Veterinarians' Competence in Applying Basic Genetic Principles and Daily Implementation of Clinical Genetics: A Study in a University Environment

Evelien Bogaerts ■ Else den Boer ■ Luc Peelman ■ Filip Van Nieuwerburgh ■ Hille Fieten ■ Jimmy H. Saunders ■ Bart J.G. Broeckx

ABSTRACT

Veterinarian competency in genetics is vital for a meaningful application of the rapidly growing number of genetic tests available for animals. We evaluated the use of genetic tests in the daily veterinary practice and the competency of university-employed veterinarians in applying basic principles of genetics in a clinical setting through an electronic survey with 14 cases and 7 statements on genetics. Ninety-one non-geneticist veterinarians from two veterinary faculties in two different countries responded. Almost half of the participants apply genetic tests during their daily work, with frequencies varying between weekly and once a year. The most common indication to request a genetic test was diagnostic testing of clinically ill patients. Although 80% of the veterinarians communicated the result of a genetic test themselves, only 56% of them found it "very to rather easy" to find the correct test, and only 32% of them always felt competent to interpret the result of the test. The number of correctly answered questions varied widely, with median scores of 9/14 (range: 0–14) and 5/7 (range: 0–7) for the cases and statements, respectively. Most difficulties were seen with recognition of pedigree inheritance patterns, while veterinarians scored better in breeding advice and probability of disease estimations. Veterinarians scored best on questions related to autosomal recessive inheritance, followed by complex, autosomal dominant, X-linked recessive, and X-linked dominant inheritance. This study exposed pain points in veterinarians' knowledge and has led to the formulation of recommendations for future education and communication between laboratories, geneticists, and veterinarians.

Key words: questionnaire, non-geneticists, use of genetic tests, basic genetic knowledge

INTRODUCTION

The widespread availability of the genomes of several species, together with the discovery of an increasing amount of loci associated with the development of disorders in animals, resulted in a continuous increase in the number of genetic tests available to veterinarians.[1–6] Reasons for performing genetic tests vary and include predictive genetic testing (i.e., the use of a genetic test in an asymptomatic animal to predict future risk of disease), diagnostic genetic testing (i.e., the use of a genetic test to obtain information about an animals current condition), and breeding advice.[7] The central goal in breeding advice based on genetic tests is to select breeding pairs that will not produce phenotypically affected offspring for a specific trait while also limiting the exclusion of potential breeding animals to prevent the loss of genetic diversity in a population.[8,9] An example of predictive testing of healthy animals is identifying variants associated with late-onset hereditary diseases, like a frameshift mutation in the *SLC4A3* gene in the golden retriever linked to the development of progressive retina atrophy at an adult age.[10] Diagnostic genetic testing can also be performed on animals that only have symptoms of a disease under certain circumstances, such as exercise-induced collapse in the Labrador retriever, which results in episodic limb weakness, ataxia, and collapse.[11] Future perspectives include the screening for variants associated with (for example) drug metabolism or immune response to personalize and fine-tune health care of animals.[12–14]

Regardless of the goal, it is clear that veterinarians nowadays already have the opportunity to implement genetic tests in their daily practice. Since many routinely performed genetic tests are commercially available, requesting these tests is not reserved exclusively for veterinarians specialized in the field of genetics.[3,5] Furthermore, even the owners can order them and present a test result to a veterinarian. This means that non-geneticist practitioners—that is, veterinarians who are not trained extensively in the field of genetics—are involved in all aspects of the genetic testing procedure, including requesting the test, interpreting the result, communicating with the owner of the animal, and providing correct advice at an individual and population level.[15] Consequently, it is important that these veterinarians have the necessary competences to exercise these roles. However, studies in human medicine, both in primary practice and specific fields, have indicated a deficient knowledge of genetic principles and the interpretation of available genetic tests.[16–21]

To the authors' knowledge, this has not yet been investigated in veterinarians. The goals of this study were, first, to get an overview on the daily use of genetic tests by veterinarians working at university and, second, to evaluate basic applied genetic knowledge among non-geneticist veterinarians for various modes of inheritance and various types of questions with cases and statements based on real-life situations. We hypothesized a highly variable utilization of genetic tests between the participants and a rather limited basic knowledge of genetic principles among non-geneticists despite the growing importance in daily veterinary practice.

MATERIALS AND METHODS

Study Design

A cross-sectional study was conducted among veterinarians working at the Faculty of Veterinary Medicine in Belgium (Ghent University) and the Netherlands (Utrecht University).

Survey Development

A questionnaire investigating various aspects of the use of genetic tests during daily work and knowledge on basic genetic principles and clinical genetics was designed by geneticists from the Faculty of Veterinary Medicine at Ghent University and modified after input of geneticists from the Faculty of Veterinary Medicine at Utrecht University. In several pre-test rounds completed by geneticists and non-geneticists, refinements were made. The final questionnaire took approximately 15 minutes and 25 minutes to be completed by geneticists and non-geneticists, respectively. The final questionnaire was available in English and Dutch.

Final Survey

The final questionnaire contained 38 questions divided over 4 sections. The first section contained seven questions on demographic and practice characteristics. The second section contained 10 questions on the use of genetic tests during daily practice and the need for post-graduation education on clinical genetics. The third section contained 14 cases to evaluate the general knowledge on basic and clinical genetics. The cases were divided into three types: estimation of the probability of disease, recognition of pedigree inheritance patterns, and breeding advice. For each type, one question was made for each of the following inheritance patterns: autosomal recessive (AR), autosomal dominant (AD), X-linked recessive (XR), X-linked dominant (XD), and complex. No pedigree inheritance question was made for complex inheritance. The fourth section contained seven general knowledge statements. All cases had one correct answer and three incorrect alternatives, except for one, for which there were only two incorrect alternatives (breeding advice for a complex disorder). For the statements, there was also only one correct answer, but the number of incorrect alternatives varied between one (four questions) and two to four (one question each), respectively. To reduce random guessing, the option "I don't know" was also available for every case and statement.

Survey Distribution and Study Time

The questionnaire was made available online in English and Dutch using Qualtrics survey software.[a] An email was sent to the veterinarians working at the faculties of Veterinary Medicine of Ghent and Utrecht University with the request for participation containing an explanatory cover letter in English and Dutch and a link to the online questionnaire. The cover letter explicitly specified to not look up anything about genetics prior to or while filling in the questionnaire to not bias the results. The email was sent in January 2020, and a reminder was sent after 4 weeks. The questionnaire remained available for 6 weeks. As an incentive for participation, participants could register for a free lesson on basic genetic principles and clinical genetics on a date to be determined. We confirm that all methods were carried out in accordance with relevant guidelines and regulations. We confirm that Ghent University approved all experimental protocols. Informed consent was obtained from all participants.

Statistical Analysis

The statistical analysis was done in R version 3.6.3 ("Holding the Windsock").[b] Significance was set at $\alpha \leq .05$. As a prerequisite for the analysis, only questionnaires of respondents working at the university full- or part-time were retained. General descriptive statistics are provided per question. In addition, for the cases and statements, a median overall score is provided. The answers on the 14 cases and the 7 statements were recoded to correct, incorrect, and "I don't know." Median and range are used for continuous variables, and frequency tables are used for categorical variables. A linear model was used to evaluate the potential association between the number of times a case/statement was incorrectly answered and the number of times "I don't know" was answered. For the cases, to assess the potential effect of (a) inheritance pattern (AR, AD, XR, XD, and complex), and (b) type of knowledge evaluated (probability, pattern recognition, and breeding advice), logistic linear mixed models were used with responder as a random effect, inheritance pattern or type of knowledge as a fixed effect, and correct/incorrect or answered "I don't know" as a response variable. Similar models were used to assess the effect of period of graduation, the frequency of genetic tests requested, the frequency of contact with genetically related questions, ease of finding genetic tests, personal feeling of competence to communicate results of genetic tests, and whether additional training was followed (each time one of these variables as a fixed effect) on the amount of correctly answered questions (dependent variable) for the entire data set of cases and statements. Significance was assessed using the likelihood ratio test. To correct for multiple testing, a Bonferroni correction was applied. All p values are reported with this correction applied.

RESULTS

A total of 101 people filled in the questionnaire. After excluding the participants who had not worked at least part-time at the university, a total of 91 participants remained. The 91 participants filled in (at least partially) the first section on demographic and practice characteristics, 68 participants completely filled in the case section, and 66 participants completely filled in the statements section.

Demographic and Practice Characteristics

Among the 91 participants, the number of diplomates and PhD students were the same (n = 16/91, 17.5% each), followed by residents (n = 13/91, 14%). Other types of veterinarians were represented in small numbers (n = 19/91, 21%) and 27 participants (30%) combined multiple functions. The majority (n = 83/91, 91%) worked in a university setting full-time, seven participants (n = 7/91, 8%) combined university employment with working in a veterinary clinic, and one participant (n = 1/91, 1%) combined university employment with working in a group practice. Overall, two thirds of the participants were female (n = 62/91, 68%). The largest group of participants graduated between 2016 and 2020 (n = 25/91, 27%), followed by 2011–2015 (n = 18/91, 20%) and 2006–2010 (n = 14/91, 15%). Almost half of the participants worked exclusively with small animals (n = 40/91, 44%), followed by participants working exclusively with horses (n = 15/91, 16%), ruminants (n = 9/91, 10%), or pigs, rabbits, and poultry (n = 5/91, 5%). A total of 20 participants (n = 22/91, 22%) combined different species during their daily work. A summarized overview of the participants is provided in Table 1. For a complete overview of all demographic and practice characteristics, see Appendix 1 available online at https://doi.org/10.3138/jvme-2020-0029.

Table 1: Overview of types and specializations of participants and main species worked with

Type of veterinarian		Specialization		Species	
Category	*n* (%)	Category	*n* (%)	Category	*n* (%)
General practitioner	1 (1.10)	Surgery	11 (12.09)	Small animals	40 (43.96)
Referral	2 (2.20)	Reproduction	10 (10.99)	Horses	15 (16.48)
Certificate	0 (0.00)	Orthopedics	7 (7.69)	Ruminants	9 (9.89)
Intern	0 (0.00)	Health care farm animals	7 (7.69)	Pigs. rabbits. poultry	5 (5.49)
Resident	13 (14.29)	Anesthesiology	6 (6.59)	Other species	2 (2.20)
Diplomate	16 (17.58)	Internal medicine and neurology	5 (5.49)	Combinations	20 (21.98)
PhD student	16 (17.58)	Pathology	4 (4.40)		
Post-doctoral	2 (2.20)	Radiography	4 (4.40)		
Professor	10 (10.99)	Emergency and ICU	3 (3.30)		
Non-practicing	0 (0.00)	Surgery + orthopedics	3 (3.30)		
Other type	4 (4.40)	Other specializations	1 (1.10)		
Combinations	27 (29.67)	No specialization mentioned	30 (32.97)		

Genetic Testing in the Practice

Contrary to a small group (n = 12/89, 13%), the majority of participants (n = 77/89, 87%) in this study encountered genetics or genetic tests in their daily job, although the frequency was rather variable: very frequent (n = 13/89, 15%), occasionally (n = 25/89, 28%), and rarely (n = 39/89, 44%). This number decreases when it comes to requesting genetic tests, with 55% (n = 50/91) never requesting a genetic test. From the other half, 1 participant had requested genetic tests on a weekly basis (n = 1/91, 1%), 7 participants on a monthly basis (n = 7/91, 8%), 9 participants every 3 months (n = 9/91, 10%), 5 participants every 6 months (n = 5/91, 5%), and 19 participants (n = 19/91, 21%) once during the past year.

The most common indication for genetic testing was diagnostic testing of clinically ill patients (n = 15/41, 37%), followed by the combination of clinically ill patients and for research purposes (n = 11/41, 27%). Other indications were screening in healthy animals (n = 4/41, 10%), research purposes exclusively (n = 1/41, 2%), and DNA sampling for inclusion in a studbook (n = 1/41, 2%). Nine participants (n = 9/41, 22%) gave multiple reasons for performing genetic tests.

Fifty-four percent of the participants (n = 22/41) found it "rather easy" to select a suitable test, contrary to 42% (n = 17/41) that reported this as "rather difficult." Only one person (n = 1/41, 2%) reported "very easy" and one person (n = 1/41, 2%) "very difficult." On self-estimated competency for the interpretation of genetic tests, 13 participants (n = 13/41, 32%) always feel competent, while 63% (n = 26/41) reported their competency as test-dependent, and 5% (n = 2/41) do not feel competent in interpreting genetic tests. Communication of test results toward the owner was done by the veterinarian in most cases (n = 33/41, 80%), although the veterinarian can also do this in combination with the laboratory (n = 2/41, 5%), a geneticist (n = 2/41, 5%), or by others (n = 4/41, 10%). None of the respondents indicated that the veterinary assistant communicates the test result.

Of all participants, 72% (n = 64/89) believe that the importance of genetic testing will augment in the upcoming 5 to 10 years and 86% (n = 77/89) feel that additional trainings are of essential importance. The preferred manners to attend these additional courses vary, with 34% (n = 30/89) choosing in-person training, 30% (n = 27/89) several short webinars, 28% (n = 25/89) online lessons, and the remaining 8% (n = 7/89) workshops in small groups. For an overview of the answers on the use of genetics and genetic testing, see Appendix 2 available online at https://doi.org/10.3138/jvme-2020-0029.

Knowledge of Basic and Clinical Genetics

The median score of participants was 9 out of 14 correctly answered cases (range: 0–14, n = 68) and 5 out of 7 correctly answered statements (range: 0–7, n = 66). The median score of correct answers per question was 69% (range: 32%–94%) and 73% (range: 44%–100%) for the cases and the statements, respectively. For an overview of all cases and statements included in the questionnaire, see Appendix 3 available online at https://doi.org/10.3138/jvme-2020-0029. Every participant who started answering the cases completely filled in all the cases, and the same was true for the statements. Two people stopped after the cases. One of them answered all 14 cases with "I don't know," while the other scored rather well with 12 out of 14 cases correct and never used the option "I don't know."

There was a clear effect of the different types of inheritance patterns on the participants' performance (p < .001). Overall, questions related to AR inheritance scored best, followed by complex, AD, XR, and XD. Additionally, the type of question had a clear influence on performance (p < .001). Participants scored best on questions related to the probability of a disease, followed closely by breeding advice, while questions on the recognition of pedigree inheritance patterns displayed the lowest score. In Table 2 and Figure 1, an overview is provided on the number of correct, incorrect, and "I don't know" answers for every statement and case, sorted by the type of inheritance pattern and type of question.

"I don't know" was answered most often for questions related to an XD inheritance pattern, followed by complex, AR, XR, and finally AD (p < .001). Participants used the "I don't know" answer most when questions were related to the interpretation of a pedigree inheritance pattern, followed by estimation of the

Table 2: Overview of results sorted by inheritance pattern and type of question

Cases		Correct		Incorrect		"I don't know"	
Inheritance pattern	Type of question	*n*	%	*n*	%	*n*	%
Autosomal recessive	Prb	50	73.53	12	17.65	6	8.82
	Pat	46	67.65	14	20.59	8	11.76
	Adv	59	86.76	6	8.82	3	4.41
Autosomal dominant	Prb	49	72.06	18	26.47	1	1.47
	Pat	38	55.88	24	35.29	6	8.82
	Adv	64	94.12	2	2.94	2	2.94
X-linked recessive	Prb	53	77.94	11	16.18	4	5.88
	Pat	32	47.06	28	41.08	8	11.76
	Adv	37	54.41	26	38.24	5	7.35
X-linked dominant	Prb	48	70.59	11	16.18	9	13.24
	Pat	22	32.35	35	51.47	11	16.18
	Adv	43	63.24	18	26.47	7	10.29
Complex	Prb	54	79.41	4	5.88	10	14.71
	Adv	44	64.71	20	29.41	4	5.88
Statements							
1		66	100.00	0	0.00	0	0.00
2		48	72.73	17	25.76	1	1.52
3		33	50.00	26	39.39	7	10.61
4		58	87.88	5	7.58	3	4.55
5		29	43.94	25	37.88	12	18.18
6		38	57.58	20	30.30	8	12.12
7		57	86.36	5	7.58	4	6.06

Prb = probability; Pat = pedigree pattern; Adv = breeding advice

probability of a disease, while "I don't know" was entered the least for breeding advice question types ($p < .01$). There was a clear positive association between the number of times a question was answered incorrectly and the number of times a question was answered with "I don't know."

Finally, multiple variables that potentially relate to participants' scores were examined; however, none of them showed a significant influence on the score outcome determined: graduation period ($p = 1$), how frequent the participant requested a genetic test during the past year ($p = .82$), how easy the participant experiences it to find a suitable genetic test ($p = 1$), how competent the participant feels to communicate the result of a test to the owner of an animal ($p = 1$), how often genetics and genetic testing are part of the daily job of the participant ($p = 1$), and whether the participant had already participated in additional courses on genetics ($p = 1$).

DISCUSSION

In the past decades, the number of genetic tests available to veterinarians increased tremendously. Consequently, the demands in terms of the amount of basic knowledge on genetics are augmenting as well, not only for veterinarians specialized in the field of genetics but also for non-geneticist veterinarians. However, to our knowledge, studies evaluating the current use of genetic tests and the competence of veterinarians to correctly apply and interpret genetic tests are lacking. As such, we aimed to provide a first overview of how often and by whom genetic tests are requested and at what level the current knowledge on basic genetics is for veterinarians working in a university setting. This cross-sectional study shows that veterinarians currently implement genetic tests in a clinical university environment, with diagnostic testing of clinically ill patients reported as the most common reason to request a genetic test. Additionally, examination of knowledge on basic and clinical genetics revealed that pain points are most frequently situated in the interpretation of a pedigree inheritance pattern and questions related to XR and XD inheritance patterns.

As a tool to investigate this, and with broader use in mind, a questionnaire was developed. To optimally design this questionnaire, we took several recommendations and statistical considerations into account. First, the questionnaire went through several pretest rounds by experts (to ensure the correctness of the answers) and by veterinarians with the profile of the target audience (to estimate the level of difficulty and time required for completion). Second, to be able to compare the proportion of correct answers from the different cases, it was attempted to standardize the number of (correct and incorrect) answers as much as possible. This was the case for all questions except for one, which was a question on breeding advice for complex disorders. However, the trend (a marked decrease relative to the probability-related question) for that question was similar to that observed for all other inheritance patterns, even though the number of incorrect answers was lower and, thus, the chance of guessing correctly was higher. As such, the effect of this deviation in the number of incorrect answers likely was limited. Third, there is always a risk that these types of evaluations are biased by looking up the correct answers. To reduce this as much as possible, it was explicitly specified in the explanatory cover letter that this should not be done. In addition, we attempted to write the questions in such a way that they probed for the correct application of genetic principles instead of knowledge-based questions, which are easier to look up. Fourth, even though adding the "I don't know" option to each question will not necessarily avoid guessing, it provides an (honest) alternative compared with when this would not be available. The clear association between the number of incorrect answers and the number of times "I don't know" was answered does seem to be a good indication of the difficulty of a specific question. Overall, taking into account that trends between the different questions were generally consistent and that the scores per person varied widely, the questionnaire seems to allow distinguishing whether genetic principles are mastered at the level of the individual. It also allows for identifying pain points shared by many participants.

It was a deliberate choice to execute this study in a university setting. Every department employs veterinarians that are specialized in certain species and particular fields of veterinary medicine. Given the broad participation, targeting this audience has given an immediate overview of the knowledge and utilization of genetic tests across several fields in an advanced setting. It remains to be determined, however, how the scores are outside academia. Based on similar research in the field of human medicine, the results might be less favorable among general practitioners.[16,18,22,23] One potential reason is that patients presented at these veterinary university clinics often need specialized health care, requiring a wide range of diagnostic tools, including genetic tests, so the exposure to genetics and genetic

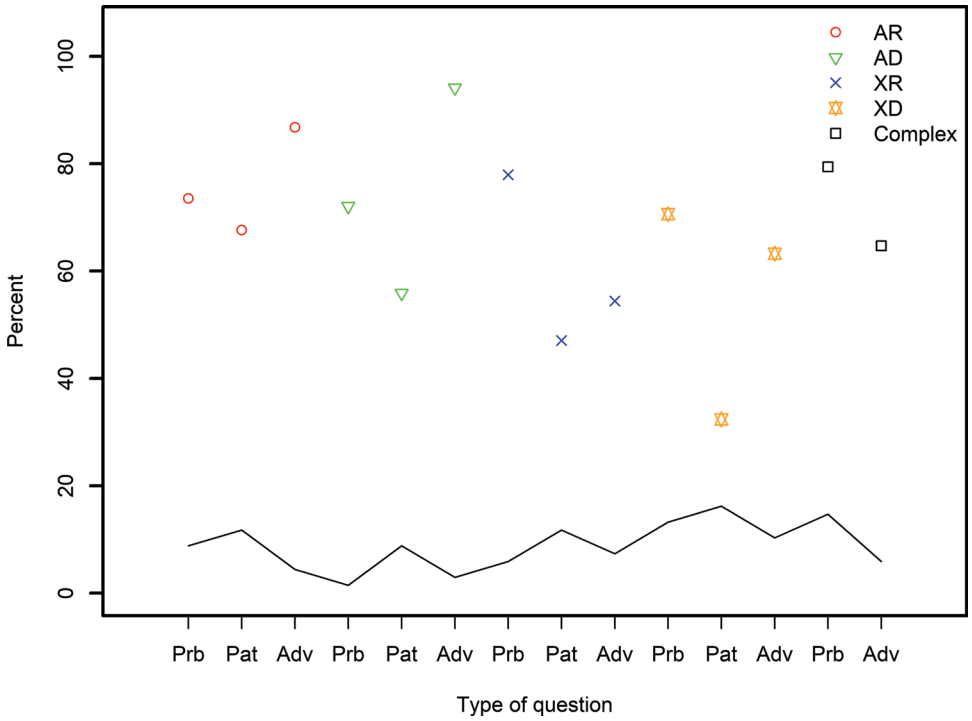

Figure 1: Inheritance pattern (AR, AD, XR, XD) relative to percentage of correct answers per type of question
The full line at the bottom of the graph shows the number of times "I don't know" was given as an answer on each question.
AR = autosomal recessive; AD = autosomal dominant; XR = X-linked recessive; XD = X-linked dominant; Prb = probability; Pat = pedigree pattern; Adv = breeding advice

testing might be higher. Additionally, it has also been suggested that university employees are more likely to come into contact with genetics than veterinarians that have no academic affiliation, because of their interactions with medical geneticists at the faculty.[19] Currently, a second study on the use of genetic tests and general knowledge on basic genetics is being executed among veterinary general practitioners to allow a direct comparison in a broader group of veterinarians.

In our study, the median score per participant varied widely, and a similar trend was visible for the scores per question, with scores ranging between 32% and 94% for the cases and 44% and 100% for the statements. This reveals that the knowledge of participants is very variable, but also that the knowledge for specific subtopics is insufficient for some while it is close to perfect for others. Although all questions only required basic genetic knowledge presumed to be present in veterinarians after graduation, many questions are more difficult to answer without the creation of a Punnett square or an in-depth analysis of a pedigree. As this increases the time one has to spend on the questionnaire, not every participant might have done this and might instead have rushed to conclusions. Indeed, we found that the questions that asked for the recognition of a pedigree inheritance pattern had the lowest scores, while questions asking to estimate the probability of a disease or to give breeding advice yielded higher scores, so the results of the first type of questions might have been related to trying to finish the questionnaire quickly. However, we consider this less likely as these results are also what we intuitively expected as the participants were non-geneticists for which we can assume that they are less regularly exposed to the analysis of pedigrees, contrary to questions related to the probability of a disease or breeding advice, which are more likely to come up during daily work and are more directly related to complaints of the patients.

Also, within expectations, a closer look at the knowledge of different inheritance patterns revealed that questions related to XR and XD conditions were the most difficult to answer. Although the basic concepts of X-linked inheritance are relatively straightforward, these questions are intuitively more difficult to answer than questions on AR and AD conditions, particularly because they require distinguishing male and female animals.[24,25] Since questions related to XD inheritance patterns did not only have the lowest scores but were also most often answered by "I don't know," these questions probably were overall most difficult for our participants.

Interestingly, scores on complex disorders were better than those for X-linked disorders, while most conditions with a complex inheritance pattern are much more difficult to understand than diseases that follow a Mendelian type of inheritance. A likely explanation is that creating questions that adequately reflect this more complex situation is extremely difficult without going beyond what is expected to be common knowledge. Furthermore, as mentioned before, as one of the questions dealing with complex diseases only had two incorrect alternatives, it cannot be completely excluded that the score was better due to guessing. Finally, both questions on complex diseases were linked to two well-known diseases within veterinary medicine (persistent ductus arteriosus and hip dysplasia in dogs), which might have also improved the results.

We also investigated the potential effect of several additional variables on participants' scores, but none of them turned out to exert a significant influence. In human studies, on the other hand, both a later year of graduation and higher exposure to

genetics in daily practice were associated with higher knowledge scores.[18,19] Possibly, the genetics education in medical school went through an adaptation during the more recent years and graduates' knowledge level improved. Additionally, in our study, no association was detected with how often genetics and genetic testing are part of the daily job of the participants. Although 15% of the participants reported encountering genetics and genetic tests very frequently in their daily job, only 9% of the participants implemented genetic tests on at least a monthly basis. As such, their contact with genetic diseases is likely more at the level of treatment than at the level of analyzing the results of a genetic test. An effect on the knowledge scores when a participant attended additional courses on genetics could also not be detected.

Nevertheless, Metcalfe et al.[26] demonstrated a positive effect of education in human medicine with a significantly improved knowledge of prenatal testing and general confidence in the implementation of genetics in daily practice immediately and 6 to 8 months after a case-based workshop.[27] The absence of an effect might be a consequence of the way the question was phrased. The question was: "have you attended additional training/courses where knowledge about genetic testing was included?" Possibly, participants answered "yes" to this question when genetic testing was a part of an additional training/course but not the main subject. Furthermore, it has been described that the knowledge gained after training is not necessarily long-term, so the time between taking the course and participating in this study might also have had an effect.[27] Finally, the type of course (short versus long, in real life or online) can also influence the outcome. Overall, this is clearly still an area with many opportunities for research. No comparable studies were found in human medicine for the remaining nonsignificant variables.

Specific attention was given to the various aspects of performing genetic testing, with the first step finding the correct test. When the results of a genetic test are obtained, they need to be interpreted, and a decision should be made on how to implement the results. However, finding the correct test was not considered easy for close to 50% of the participants. In addition, while in our study, 80% of the results were communicated by a veterinarian, only one third of the participants felt competent to do so in every situation. Finally, the median score for correctly answering individual cases and statements was 69% and 73%, respectively. This means that it is likely that some genetic tests or cases are interpreted and communicated to the owner incorrectly. Selecting the wrong test and misinterpreting test results used in mating-related decisions can have far-reaching consequences, not only for the produced offspring but also for the population. For instance, at the level of the population, exclusion of all carrier animals in case of recessive conditions could lead to a further decrease in genetic diversity with potentially severe consequences, especially in breeds with an already small effective population size. Additionally, at the level of the individual, misinterpretation could lead to offspring that are unnecessarily affected by genetic disease.[28–30]

Comparing knowledge scores obtained in this study with scores from studies in the field of human medicine is difficult since most genetics-related questionnaires in human medicine are constructed to gauge knowledge within specific fields of human medicine instead of general knowledge on basic genetic principles. However, we have chosen to question more general knowledge as having a good grasp of the basic principles of genetics is a prerequisite for the appropriate use and interpretation of genetics tests in more specific veterinary fields. Additionally, working with a general knowledge questionnaire provides the opportunity to directly compare knowledge of different groups of veterinarians—for instance, general practitioners versus second-line veterinarians. Finally, to the authors' knowledge, no similar study has been performed in a university setting.[16,18,19,31] Although the knowledge scores cannot easily be compared between human and veterinary medicine, possible solutions to increase the knowledge of genetics transcend disciplines. Since a lack of knowledge and expertise are major barriers to applying a new technique, providing education is crucial, both during and after medical school. The demand for additional training in the field of genetics after graduation has already been a subject of research in human medicine, with the most preferred topics focusing on the evaluation of signals pointing toward a hereditary component of a disease, indications when to refer to a clinical genetics center, pointing out the possibilities and limitations of genetic tests, and how to approach genetic risk in clinical practice, although the specific needs for education may vary between countries and specializations.[32,33]

Aside from what is known based on studies in human medicine, this questionnaire allowed us to identify several additional focus points and has led us to formulate the following recommendations. For educational purposes, it is clear that pain points are X-linked diseases and evaluating pedigree inheritance patterns. While the general principles should not be neglected, continued education that pays special attention to these topics might improve the results. We also hope that the questionnaire developed for this study can be an additional tool that helps to evaluate and improve knowledge. As communication of genetic test results is mainly done by the veterinarians, it is also clear that the focus for education should be directed toward this group. Laboratories offering genetic tests can, however, also play a role by (for example) increasing the amount of information given together with the test result.

Furthermore, while a little over 50% found it easy to find the correct test, a large proportion of the participants found it rather difficult, or even very difficult, to do so. Difficulties in finding the correct genetic tests can also lead to selecting an incorrect test and misinterpretations. Especially in veterinary medicine, there is the additional complicating factor related to the breed specificity of certain tests: a genetic test for a disorder in one breed is not automatically valid for a different breed. This breed dependency should be kept in mind in both requesting and interpreting results and is an additional possible obstacle that doctors in human medicine are not confronted with.[3] Beyond what one can expect as knowledge from non-geneticists, a significant responsibility of laboratories offering genetic tests—and the scientists developing them—is also providing context on (for example) whether a mutation is causal or whether it is more likely to represent a preliminary association between a mutation and a certain disease.[34] Overall, it is clear that improved and probably more direct communication between geneticists, laboratories, and practitioners is important and will likely become even more so in the future.

In more detail, even though currently only half of the participants that filled in the questionnaire used genetic tests during their daily practice, 76% predicted that the importance of genetics will only increase in the upcoming 5–10 years. This was also reflected by the fact that 86% of the participants had the feeling that additional courses on genetics are essential. Better awareness of basic genetic principles would not only improve knowledge scores but might even increase the use of genetic

tests, since a more familiar feeling with basic genetics might result in being more confident when choosing and interpreting genetic tests.[26,35] Additional factors that might further improve the implementation of genetic tests in the daily routine of non-geneticists as a diagnostic tool are, for example, a short turnover time and decreased costs.[36]

Limitations

A potential limitation of this study might be participation bias as overall, more veterinarians working with small animals were present while veterinarians working with farm animals were underrepresented. Furthermore, it cannot be ruled out that some veterinarians might have looked up information, leading to potentially improved scores.

CONCLUSION

With the increasing availability of genetics tests, the use in daily practice by non-geneticists will only increase in the upcoming years. To assure that these diagnostic tools are used and interpreted correctly, the knowledge and expertise of the person who is requesting the test and communicating the obtained test result are of utmost importance. Our study indicated that the current knowledge of veterinarians on genetics, however, is highly variable and with a high risk of misinterpretation, especially with respect to recognizing inheritance patterns in pedigrees and X-linked disorders. To improve this, several recommendations on education, laboratories offering genetic tests, and communication are given.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

NOTES

a Qualtrics survey software, Qualtrics, Provo, UT, USA, https://www.qualtrics.com

b R version 3.6.3 (codename "Holding the Windsock"), R Core Team, 2020 R Foundation for Statistical Computing, Vienna, Austria, https://www.r-project.org/

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AUTHOR INFORMATION

Evelien Bogaerts,* DVM, PhD is a Resident of the ECVSMR College, Department of Veterinary Medical Imaging and Small Animal Orthopaedics, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 13, D4 ingang 19, 9820 Merelbeke, Belgium. Email: Evelien.Bogaerts@UGent.be.

Else den Boer,* DVM, MSc Stat Data Analysis, is a PhD student, Department of Clinical Sciences, Faculty of Veterinary Medicine, Utrecht University, Yalelaan 1, 3584 CL Utrecht, the Netherlands.

Luc Peelman, PhD, is Professor and Head of the Department of Nutrition, Genetics and Ethology, Faculty of Veterinary Medicine, Ghent University, Heidestraat 19, 9820 Merelbeke, Belgium.

Filip Van Nieuwerburgh, PhD, Apr., is a Senior Lecturer, Laboratory of Pharmaceutical Biotechnology, Faculty of Pharmaceutical Sciences, Ghent University, Ottergemsesteenweg 460, B-9000 Ghent, Belgium.

Hille Fieten,† DVM, Dipl. ECVIM, PhD, is a Senior Lecturer, Department of Clinical Sciences, Faculty of Veterinary Medicine, Utrecht University, Yalelaan 1, 3584 CL Utrecht, the Netherlands.

Jimmy H. Saunders,† DVM, Dipl. ECVDI, PhD, is Professor and Head of the Department of Veterinary Medical Imaging and Small Animal Orthopaedics, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 13, D4 ingang 19, 9820 Merelbeke, Belgium. Email: Jimmy.Saunders@UGent.be.

Bart J.G. Broeckx,† DVM, PhD, MSc Stat Data Analysis, is a Professor at the Laboratory of Animal Genetics, Department of Nutrition, Genetics and Ethology, Faculty of Veterinary Medicine, Ghent University, Heidestraat 19, 9820 Merelbeke, Belgium. Email: Bart.Broeckx@UGent.be.

* Authors contributed equally
† Authors contributed equally