilbert GE, Robinson JQ. Bovine reproductive palpation training: does the cow make a difference? *Journal of Veterinary Medical Education* 45(2):219-23, 2018.
7. Annandale A, Annandale CH, Fosgate GT, Holm DE. Training method and other factors affecting student accuracy in bovine pregnancy diagnosis. *Journal of Veterinary Medical Education* 45(2):224-31, 2018.
8. Annandale A, Fosgate GT, Eksteen CA, Kremer WDJ, Bok HGJ, Holm DE. Influence of an exercise program, muscle strength, proprioception and arm length on veterinary students' bovine pregnancy diagnosis accuracy. Accepted for publication in *The Journal of Veterinary Medical Education*.
9. Kneebone R, Baillie S. Contextualized simulation and procedural skills: a view from medical education. *Journal of Veterinary Medical Education* 35(4):595-8, 2008.
10. Baillie S, Mellor DJ, Brewster SA, Reid SWJ. Integrating a bovine rectal palpation simulator into an undergraduate veterinary curriculum. *Journal of Veterinary Medical Education* 32:79-85, 2005.
11. Baillie S, Crossan A, Brewster SA, May SA, Mellor DJ. Evaluating an automated haptic simulator designed for veterinary students to learn bovine rectal palpation. Simulation in Healthcare: *Journal of the Society for Simulation in Healthcare* 5:261-6, 2010.
12. Giese H, Gundelach Y, Dilly M. Simulationsbasiertes Training der transrektalen gynäkologischen Untersuchung beim Rind. Jahrestagung der Gesellschaft für Medizinische Ausbildung (GMA). Hamburg: Düsseldorf: *German Medical Science GMS Publishing House*; 2014.
13. Giese H, Gundelach Y, Geuenich K, Ehlers JP, Dilly M. Effects of training methods for rectal palpation in cattle on student's performance and self-evaluation. AMEE. Glasgow 2015.
14. Annandale A, Fosgate GT, Bok H, Holm DE. Ability of a bovine transrectal palpation objective structured clinical examination to predict veterinary students' pregnancy diagnosis accuracy. *The Veterinary Record* 185(6):171-180, 2019.
15. Goble DJ. Proprioceptive acuity assessment via joint position matching: from basic science to general practice. *Physical therapy* 90(8):1176-84, 2010.
16. Paul ES, Podberscek AL. Veterinary education and students' attitudes towards animal welfare. *The Veterinary record* 146:269-72, 2000.
17. Ericsson KA, Charness N. Expert performance: Its structure and acquisition. *American Psychologist* 49(8):725-47, 1994.

18. Scalese RJ, Issenberg SB. Effective use of simulations for the teaching and acquisition of veterinary professional and clinical skills. *Journal of Veterinary Medical Education* 32(4):461-7, 2005.

19. George JH, Doto FX. A simple five-step method for teaching clinical skills. *Family Medicine* 33(8):577-8, 2001.

20. McGaghie WC, Issenberg SB, Cohen ER, Barsuk JH, Wayne DB. Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. *Academic medicine: Journal of the Association of American Medical Colleges* 86(6):706-11, 2011.

21. Annandale A, Scheepers E, Fosgate GT. The effect of ovariohysterectomy model practice on surgical times for final-year veterinary students' first live-animal ovariohysterectomies. *Journal of Veterinary Medical Education*:1-12, 2019.

22. Strauss E, Sherman EMS, Spreen O. A compendium of neuropsychological tests: Administration, norms, and commentary, 3rd ed. New York, NY, US: Oxford University Press; 2006.

23. Rocha ACP, Tudella E, Pedro LM, Appel VCR, Da Silva LGP, Caurin GAdP. A novel device for grasping assessment during functional tasks: Preliminary results. *Frontiers in Bioengineering and Biotechnology* 4:16-, 2016.

24. Valero-Cuevas FJ, Smaby N, Venkadesan M, Peterson M, Wright T. The strength-dexterity test as a measure of dynamic pinch performance. *Journal of Biomechanics* 36(2):265-70, 2003.

25. Irons PC, Holm DE, Annandale CH. Curricular renewal at the southern tip of Africa: the 2016 veterinary curriculum at the University of Pretoria. *Journal of Veterinary Medical Education* 44(3):440-9, 2017.

26. Annandale A, Kruger S, Van der Walt I, Heyns R, Holm DE. Using pressure sensor technology to improve bovine transrectal palpation training: Development of the 'pressure sensor glove'. International Veterinary Simulation in Teaching Conference. Knoxville, Tennessee, USA 2018. p. 39.

27. Berry SL, Susitaival PI, Ahmadi A, Schenker MB. Cumulative trauma disorders among California veterinarians. *American Journal of Industrial Medicine* 55(9):855-61, 2012.

28. Cattell MB. Rectal palpation associated cumulative trauma disorders and acute traumatic injury affecting bovine practitioners. *Bovine Practitioner* 34:1-5, 2000.

29. Kozak A, Schedlbauer G, Peters C, Nienhaus A. Self-reported musculoskeletal disorders of the distal upper extremities and the neck in German Veterinarians: A Cross-sectional study. *Plos One* 9(2), 2014.

30. Smith DR, Leggat PA, Speare R. Musculoskeletal disorders and psychosocial risk factors among veterinarians in Queensland, Australia. *Australian Veterinary Journal* 87(7):260-5, 2009.

31. Scuffham AM, Legg SJ, Firth EC, Stevenson MA. Prevalence and risk factors associated with musculoskeletal discomfort in New Zealand veterinarians. *Applied Ergonomics* 41(3):444-53, 2010.

32. Scuffham AM, Firth EC, Stevenson MA, Legg SJ. Tasks considered by veterinarians to cause them musculoskeletal discomfort, and suggested solutions. *New Zealand Veterinary Journal* 58(1):37-44, 2010.

Chapter 8
Summary

Clinical hands-on training is an integral part of veterinary education. Skills acquisition opportunities are however limited by welfare and ethical concerns around the use of live animals for training purposes, large student cohort sizes and budget constraints, amongst others. The same holds true for bovine trans-rectal palpation (TRP) and pregnancy diagnosis (PD) training and is furthermore challenging since extensive exposure to TRP in live cows is required to ensure competency. Compared to many other skills, TRP and PD training is moreover complicated due to the nature of the procedure whereby demonstration of the technique by an instructor and observation of a trainee palpating a live cow is not possible as execution of the procedure cannot be seen. At the same time, it is an important competency for veterinary graduates as bovine PD by TRP is one of the most frequently performed procedures in large animal practice and of economic importance. The main aim of this thesis was to investigate alternative and improved undergraduate veterinary training methods for bovine trans-rectal palpation (TRP) and pregnancy diagnosis (PD) skills. The second aspiration of this thesis was that thinking differently about clinical skills training for bovine TRP and PD as an example might lead to an alternative approach to traditional skills training in general that has the potential to overcome some of the training constraints at teaching institutions. This led to a number of studies describing and evaluating TRP and PD assessment methods, identifying predictors and factors affecting students' TRP and PD accuracy, developing and implementing research-based innovative teaching ideas, including optimised simulator training, in-training assessment methods, additional training opportunities linked to or not directly linked to the TRP skill itself and the use of technology to improve skills training. The series of studies described in this thesis aimed at demonstrating how training innovations can be combined with traditional training to improve overall TRP and PD training and to optimise limited live animal exposure to practice these skills. The investigations into bovine PD via TRP skills will be an example for clinical skills training in general. It is hoped that thinking differently about clinical skills training for bovine TRP and PD might lead to an alternative approach to traditional hands-on skills training that has the potential to overcome some of the training constraints at teaching institutions.

Chapter 1 illustrates how veterinary education in general and clinical skills training has changed over time and describes what the expectations for newly graduated veterinarians are while teaching institutions are facing challenges and demands in the modern workplace. It portrays the importance of PD via TRP in production animal practice and which challenges affect student training thereof. It looks at the limited research data available on student

performance in bovine TRP and PD and why comparison of training outcomes is difficult. Chapter 1 also reviews the research available on rectal examination simulator use for student training and leads to the central research questions of this thesis. First, how can students TRP and PD skills be reliably assessed and what is students' TRP and PD accuracy after training? Second, is rectal examination simulator training as good as live cow training, and could this be an effective approach to compensate for a shortage of live animal training opportunities? Third, are there specific predictors and student level variables that affect students' TRP and PD skills? And if so, can these predictors and student level variables be used to adjust training approaches or implement new teaching innovations to improve TRP and PD training? And fourth, how can these findings be used to develop a skills-oriented training programme that combines training innovations with traditional training to optimise bovine TRP and PD training outcomes.

Chapter 2 reports on a study firstly describing an approach to measure students' PD accuracy on live cows, and secondly looked at the effectiveness of rectal examination simulator training compared to live cow training while investigating factors influencing students' PD accuracy. The main findings of this initial study were that training on Breed'n Betsy® simulators (BB) was associated with lower student sensitivity for pregnancy detection in cows < 6 months pregnant. Student sensitivity for pregnancy detection in cows > 6 months pregnant was similar for training on BB and live cows. No evaluated factors were significantly associated with specificity of PD. Results of this study also indicated that fourth-year student training resulted in insufficient student PD skills, highlighting specificity of PD as an area that needs improvement. The study concluded that teaching efforts focusing on specificity of PD and repeated simulator-based training in conjunction with live cow exposure were recommended.

Chapter 3 describes a study evaluating validity and reliability of a TRP Objective Structured Clinical Examination (OSCE) on non-pregnant live cows. The same study further evaluated if students' TRP OSCE scores are predictors for students' future PD accuracy. It was confirmed that the described TRP OSCE is a valid and reliable assessment and that a TRP OSCE has the ability to predict students' future PD accuracy. The results showed that students with 'competent palpation skills' on the TRP OSCE had higher PD specificity. The individual OSCE components that were predictive of higher PD accuracy were students' ability to estimate ovarian size, identify uterine position and exclude intrauterine fluid. These findings resulted in the development of the

"Mini Cow Palpation Box" which enables students to practice object size estimations without visualisation in preparation for live cow palpations and/or in training assessments.

The TRP and PD assessment methods described in Chapter 2 and 3 were further implemented and validated in the studies described in Chapters 4 and 6.

Chapter 4 reports on a study based on the unusual physical activity involved in bovine TRPs and the "Learner Trait Ability". It investigated the effects of arm muscle strength, grip strength, proprioception and an exercise programme on students' PD accuracy. Results showed that hand grip strength and participation in an exercise programme are significant predictors of veterinary students' PD accuracy. The implementation of an exercise programme aimed at improving grip strength in the veterinary curriculum is a novel approach to improve bovine TRP and PD training.

The findings outlined in Chapter 4 led to the investigation reported on in Chapter 5 where an electromyographic (EMG) study took the results of the previous study a step further in order to identify which muscles are used during TRPs and to improve the exercise programme described in Chapter 4. Electromyographic analysis was used to identify muscle activation patterns and muscle activity levels during bovine TRPs. The results have been used to modify the previously developed exercise programme in effort to improve students' TRP and PD skills. **"The bovine PD improvement exercise programme"** is available to students through an online application (http://icarus.up.ac.za/vetmlp/), and aims to not only improve grip strength and TRP accuracy but also stamina and wellbeing while adding fun to busy study schedules.

Chapter 6 describes a study based on the findings reported on in Chapters 2, 3 and 4, and investigates the effect of a one-week intense training programme on final-year veterinary students' PD accuracy. The training involved TRP and PD coaching at the training institution in combination with live cow PDs under large animal veterinarian supervision in private practice. Palpation skills were assessed before and after training using the validated TRP OSCE in non-pregnant cows described in Chapter 3. Students' scores improved from the first to the second OSCE, mostly as a result of improved ability to identify uterine symmetry (or asymmetry) and the presence (or absence) of a corpus luteum on the right ovary. Overall student sensitivity and specificity were higher than for the student cohorts reported on in Chapters 2, 3 and 4. In conclusion, this study describes a strategy to improve students' TRP skills while further validating the TRP OSCE. This approach has the potential to reduce training time and animal use at teaching institutions by outsourcing student training to private practitioners with access to real patients.

Chapter 7, the concluding chapter, discusses the results described in the previous chapters within existing literature context and is divided into three parts: Part one describes how each of the chapters in this thesis contributed to the understanding of bovine TRP and PD training and assessment, and how the results presented in these chapters have led to training innovations and improvements. Part one is the main section of Chapter 7 which reviews how each chapter of this thesis contributed to achieve the overall aim of this project: to discover alternative and improved undergraduate veterinary training methods for bovine TRP and PD skills. It outlines these training methods for bovine TRP and PD skills based on the research findings of this thesis. It focuses on students' TRP and PD skills assessments and accuracy, optimised rectal examination simulator training, as well as predictors and student level variables affecting students' TRP and PD skills. Part 1 furthermore looks at how the findings of this thesis can be implemented to respect and maintain high ethical standards for the use of teaching animals. Finally, it leads to a description of practical implications for undergraduate bovine TRP and PD skills training methods which summarises the teaching strategies and interventions for bovine TRP and PD training. The practical recommendations described can be used to design or improve bovine TRP and PD training programmes at veterinary teaching institutions. Part two of Chapter 7 describes a new concept to teach clinical hands-on skills (The "Predictor Micro-Skills Concept") which is based on the TRP and PD skills training investigations done as part of this PhD thesis and which are considered to be applicable to many other clinical skills. Part three of the discussion describes the approach to blending of a fun student project and research while teaching, which as part of the PhD investigations has led to an annual PD training intervention at our institution. To conclude, this thesis ends by describing its strengths and limitations, as well as implications for further research and educational practice.

Chapter 9

Nederlandse samevatting

Het trainen van klinische vaardigheden is een integraal onderdeel van de veterinaire opleiding. De mogelijkheden hiervoor worden echter beperkt door welzijns- en ethische bezwaren rond het gebruik van levende dieren voor trainingsdoeleinden van grote cohorten studenten en budgetbeperkingen. Hetzelfde geldt voor transrectale palpatie (TRP) en drachtigheidsdiagnostiek (pregnancy diagnosis - PD) bij het rund, zeker omdat een intensieve training (en dus veel dieren) vereist zijn om deze vaardigheid te ontwikkelen. Vergeleken met veel andere vaardigheden is TRP- en PD-training bovendien gecompliceerd vanwege de aard van de procedure waarbij demonstratie van de techniek door een instructeur en observatie van een student die een levende koe palpeert niet mogelijk is omdat de uitvoering van de procedure niet te zien is. Tegelijkertijd is het een belangrijke vaardigheid voor veterinaire afgestudeerden, aangezien PD van runderen door TRP een van de meest uitgevoerde procedures is in de landbouwhuisdieren praktijk.

Het hoofddoel van dit proefschrift was het onderzoeken van alternatieve methoden en het verbeteren van bestaande methoden voor het trainen van TRP- en PD-vaardigheden bij het rund in de eerste jaren van de opleiding tot dierenarts. De tweede doelstelling van dit proefschrift was dat anders denken over klinische vaardigheidstraining van TRP en PD van runderen als voorbeeld zou kunnen leiden tot een alternatieve benadering van traditionele vaardigheidstraining in het algemeen.

Dit proefschrift bevat studies die TRP- en PD-vaardigheidstraining beschrijven en evalueren, studies die voorspellers en factoren identificeren die de TRP- en PD-nauwkeurigheid van studenten beïnvloeden, en studies die innovatieve onderwijsideeën ontwikkelen en implementeren. Deze implementaties omvatten onder andere geoptimaliseerde simulatortraining, in-training beoordelingsmethoden en het gebruik van technologie om vaardigheidstraining te verbeteren.

Het proefschrift laat zien hoe de bestaande aanpak van het trainen van TRP en PD-vaardigheden bij het rund gecombineerd kan worden met een nieuwe wijze van het trainen van deze vaardigheden en het gebruik van levende dieren daarbij te beperken. Het onderzoek naar PD van runderen via TRP-vaardigheden kan een voorbeeld zijn voor innovatie van klinische vaardigheidstraining in het algemeen. Het is te hopen dat anders denken over klinische vaardigheidstraining voor TRP en PD bij runderen zou kunnen leiden tot een alternatieve benadering van traditionele hands-on vaardigheidstraining in de diergeneeskunde opleiding.

Hoofdstuk 1 beschrijft hoe het veterinair onderwijs in het algemeen en klinische vaardigheidstraining in de loop van de tijd is veranderd en beschrijft de verwachtingen van recent afgestudeerde dierenartsen, in een tijd waarin onderwijsinstellingen worden geconfronteerd met uitdagingen en eisen van deze tijd. Dit hoofdstuk beschrijft het belang van PD via TRP in de Landbouwhuisdierenpraktijk en de uitdaging van de diergeneeskunde opleiding om studenten hierop voor te bereiden. Er wordt gekeken naar de beperkte onderzoeksgegevens die beschikbaar zijn over de prestaties van studenten in TRP en PD van runderen en waarom de vergelijking van trainingsresultaten moeilijk is. Hoofdstuk 1 bespreekt tevens het onderzoek dat beschikbaar is over het gebruik van simulatoren voor studententraining en leidt tot de centrale onderzoeksvragen van dit proefschrift. Ten eerste, hoe kunnen TRP- en PD-vaardigheden bij het rund in de ontwikkeling van de student betrouwbaar worden beoordeeld en wat is daarbij de invloed van training? Ten tweede staat de vraag centraal of de simulatortraining net zo goed is als training in levende koeien, en of een simulator training een effectieve aanpak kan zijn om een tekort aan trainingsmogelijkheden voor levende dieren te compenseren? Ten derde: zijn er specifieke voorspellers en variabelen op studentniveau die de TRP- en PD-vaardigheden van studenten beïnvloeden? En zo ja, kunnen deze voorspellers en variabelen op studentniveau worden gebruikt om trainingsmethodiek aan te passen of nieuwe onderwijsinnovaties te implementeren om TRP- en PD-training te verbeteren? En ten vierde, hoe kunnen deze bevindingen worden gebruikt om een trainingsprogramma te ontwikkelen waarin een traditionele vorm van vaardigheidstraining wordt gecombineerd met een alternatieve aanpak.

In hoofdstuk 2 wordt in eerste instantie beschreven hoe de PD-nauwkeurigheid van studenten bij levende koeien gemeten kan worden. Vervolgens wordt de effectiviteit van een TRP-simulator vergeleken met live koe-training en de factoren bestudeerd die de PD-nauwkeurigheid van studenten beïnvloeden. De belangrijkste bevindingen van deze eerste studie waren dat training op Breed’n Betsy®-simulatoren (BB) geassocieerd was met een lagere sensitiviteit van de student voor drachtdetectie bij koeien die minder dan 6 maanden drachtig waren. De sensitiviteit van studenten voor drachtdetectie bij koeien langer dan 6 maanden drachtig waren, was vergelijkbaar voor training op BB en levende koeien. Geen geëvalueerde factoren waren significant geassocieerd met specificiteit van PD. De resultaten van dit onderzoek gaven ook aan dat de opleiding van vierdejaars studenten resulteerde in onvoldoende PD-vaardigheden van studenten, en wat een duidelijk aandachtspunt is wanneer het gaat over verbetering van de opleiding. Concluderend kan men op basis van deze studie concluderen een combinatie van herhaalde training van PD met behulp van simulatoren in combinatie met het oefenen bij levende koeien sterk wordt aanbevolen.

Hoofdstuk 3 beschrijft een onderzoek naar de validiteit en betrouwbaarheid van een TRP Objective Structured Clinical Examination (OSCE) bij niet-drachtige levende koeien. In hetzelfde onderzoek werd verder geëvalueerd of de TRP OSCE-scores van studenten een voorspeller kan zijn voor de toekomstige vaardigheid van studenten m.b.t. de nauwkeurigheid van drachtdiagnostiek. In deze studie werd bevestigd dat dit het geval is. Op basis van de resultaten werd aangetoond dat studenten met 'competente palpatievaardigheden' op de TRP OSCE een hogere PD-specificiteit hadden. De individuele componenten van de OSCE die een hogere PD-nauwkeurigheid voorspelden, waren: het vermogen van studenten om de grootte van de ovaria te schatten, de positie van de uterus te identificeren en intra-uteriene vloeistof uit te sluiten. Deze bevindingen hebben geresulteerd in de ontwikkeling van de "Mini Cow Palpation Box", die studenten in staat stelt om object-grootte-schattingen te oefenen zonder visualisatie als voorbereiding op het oefenen van PD in levende koeien en / of beoordeling van de ontwikkeling van deze vaardigheid in trainingsomstandigheden.

De TRP- en PD-beoordelingsmethoden zoals beschreven in hoofdstuk 2 en 3 werden verder toegepast en gevalideerd in de studies beschreven in hoofdstuk 4 en 6.

In hoofdstuk 4 wordt nader ingegaan om de -ongebruikelijke- fysieke activiteit die nodig is bij TRP's van runderen en de "Learner Trait Ability". In dit hoofdstuk worden de effecten van armspierkracht, grijpkracht, proprioceptie en een oefenprogramma op de PD-nauwkeurigheid van studenten beschreven. De resultaten toonden aan dat handgreepkracht en deelname aan een oefenprogramma significante voorspellers zijn van de PD-nauwkeurigheid van veterinaire studenten. De implementatie van een oefenprogramma gericht op het verbeteren van de grijpkracht in het veterinaire curriculum is een nieuwe aanpak om de TRP- en PD-training te verbeteren. De bevindingen beschreven in Hoofdstuk 4 leidden tot het onderzoek gerapporteerd in Hoofdstuk 5, waarbij een elektromyografisch (EMG) onderzoek de resultaten van het in hoofdstuk 4 beschreven onderzoek een stap verder bracht om te identificeren welke spieren worden gebruikt tijdens TRP's en om daarmee het oefenprogramma beschreven in Hoofdstuk 4 verder te verbeteren. Elektromyografische analyse werd gebruikt om spieractiveringspatronen en spieractiviteitsniveaus tijdens TRP's van runderen te identificeren. De resultaten zijn gebruikt om het eerder ontwikkelde oefenprogramma voor studenten aan te passen wat resulteerde in "Het oefenprogramma voor het verbeteren van PD bij runderen". Dit programma is beschikbaar voor studenten via een online-applicatie (http://icarus.up.ac.za/vetmlp/), en heeft als doel niet alleen de nauwkeurigheid van grijpkracht en TRP te verbeteren, maar ook uithoudingsvermogen en welzijn van de studenten maar ook het werkplezier tijdens dit onderwijs.

Hoofdstuk 6 beschrijft een studie gebaseerd op de bevindingen gerapporteerd in de hoofdstukken 2, 3 en 4, en onderzoekt het effect van een intensief trainingsprogramma van een week op de nauwkeurigheid van PD van laatstejaars veterinaire studenten. De training omvatte TRP- en PD-coaching in de trainingsfaciliteiten van de opleiding in combinatie met het oefenen in levende koeien onder toezicht van dierenartsen in de privépraktijk. Palpatievaardigheden werden beoordeeld voor en na de training met behulp van de gevalideerde TRP OSCE bij niet-drachtige koeien beschreven in hoofdstuk 3. De scores van studenten verbeterden van de eerste op de tweede OSCE, voornamelijk als gevolg van een verbeterd vermogen om baarmoedersymmetrie (of asymmetrie) vast te stellen en om de aanwezigheid (of afwezigheid) van een corpus luteum op het rechter ovarium vast te kunnen stellen. De algehele vaardigheid voor het wel of niet drachtig verklaren door deze studenten was hoger dan voor de studentencohorten die worden beschreven in de hoofdstukken 2, 3 en 4. Concluderend wordt in deze studie een strategie beschreven om de TRP-vaardigheden van studenten te verbeteren en de TRP OSCE verder te valideren. Deze aanpak heeft de potentie om de trainingstijd én het gebruik van dieren in onderwijsinstellingen te verminderen door de opleiding van studenten deels uit te besteden aan dierenartsen in het werkveld met toegang tot echte patiënten.

Hoofdstuk 7, het afsluitende hoofdstuk, bespreekt de resultaten die zijn beschreven in de voorgaande hoofdstukken binnen de bestaande literatuur en is onderverdeeld in drie delen: Deel één beschrijft hoe elk van de hoofdstukken in dit proefschrift hebben bijgedragen aan het begrip van TRP- en PD-training en -beoordeling bij runderen, en hoe de in deze hoofdstukken gepresenteerde resultaten hebben geleid tot verbetering van de bestaande trainingsmethodieken. In dit deel wordt tevens besproken hoe elk hoofdstuk van dit proefschrift heeft bijgedragen aan het bereiken van het algemene doel van dit project: het ontdekken van alternatieve en verbeterde trainingsmethoden voor aanleren van TRP en PD bij runderen voor studenten diergeneeskunde. Het beschrijft nieuwe trainingsmethoden voor TRP- en PD-vaardigheden van runderen op basis van de onderzoeksresultaten van dit proefschrift en richt zich op de beoordeling en nauwkeurigheid van TRP- en PD-vaardigheden van studenten, geoptimaliseerde simulatie-training voor vaardigheidstoetsing en beschrijft voorspellers en variabelen op studentniveau die de TRP- en PD-vaardigheden van studenten beïnvloeden. Deel 1 kijkt verder hoe de bevindingen van dit proefschrift kunnen worden ingezet om een zorgvuldig gebruik van onderwijsdieren te bevorderen. Ten slotte worden de praktische implicaties voor TRP- en PD-vaardigheidstrainingsmethoden bij runderen voor studenten diergeneeskunde beschreven, waarin de leerstrategieën en interventies voor TRP- en PD-training voor runderen worden samengevat. De beschreven praktische aanbevelingen kunnen worden gebruikt om TRP- en PD-trainingsprogramma's voor runderen bij veterinaire onderwijsinstellingen te ontwerpen of te verbeteren.

Deel twee van Hoofdstuk 7 beschrijft een nieuw concept voor het aanleren van klinische praktische vaardigheden (het "Predictor Micro-Skills Concept") dat is gebaseerd op de TRP- en PD-vaardigheidstrainingsonderzoeken zoals die in dit proefschrift zijn beschreven, en als model kunnen dienen voor het ontwerpen van trainingsprogramma’s voor andere klinische vaardigheden. Deel drie van de discussie beschrijft de aanpak van hoe het combineren van een leuk studentenproject en onderzoek tijdens het lesgeven, wat in het kader van de promotieonderzoeken heeft geleid tot een jaarlijkse ‘PD-trainingsinterventie’ bij onze instelling. Tot slot eindigt dit proefschrift met het beschrijven van de sterke punten en beperkingen ervan, evenals implicaties voor verder onderzoek en de onderwijspraktijk.

Chapter 10
Acknowledgements

I would like to thank the following people, without whom I would not have been able to complete this research and thesis, or made it through my PhD studies.

A project of this nature, based on two continents, is only possible with the help of very special supervisors. I would like to thank my wonderful Dutch supervisors, Wim Kremer and Harold Bok, not only for the patient guidance, encouragement and advice they provided but also for always sharing my joy on accepted manuscripts or feedback on the thesis. Thank you for always responding to my questions and queries promptly, for the Skype calls and the assistance with the administrative parts of the PhD. The careful editing contributed enormously to the production of this thesis.

On the South African side of this PhD I would like to express my sincere appreciation to Dietmar Holm. I have been very lucky to have such a fantastic supervisor who cared so much about our work, was always supportive and encouraging, particularly so when exploring new ideas. His positive outlook and confidence in my research inspired me and gave me motivation. Dietmar, you are not just a great supervisor but also an exceptional colleague and friend. It is always a pleasure working with you!

I would like to extend my sincere thanks to Geoff Fosgate for all his time and effort to perform the statistical analyses for the projects described in this dissertation. I especially appreciate your patience to explain analyses and results and your valuable contributions when editing manuscripts.

My sincere gratitude goes to David and Susan Hill of Hall's Hill Farm, Doornpoort, South Africa, for their generosity in making their Nguni cattle herd and their facilities available in support of this veterinary education research. I appreciate all the time spent to accommodate data collection and student training. Sue, your interest in our projects was amazing! I sincerely enjoyed discussing them with you.

I gratefully acknowledge the financial support for these PhD studies by the *Health and Welfare Sector Education and Training Authority* (*HWSETA*), South Africa, as well as the *University of Pretoria's Research Development Programme (RDP)* grant.

Zoetis South Africa deserves a word of thanks - not only for the generous financial support for all the Pregnancy Diagnosis Challenges that have been hosted so far, but also to the special individuals working for Zoetis who were involved way past their duties in our projects: Llewellyn Sinclair, Gorete Moutinho, Chantelle Erwee and David Human. Thank you for sharing our passion and your genuine interest in the hands-on skills education of our future veterinary colleagues!

Members of the examination committee, thank you for the time you have devoted reading and assessing this thesis. I truly appreciate it!

I would also like to thank all the veterinary students who made this PhD dissertation possible by participating in the Pregnancy Diagnosis Challenges.

The completion of my dissertation would not have been possible without the support of Liani Kitshoff, San Fick and Elrien Scheepers. You are truly the best work team I could have ever asked for! Liani, thank you for always being supportive, offering assistance and giving kind words of encouragement. Also for testing the three-month exercise program enthusiastically with me. It would have been a lot less fun without you! San, I am deeply grateful for all the small and so very important activities behind the scenes such as printing and scanning of documents, student and financial admin, help to transfer research data from hard copies into excel sheets for days on end, and always, always making sure that everyone had that perfect cup of coffee at exactly the right time! Elrien, thank you for always listening to my ideas, sharing your thoughts and holding the fort in the skills laboratory while I was collecting data and writing manuscripts.

A special mention goes to Alet Wannenburg whose support and help with administrative tasks during the Pregnancy Diagnosis Challenges was invaluable. Thank you for always being friendly and professional (and for entertaining all the last-minute requests…)!

I very much appreciate the involvement of Carina Eksteen. Thank you for being interested and becoming involved in our “out of the ordinary projects”. And for running and managing the six-week exercise programme in 2016, all the time spent to collect the proprioception data at the High Performance Centre, the participation in the EMG study and your valuable input to the manuscripts.

A special thank-you goes to Candice Attree of Attree Biokineticists. I am extremely grateful for your involvement, invaluable input, all the time that went into muscle strength testing (on weekends!), the exercise programme development, equipment ordering and for being as excited about these projects as I was! It was an absolute pleasure working with you.

I would further like to recognize the involvement of Kayla Haasbroek in the exercise video productions. Thank you for volunteering to demonstrate all the exercises!

I'd like to acknowledge the assistance and effort of André du Plessis for video recording and professionally editing the exercise videos and photos. Thank you for taking the time to make them perfect.

I gratefully acknowledge the assistance of Isak van der Walt to design and publish the "Bovine PD Improvement Exercise Programme" content on the University of Pretoria's mobile learning platform.

Sarah Clift, thank you for having been my external PhD moderator. Even more so for your friendship, for always listening, offering relentless support and advice. You have always been an inspiring role model and colleague.

Maria Mtsweni and Susan Marsh, the best librarians ever, who were always willing to help me find the publications I was not able to source. Thank you for always responding promptly and giving it your best to help!

Many thanks to Sarah Johnson for recording the exercise programme introduction video voice over numerous times until it was just right. And for eagerly participating in the three-month test run of the exercise programme. Sarah, you made the exercising extra fun!

Thank you Rina Serfontein for proof-reading, editing and formatting this dissertation.

Thanks should also go to Lize-Mari Mouton- a wonderful photographer- for taking the time to chase Ngunis all morning long to get the perfect cattle pictures for this dissertation!

Ich möchte gern meinen Eltern für ihre Liebe und Unterstützung danken. Ich danke euch beiden, dass ihr es mir ermöglicht habt, nach den Sternen zu greifen und meine Träume zu verfolgen. Ihr habt euch oft auf den folgenden Vers bezogen: "Gebt Kindern Wurzeln um zu wachsen und Flügel um zu fliegen" und das ist genau was ihr gemacht habt!
Ich hätte dieses PhD nicht ohne euch machen können. Ich habe euch lieb!

I would like to thank my parents, Rüdiger and Waltraut Heise, for their love and support. Thank you both for giving me the opportunities to reach for the stars and chase my dreams. You have often referred to the following verse: "Give children roots to grow and wings to fly" and that is exactly what you have done! I could not have achieved this PhD without you. I love you!

I would also like to acknowledge my parents in law, Rita and John Annandale. Thank you for always asking about my projects, listening to my explanations, supporting me throughout the entire time and your encouraging words. It means a lot to me!

Above all, I would like to acknowledge my husband Henry Annandale. Henry, without your encouragement, constructive criticism, insightful suggestions, unwavering support and your profound belief in my abilities I would have not been able to finish this dissertation! I would have also not been able to start this PhD without you: thank you for sharing your "Mastermind" idea of the first Pregnancy Diagnosis Challenge and let me run with it! I would also like to thank you for always being there for me, making me laugh and telling me that you are proud of me. I love you!

And last but not least, thank you Finn and Ollie for your unconditional love and support, no matter what! And for adding all the sunshine in the world to our lives.

Chapter 11

Curriculum vitae

Annett Annandale was born in Neindorf, Germany, on the 30th of April 1980. She obtained her MedVet degree from the University of Leipzig, Germany, and her DrMedVet from the VetSuisse Faculty, University of Zurich in Switzerland. She moved to South Africa in 2004 where she completed a residency in Theriogenology at the Faculty of Veterinary Science, University of Pretoria. Annett became a Diplomate of the American College of Theriogenologists (ACT) in 2007 and obtained her MSc (cum laude) from the Faculty of Veterinary Science, University of Pretoria, in 2010. Whilst maintaining her clinical skills in her specialist discipline, Annett took the manager position of the new Skills Laboratory at the Faculty of Veterinary Science, University of Pretoria in November 2014. Annett's interest lies in model development and validation, using technology to enhance student learning and advancing veterinary education. Her vision for skills laboratory training within veterinary education is to enhance the combination of model training with technology while providing an engaging environment for students to foster hands-on and cognitive skills simultaneously. Annett has presented numerous papers and posters at international veterinary education meetings such as Veterinary Education Symposia (VetEd) and International Veterinary Simulation in Teaching conferences (InVest). Her current research focuses on student training of bovine trans-rectal palpation skills and model validation. Her skills laboratory project "Development, validation and implementation of in-house manufactured veterinary models for innovative teaching of clinical skills" was awarded the Bronze Winner for the Category Regional Award Africa at the renowned international Wharton QS Stars Reimagine Education Awards (Philadelphia, USA) in 2015, and Annett was awarded the University of Pretoria's Faculty of Veterinary Science's "Teaching Innovation and Excellence " award in 2018. Annett is married to Henry Annandale. They recently moved to Perth, Australia, and have two sons, Finn (2010) and Oliver (2012).