Tailoring surgical management of dislocated clavicle fractures
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Tailoring surgical management of dislocated clavicle fractures

Op maat gemaakte chirurgische behandeling van gedisloceerde clavicula fracturen

(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. G.J. van der Zwaan, ingevolge het besluit van het college voor promoties in het openbaar te verdedigen op donderdag 13 juni 2013 des middags te 4.15 uur

door

Franciscus Jasper Gerardus Wijdicks

geboren op 15 maart 1986
te Breda

Promotor:

Prof. dr. L.P.H. Leenen

Co-promotoren:

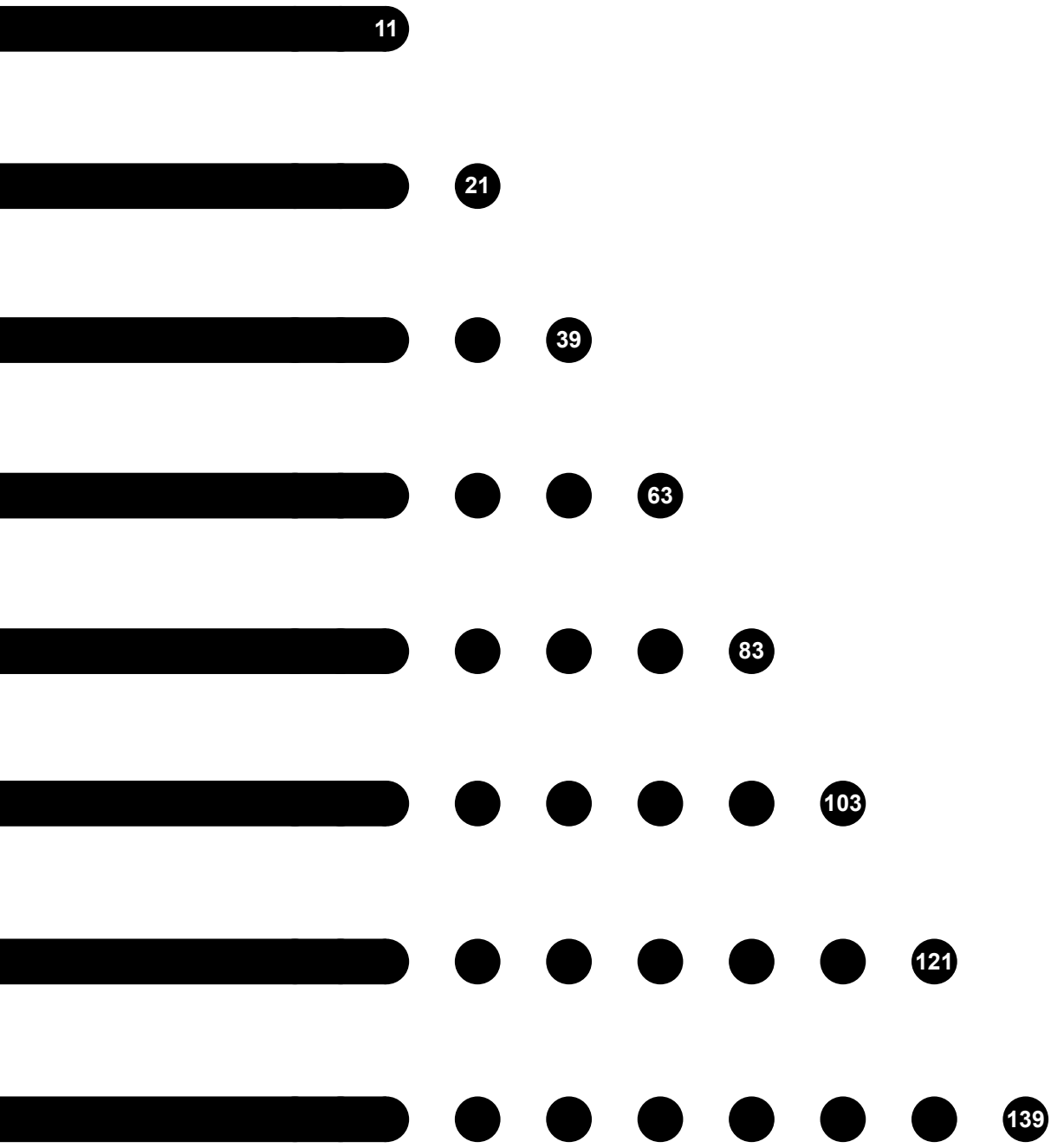
Dr. E.J.M.M. Verleisdonk

Dr. R.M. Houwert

Hij steeg te paard
En reed daarheen
En nog brak hij zijn sleutelbeen.
Komt rijden wij thans allen henen
En breken onze sleutelbenen.

Hollands kinderliedje uit 1702/Dutch Children's song from 1702

Content


11
21
39
63
83
103
121
139

Content

Chapter 1

Introduction and aim of this thesis

Introduction

The translation of the Latin word 'clavicula' literally means "little key" because the bone rotates along its axis like a key when the shoulder is abducted, and it is roughly the same shape as a key for a Roman door lock. The bone is responsible for a smooth and wide set of movements of the shoulder. Not only is it responsible for movement, but it has also changed history.

On February 20th in the year 1702 a horse tripped over a mole's burrow near Hampton Court in England. The rider fell of the horse and broke his clavicle. He died on March 8 of that year as a result of pneumonia due to his clavicle fracture. The rider was His Majesty the King, William III of Orange-Nassau (figure 1). Because William III had no children, the Windsors claimed the throne and are still the ruling monarchy in the United Kingdom until this date [1]. The course of history in the United Kingdom was decided by a fracture of the clavicle that is responsible for a smooth and wide set of movements of the shoulder. Clavicle fractures occur frequently; approximately 5% of all fractures concern the clavicle [2,3]. The typical mechanisms of injury are direct axial trauma to the shoulder or forward fall with outstretched arms, and most clavicle fractures occur during traffic accidents [4]. The clavicle can be divided into three different segments: the medial segment, the midshaft segment and the lateral segment of the bone [5]. The vast majority of fractures, approximately 80%, is located in the midshaft of the clavicle [2,6]. Half of these midshaft fractures are displaced, meaning there is no cortical contact between fracture parts and the fracture parts are dislocated a minimum of one shaft width [2,6]. In both the traumatic and post-traumatic setting a risk of shortening is present when the fracture is dislocated. The severity of shortening is associated with the risk of nonunion and patient dissatisfaction [7].

The type of treatment for a dislocated midshaft clavicle fracture is still debated. In the 60's of the last century conservative treatment was recommended, even for heavily displaced fractures, due to low major complication rates [8,9]. CS Neer and CR Rowe separately reported on a large group of clavicle fractures that healed uneventfully with conservative management regardless of dislocation. Even severe dislocated clavicle fractures healed with minimal complications. According to these studies nonunion was extremely rare. However, some reservations need to be addressed regarding these studies. The large patient population used by Neer [8] and Rowe [9] included children and adolescents; fractures in children usually heal uneventfully and due to the late closure of the

Figure 1. King William III of Orange-Nassau

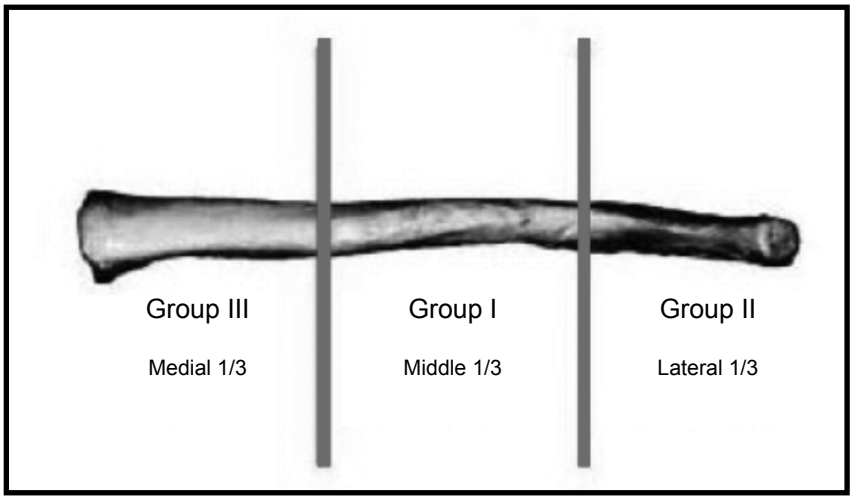


Figure 2. The Allman Classification for clavicular fractures

epiphysis the clavicle in children has the potential of remodelling. Even more, several patient-based scoring systems with objective and subjective parameters were not available as we have them today. Nowadays pain, limitations in daily activities and patient satisfactory is taken into account in latest scoring systems. The last factor that influenced a change in management of clavicle fractures is the introduction of several other classification systems. The Allman classification (figure 2) focuses primarily on the location of the fracture in the clavicle but provides no information on fracture pattern and severity of comminution. The introduction of newer classification systems (like the Robinson's classification [3] or the AO classification system (figure 3) [10]) also describes severity of comminution and fracture patterns. These classifications have contributed to optimisation of prognosis and treatment [3].

The concept and management of clavicle fractures has changed over time and the idea of solely conservative management of clavicle fractures based on studies of the 1960's is not applicable anymore in current times. Latest studies describe high rates of nonunion and patient dissatisfaction after conservative treatment. In 1997 Hill et al. reviewed a group of patients with severe dislocated midshaft clavicle fractures who had undergone conservative management. A total of 15% developed a nonunion and 31% of patients were not satisfied with the result. Their recommendation is to treat these fractures operatively [7]. A few years later Zlowodzki et al. performed a systematic review in which they portrayed that if a dislocated midshaft clavicle fracture is treated with plate fixation or intramedullary fixation, an 86-87% risk reduction is achieved for a nonunion when compared to conservative management [11].

Recently two large randomized controlled trials compared conservative therapy to operative management [12,13]. The Canadian Orthopaedic Trauma Society compared the functionality of the shoulder between dislocated midshaft clavicle fractures treated with plate fixation and conservative management in a randomized controlled trial and showed that regarding postoperative pain and shoulder functionality the plate fixation group had better results than the conservative group. [12] Smekal et al. also compared operative management to conservative management in a randomized controlled trial using the intramedullary nail as operative method. Also in this study the functionality of the shoulder scores better in the operative group [13]. These studies set in motion a worldwide increase in operative treatments for dislocated midshaft clavicle fractures.

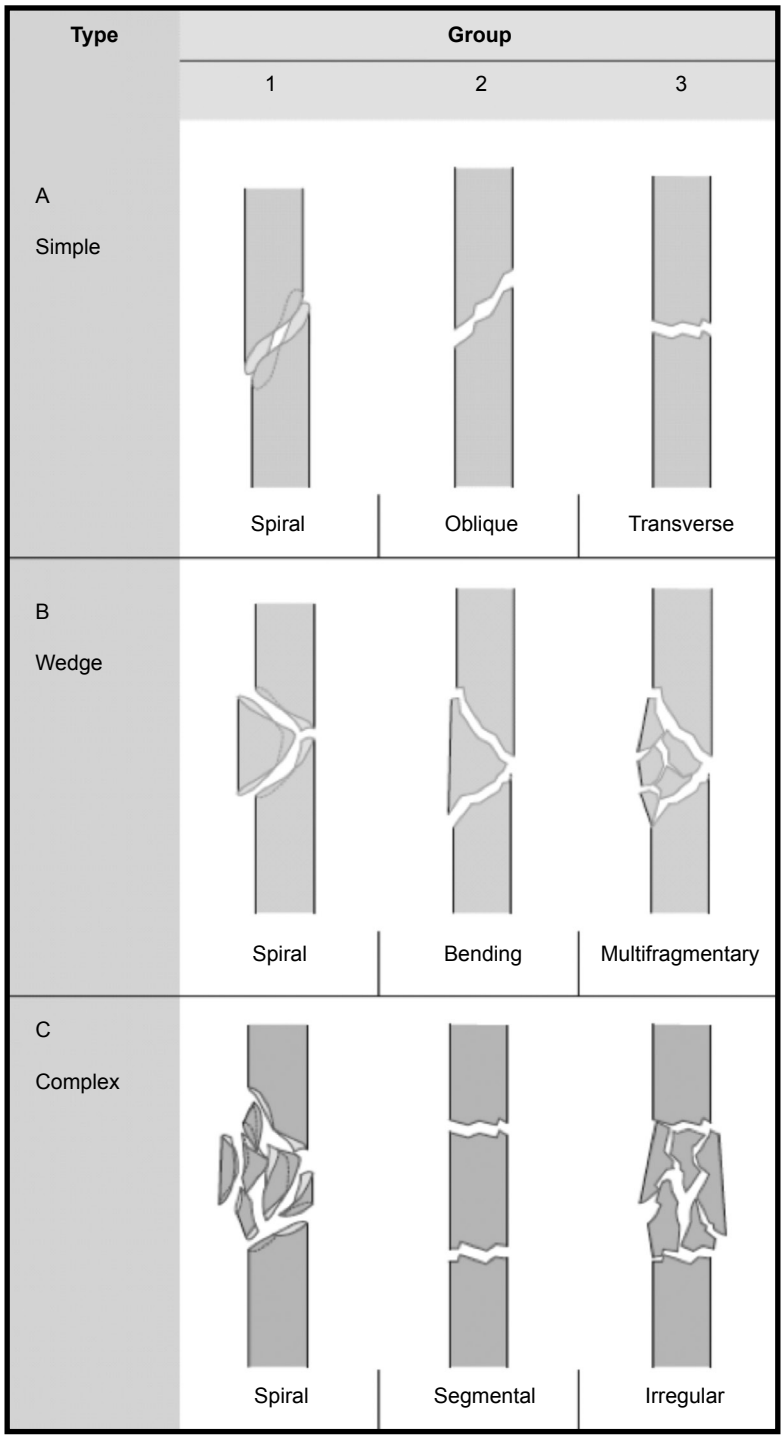


Figure 3. **The AO Muller Classification System**

Several techniques can be used but the two most used types are plate fixation and intramedullary fixation [14].

Plate fixation

In the past reconstruction plates, DC-plates and drittelrohr plates were used to treat clavicle fractures. These plates were associated with irritation, loosening and breakage. These were complex procedures due to the prominence and stiffness of the plate [15]. Eventually the locking system plates became available claiming to provide a relatively more flexible though stable construct. This made it easier to contour the plate to the natural form of the clavicle resulting in less irritation. The locking system lowered the chance of breakage or loosening of the implant [12, 16]. Recently the pre-contoured clavicle plate became available which allows the surgeon to fit the plate more accurately to the natural form of the clavicle potentially minimizing surgical time by eliminating plate contouring during surgery. Advantages of pre-contoured clavicle plates are less irritation by the plate and risk reduction of plate fatigue fracture [17,18]. In conclusion, possible advantages of plate fixation are a larger experience of the technique and a relatively more stable construct than intramedullary fixation [19].

Intramedullary fixation

The first series of intramedullary fixation for clavicle fractures date back to the late 1960's [20]. There are various forms of intramedullary fixation such as Hagie pins, Rockwood pins and the Titanium Elastic Nail [21,22,23]. Possible advantages of intramedullary fixation are a smaller incision and preservation of the fracture hematoma [24].

A recent Cochrane review concludes that prospective randomized controlled trials that compare operative techniques are lacking [25]. To personalize and tailor the surgical treatment of dislocated midshaft clavicle fractures it is necessary for physicians to make an evidence-based decision which operative treatment is best suited for each individual patient. So the main question remains; which technique is the best for dislocated midshaft clavicle fractures?

The aims of this thesis are:

1. To review current literature about studies comparing plate fixation and intramedullary fixation for dislocated midshaft clavicle fractures. (Chapter 2)

2. To provide insight in complications after plate fixation and intramedullary fixation for dislocated midshaft clavicle fractures. (Chapter 3,4,5)

3. To provide the rationale and design of a prospective randomized multicentre study comparing plate fixation and intramedullary fixation for dislocated midshaft clavicle fractures (POP study). (Chapter 6)

4. To present the short term results of the POP study. (Chapter 7)

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Chapter 2

Plate fixation versus intramedullary fixation for displaced midshaft clavicle fractures: a systematic review

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Abstract

Purpose

The optimal surgical approach for displaced midshaft clavicle fractures remains controversial. The objective of this systematic review is to compare functional outcome and complications after plate fixation and intramedullary fixation for displaced midshaft clavicle fractures.

Methods

A computer aided search of PUBMED and Embase was carried out on January 11th 2011. Every study that was published in the English, German, French or Dutch language was considered for inclusion.

Results

A total of four studies could be included of which two compared intramedullary fixation with plate fixation, and two compared intramedullary fixation and plate fixation with conservative treatment for displaced midshaft clavicle fractures. All studies that compared plate fixation with intramedullary fixation in patients with fresh unilateral displaced midshaft clavicle fractures were included. Dislocation or displacement had to be mentioned in the inclusion criteria of the study for inclusion in this review. The modified version of the Cochrane Bone, Joint and Muscle Trauma Group's former quality assessment tool was used. Furthermore, the studies included were scored according to the GRADE approach to assess the quality. The chosen studies were summarized in a data-extraction form. Because of the different study designs and characteristics data were summarized separately for each study.

Conclusions

High quality evidence from one study and low quality evidence from three studies showed no difference in functional outcome or complications after plate fixation or intramedullary fixation for displaced midshaft clavicle fractures.

Introduction

The clavicle is one of the most commonly fractured bones, accounting for 5–10% of all fractures. Around 80% of clavicle fractures involve the midshaft and over half of these fractures are displaced [1, 2]. Traditionally acute displaced midshaft clavicle fractures (DMCF) have been treated conservatively, with the expectation that even severe radiographic malalignment would not influence functional results [3]. However, recent studies have uncovered the disadvantages of conservatively treated DMCF [4–6]. The relatively high number of nonunions, residual deficits in shoulder strength and endurance, persistent pain and disappointing cosmetic results might have led to unsatisfactory results in approximately 30% of the patients with DMCF [4–6]. Therefore there is a tendency towards surgical treatment for DMCF [7, 8].

Open reduction and internal plate fixation and intramedullary fixation are two of the most commonly used surgical techniques for treating DMCF [7, 8]. For plate fixation different types of plates are available: (precontoured) dynamic compression plates (DCP) [9], tubular plates or reconstruction plates [10]. For intramedullary fixation the Knowles pin [11], Rockwood pin [12] or elastic stable intramedullary nailing (ESIN) using a titanium elastic nail (TEN) [13] have been described. In recently published prospective randomized studies, functional results after both plate fixation and intramedullary fixation proved to be superior compared to nonoperative treatment of DMCF [15, 16]. This was also underlined by the systematic review by Zlowodzki et al. that reported a relative risk reduction of 86% (plate fixation) and 87% (intramedullary fixation) for nonunion compared with conservative treatment [14]. Theoretically, both plate fixation and intramedullary fixation have their own advantages. A biomechanical study shows that plate fixation provides a more rigid stabilisation compared to intramedullary fixation and may provide a stronger construction for early rehabilitation protocols [17]. On the other hand, intramedullary fixation has the advantage of preserving the soft tissue envelope, periosteum, and vascular integrity of the fracture site. Therefore infection rates may be decreased and fracture callus formation enhanced [18].

The optimal surgical approach for DMCF remains controversial. Only one systematic review addressed the different surgical methods but at that time could not include multiple studies comparing plate fixation versus intramedullary fixation [19]. The goals of this systematic review are (1) to compare functional outcome and complications after plate fixation and intramedullary fixation for DMCF and (2) to assess the scientific quality of the available evidence.

Methods

Search strategy

A computer aided search of PUBMED and Embase was carried out on January 11th 2011. In PUBMED the first two phases of the optimal trial search strategy (www.cochrane-handbook.org) were combined with the subject specific search. In addition the reference lists of identified studies were searched (reference tracking) and studies that cited these studies where screened (citation tracking).

Inclusion criteria

Studies that compared plate fixation with intramedullary fixation in patients with acute unilateral DMCF were included. Dislocation or displacement had to be mentioned in the criteria of the study for inclusion in this review. Every study that was published in the English, German, French or Dutch language, except review articles or case reports, was considered for inclusion. Studies that assessed clavicle malunion or nonunion, fractures with initial nonoperative treatment or biomechanical studies were excluded.

Selection of studies

Three independent reviewers (RMH, FJW, CSB) screened the titles and abstracts of identified studies for eligibility. The full text articles were read for inclusion. Disagreement between the reviewers was resolved by discussion with another independent reviewer (MCK).

Quality assessment

Two reviewers (RMH, CSB) independently assessed various aspects of methodological quality of the included studies without masking the source or authorship of trial reports (Table 1). The modified version of the Cochrane Bone, Joint and Muscle Trauma Group's former quality assessment tool was used. This tool consists of 11 items: the first seven items relate to bias (internal validity), and the remaining four items relate to external validity. Furthermore, they scored the included studies according to the GRADE approach (www.cochrane-handbook.org). The GRADE approach is a quality tool that specifies four levels of evidence (high, moderate, low and very low). The highest quality rating is for randomized trial evidence, while moderate quality is for downgraded randomized trials or upgraded observational studies. Low quality rating is reserved for double downgraded randomized trials or observational studies and finally very low quality

is for triple downgraded randomized trials, downgraded observational studies or case series/case reports. A study can be downgraded one or more levels for every limitation factor a review author finds (limitations in the design, imprecise results, indirectness of evidence, high probability of publication bias and unexplained heterogeneity or inconsistency of results). Disagreement between the reviewers about the quality assessment was resolved by discussion with another independent reviewer (MCK).

Data extraction and analysis

Included studies were summarized in a data-extraction form, including the following items: type of study, surgery (type of plate fixation or specified method of intramedullary fixation), descriptive data (sample size, missing data, follow-up), patient characteristics, functional outcome, operation characteristics (amount of blood loss and duration of the surgery) and complications. Functional outcome was defined as shoulder function with the Disabilities of the Arm, Shoulder and Hand (DASH) and Constant scores [20, 21]. The DASH questionnaire is a self administered outcome instrument developed as a measure of self-rated upper extremity disability and symptoms. The Constant score includes an analysis of pain, shoulder motion, strength, and function. Definitions were used according to the definitions of the authors in the different studies. Data were presented as mean ± standard deviation or as percentages. Because of the different study designs and characteristics, data could not be pooled and the data were summarized separately for each study.

Table 1. Quality assessment

Parameter	Study			
	Ferran et al. [23]	Liu et al. [24]	Thyagarajan et al. [25]	Bohme et al. [26]
Allocation concealment	2	0	0	0
Intention-to-treat analysis	2	0	0	0
Assessor blinding	0	0	0	0
Comparable baseline characteristics	2	2	2	0
Participant blinding	0	0	0	0
Treatment provider blinding	0	0	0	0
Care program comparability	2	2	0	0
Defined in- and exclusion criteria	2	2	2	2
Well defined interventions	2	2	1	2
Well defined outcome measures	2	2	2	2
Clinically useful diagnostic tests	2	2	0	2
Adequate duration of follow-up	2	2	0	0
QAT-Score	18	14	7	8
Grade	High	Very low	Very low	Low

Results

We identified 593 articles, of which 57 were potentially relevant after screening the title and abstract. One comparative study had to be excluded because all types of midshaft clavicle fractures were included regardless of dislocation [22]. A total of four studies could be included of which two compared intramedullary fixation versus plate fixation, and two compared intramedullary fixation and plate fixation versus conservative treatment for DMCF (Fig. 1). There was no disagreement between the reviewers about the selection of the four final articles.

Quality assessment

In none of the studies patients or outcome assessors were blinded. In all four studies, rehabilitation programs were identical for all groups and functional outcome and the diagnostic tests used were adequately defined. The length of follow-up was sufficient in two trials [23, 24] and relatively short in the other two [25, 26]. One high quality RCT was identified [23]. This study described adequate methods of randomisation and concealment of allocation. No loss to follow-up occurred in this study and each patient was treated according to the randomisation. The study was powered to identify a clinically significant difference with 1−ß = 80%. Contrary to the other three studies, this study failed to provide sufficient information on inclusion and exclusion criteria to define their study population. Another drawback may have been the age difference that was present between the two groups. The observational trials by Liu et al. and Thyagarajan et al. reported and compared baseline characteristics between the two groups without differences [24, 25]. In the observational study of Bohme et al. baseline characteristics are reported but not compared [26].

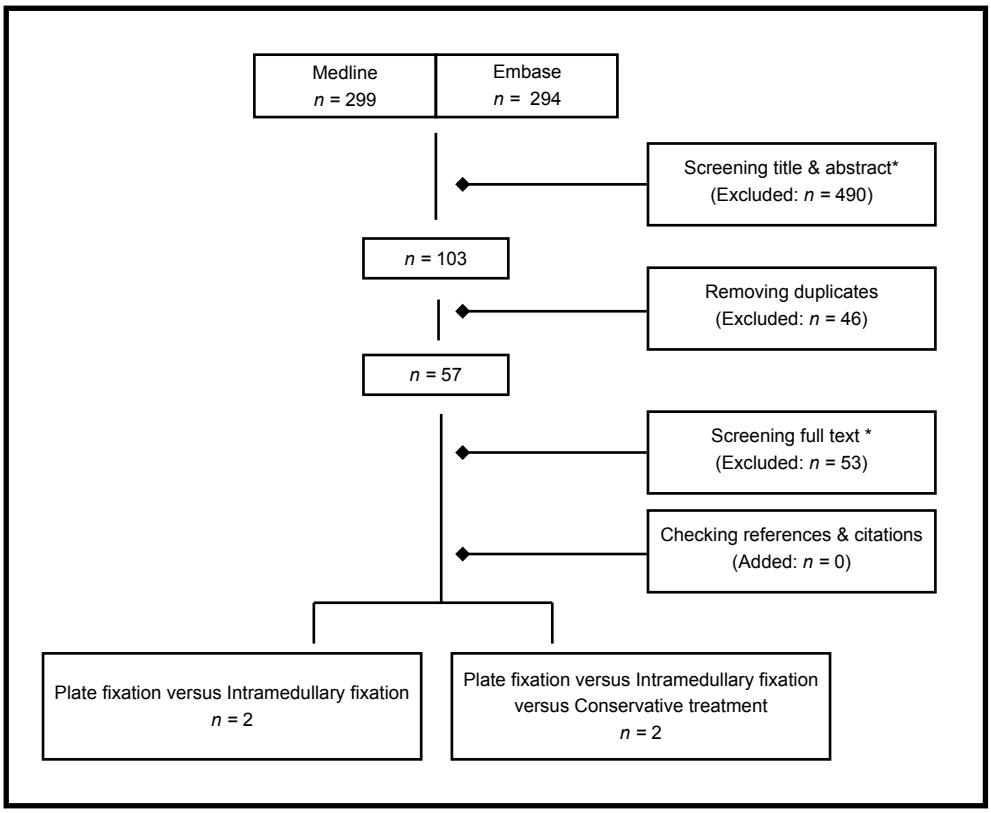

Figure 1. Literature search performed on 11 January 2011

***n* = number of studies**
*** Indicates use of inclusion and exclusion criteria**

Intramedullary fixation versus plate fixation

Ferran et al. found no significant difference between plate fixation and intramedullary fixation after 12 months in functional outcome (Constant score p=0.37) (Table 2). Complications occurred in 12% of the intramedullary fixation group and in 40% of the plate fixation group, but no statistical analysis was applied. In the comparative case series, Liu et al. reported no significant difference between intramedullary and plate fixation after 18 months in functional outcome (DASH score p=0.42, Constant score p=0.17). No significant differences were observed regarding complications. However, a tendency towards increased implant removal was found in the plate group (p=0.10) [24].

Table 2. Plate fixation versus Intramedullary fixation

Study (author, year)	Ferran et al. [23], 2010			Liu et al. [24], 2010		
Design	RCT			Case series		
Treatment	Rockwood Pin	LC-DCP	*p*-value	TEN	Reconstr Plate	*p*-value
Descriptive						
Sample size	17	15		51	59	
Missing data	0	0		NR	NR	
Sample size at follow-up	17	15		NR	NR	
Follow-up (months)	13	12		18	18	
Patient						
Age (years)	24	35		34 ± 14	32 ± 10	
Gender (female/male)	3/14	2/13		19/32	30/29	
DMCF classification	NR	NR		Orthopedic Trauma Association		
Functional outcome						
DASH score	NR	NR		14 ± 4	13 ± 4	p = 0,42
Constant score	92 ± 6	89 ± 9	p = 0,37	87 ± 5	88 ± 5	p = 0,17
Operation						
Blood loss (ml)	NR	NR		67 ± 37	128 ± 49	$p < 0.01$
Duration (min)	NR	NR		73 ±26	76 ± 23	p = 0,52
Complications						
Infection	0	3 (20%)**		3 (6%)	6 (10%)	p = 0,50
Malunion	0	0		4 (8%)	2 (3%)	p = 0,41
Nonunion	0	0		5 (10%)	6 (10%)	p = 1,00
Implant failure requiring removal	1 (6%)*	6 (40%)		4 (8%)	12 (20%)	p = 0,10
Implant irritation	1 (6%)	0		NR	NR	
Re-osteosynthesis	1 (6%)*	0		NR	NR	

***NR* not reported, *y* year, *(LC-)DCP* (low contact) dynamic compression plate, *TEN* titanium elastic nail, *Reconstr* reconstruction, *RCT* randomized controlled trial**

*** Implant removal and re-osteosynthesis was needed in the same patient**
**** All infections required removal of the implant**

Intramedullary fixation and plate fixation versus nonoperative treatment

Bohme et al. reported in an observational cohort study a Constant score of 97 for the intramedullary fixation group and of 94 for the plate fixation group after eight months [26] (Table 3). Complications occurred in 15% of the intramedullary fixation group and in 13% of the plate fixation group. Thyagarajan et al. reported a constant score of 98 for the intramedullary fixation group and of 94 for the plate fixation group after six months. Complications occurred in 12% of the intramedullary fixation group and in 65% of the plate fixation group [25]. In both studies, no statistical analysis was applied on differences between the intramedullary- and plate fixation groups. Neither of the studies used the DASH score.

Table 3. Plate fixation and Intramedullary fixation versus conservative treatment

Study (author, year)	Thyagarajan et al. [25], 2009			Bohme et al. [26], 2010		
Design	Case series			Observational cohort		
Treatment	Rockwood Pin Open Rep	LC-DCP	Conservative	ESIN 75% closed Rep 25% open Rep	DCP LC-DCP Recon. Plate	Conservative
Descriptive						
Sample size	17	17	17	20	53	47
Missing data	NR	NR	NR	NR*	NR	NR
Sample size at follow-up	NR	NR	NR	NR	NR	NR
Follow-up (months)	6	6	6	8	8	8
Patient						
Age (year)	28	32	35	NR*	NR	NR
Gender (female/male)	1/16	2/15	2/15	NR	NR	NR
DMCF classification	NR	NR	NR	AO	AO	AO
Functional outcome						
DASH score	NR	NR	NR	NR	NR	NR
Constant score	98	94	89	97	94	90
Operation						
Blood loss (ml)	NR	NR		NR	NR	
Duration (min)	NR	NR		43 (10-95)	61 (20-133)	
Complications						
Infection	2 (12%)	2 (12%)		0	2 (4%)	0
Malunion	0	0	1 (6%)	0	0	1 (1%)
Nonunion	0	1 (6%)	3 (18%)	0	0	1 (1%)
Implant failure requiring removal	0	2 (12%)		1 (5%)	6 (11%)**	
Implant irritation	0	6 (35%)		1 (5%)	0	
Re-osteosynthesis	0	0		1 (5%)	6 (11%)	

***NR* not reported, *(LC-)DCP* (low contact) dynamic compression plate, *Reconstr* reconstruction, *RCT* randomized controlled trial, *Rep* reposition, *ESIN* elastic stable intramedullary nailing, *AO* Muller AO classification of fractures- long bones**

*** Only reported for total study population**
**** All patients required re-osteosyntheses**

Discussion

High quality evidence from one study and low quality evidence from three studies showed no difference in functional outcome and complications after plate fixation or intramedullary fixation for DMCF [23–26]. However, only one high quality RCT was identified with relatively small sample sizes per condition (n = 15 for plate fixation; n = 17 for intramedullary fixation) [23]. Furthermore, it is difficult to draw conclusions concerning complications as all group sizes were small. Therefore, future high quality studies comparing plate fixation and intramedullary fixation with sufficient power are needed to aid evidence-based decisions about surgical management of DMCF.

Our findings are in agreement with the previous review by Lenza et al.. They stated that there was limited evidence about the superiority of one surgical approach for DMCF above another [19]. However, they found only one comparative study in the scope of this review [22]. In this comparative study, Lee et al. did not report if there was displacement of the fracture. Due to our inclusion criteria we excluded this study. Both surgical procedures have their own (dis)advantages. Plate fixation is technically easy to perform and long-term experience is available. With improved implants, prophylactic antibiotics, and better soft-tissue handling, plate fixation has been a reliable and reproducible technique [15]. Despite experience and improvement, plate fixation is not free from complications. Typical complications of plate fixation include infection, hypertrophic scars, implant loosening, nonunion and refracture after implant removal [27, 28]. Compared to plate fixation, intramedullary fixation is technically more demanding [29]. In approximately 50% of the patients open reduction was necessary to reduce the fracture. The main complications are migration and perforation of the device [16, 29–32] and one iatrogenic brachial plexus injury is described [33]. Nevertheless, several studies describe excellent results after intramedullary fixation of DMCF with significant improvement of shoulder function, reduction of pain postoperatively, good cosmetic results and minimal nonunion rates [16, 29–32].

A disadvantage of clavicular surgery in general is the putative need for implant removal and therefore a second operation. Implant removal is standard treatment offered to all patients after intramedullary fixation. The rationale behind implant removal is to prevent migration of the implant even in designs that provide locking bolts. In some patients implant removal of intramedullary fixation can be performed using local anaesthesia [16]. A possible advantage of plate fixation

is that implant removal is less often required. However, prominence of the plate will usually cause some patient discomfort. Exact numbers on plate removal differ between studies but vary from 0 up to 74% of the cases [34, 35].

The following limitations of this review have to be addressed. In the current literature, dislocation (or displacement) is often poorly defined which might lead to heterogeneity of the results. For example, exact definitions of displacement and shortening were lacking in the study of Ferran et al. [23]. In another comparative study displacement was not even described [22]. Proceedings from annual meetings (conferences) were not included in this review. Only PUBMED, EMBASE and the Cochrane databases were used for search. Therefore some valuable information might be lost. However, at proceedings mostly interim analyses are reported and these results might differ from the final results. PUBMED and EMBASE are the largest medical databases. The Cochrane database showed one review by Lenza et al. [19]. This review contained only one comparative study in the scope of this review [22]. Therefore we feel confident in having assessed all relevant available evidence. However, the authors realize the amount of available literature is small, but this emphasizes the need for future high quality studies comparing plate fixation and intramedullary fixation with sufficient power to aid physicians in making evidence-based decisions about surgical treatment of DMCF. Prospective cohort series of plate fixation or intramedullary fixation were not included in this review. These studies might provide a great deal of information regarding complications of both procedures. However, due to heterogeneity of these studies, pooling of the data and subgroup analyses are difficult to perform.

We conclude that despite the limited number of prospective comparative studies at this moment, there is evidence that functional outcomes are not influenced by the method of surgical treatment of displaced midshaft clavicle fractures, plate fixation or intramedullary fixation.

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Chapter 3

Systematic review of the complications of plate fixation of clavicle fractures

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Abstract

Background

The number of displaced midshaft clavicle fractures treated surgically is increasing and plate fixation is often the treatment modality of choice. The study quality and scientific levels of evidence at which possible complications of this treatment are presented vary greatly in literature.

Purposes

The purpose of this systematic review is to assess the prevalence of complications concerning plate fixation of dislocated midshaft clavicle fractures.

Methods

A computer-based search was carried out using EMBASE and PUBMED/MEDLINE. Studies included for review reported complications after plate fixation alone or in comparison to either treatment with intramedullary pin fixation and/or nonoperative treatment. Two quality assessment tools were used to assess the methodological quality of the studies. Included studies were ranked according to their levels of evidence.

Results

After study selection and reading of the full texts, 11 studies were eligible for final quality assessment. Nonunion and malunion rates were less than 10% in all analysed studies but one. The vast majority of complications seem to be implant related, with irritation or failure of the plate being consistently reported on in almost every study, on average ranging from 9 to 64%.

Conclusion

The quantity of relevant high evidence studies is low. With low nonunion and malunion rates, plate fixation can be a safe treatment option for acute dislocated midshaft clavicle fractures, but complications related to the implant material requiring a second operation are frequent. Future prospective trials are needed to analyse the influence of various plate types and plate position on implant-related complications.

Introduction

Clavicle fractures in adults occur quite frequently; approximately 5% of all fractures concern the clavicle. The vast majority of fractures, approximately 80%, is located in the midshaft of the clavicle and half of these fractures are displaced [25, 27].

In the past, treatment of choice for most midshaft clavicle fractures was nonoperative with a sling or figure-of-eight bandage [24, 30]. Reported nonunion rates following surgical fixation of clavicle fractures were initially higher than those reported following nonoperative treatment [24, 30]. More recent studies, however, suggest higher complication and nonunion rates of up to 15% following nonoperative treatment, in particular for patients with displaced midshaft clavicle fractures (DMCF) [6, 12, 17, 22, 34, 39]. In addition, these patients are at high risk of residual pain, disappointing cosmesis and shoulder dysfunction [6, 12, 22, 39].

A regularly used surgical treatment option for DMCF is plate fixation. An advantage of plate fixation is the immediate stability it provides which enables early post-operative mobilization [13, 23, 24]. Several types of plates and fixation methods have been previously described; these include (precontoured) dynamic compression plates (DCP), tubular plates or reconstruction plates [13, 23]. Although high success rates of plate fixation of displaced clavicle fractures have been shown, reported complications of plate fixation include implant failure, (deep) infections, implant prominence, poor cosmesis, nonunions and refracture as a result of removal of the plate [4, 8, 9]. The study quality and scientific levels of evidence at which complications are presented, however, vary greatly in literature. Different reviews are performed on clavicle fractures, but none of these reviews specifically address the complications of plate fixation for dislocated midshaft clavicular fractures.

This systematic review aims at answering the following questions: (1) what is the incidence of minor and major complications after surgical plate fixation of acute DMCF? (2) What is the value of reported complications in terms of the scientific level of evidence at which they are presented? (3) What are the frequency and severity of the long-term consequences of major complications after plate fixation? (4) What conclusions may be drawn from these findings and how may it influence treatment of midshaft clavicle fractures?

Methods

Search strategy

On the 4th of April 2011, a computer-aided search using EMBASE and PUBMED/MEDLINE was conducted using the first two phases of the optimal search strategy from the Cochrane Handbook (http://www.cochrane-handbook.com). This strategy was combined with a subject specific search (''Appendix I''). Reference and citation tracking was used to complete the search database.

Inclusion criteria

Studies included for review reported complications after acute, displaced, midshaft clavicle fractures treated with plate fixation alone or in comparison to either treatment with intramedullary pin fixation and/or nonoperative treatment. Degree of fracture displacement had to be noted in the ''Materials and methods'' section for studies to be enrolled for further analysis. Studies in English, Dutch, German or French were assessed for inclusion. Case reports, biomechanical studies, papers describing a surgical technique and reviews were excluded from the database. Studies reporting on complications of the operative treatment of clavicle malunions, nonunions, open fractures, multiple fractures to the shoulder girdle, pathologic fractures, additional morbidity (i.e. floating shoulder) or fractures that had initial nonoperative treatment as starting point were also excluded.

Selection of studies

After the initial search strategy was performed, the remaining studies were screened for inclusion criteria based on their title/abstract by two researchers (FJGW, OAJvdM). Studies eligible for inclusion were additionally read completely for final inclusion. Finally, (prospective) trials without any notice of ethics committee consultation or approval were excluded from further assessment. Disagreement between the reviewers was resolved by discussion with another independent reviewer (RMH).

Quality assessment

Two quality assessment tools were used to assess the methodological quality of the final selection of studies. Assessment was performed without masking the source or authorship of trial reports. The two tools used were the level of evidence (LoE) rating according to the Oxford Centre of Evidence Based Medicine (http://www.cebm.net) and the modified version of the Cochrane Bone, Joint and Muscle Trauma Group's

former quality assessment tool (QAT, http://www.cochrane-handbook.com). Studies were first labelled according to their LoE (Level I: high evidence, Level II: moderate evidence, Level III: low evidence, Level IV: very low evidence). Secondly, the QAT was used to assess the research quality into more detail. The QAT is a tool that scores an article on 11 items: 7 items on internal validity and 4 items on external validity. Disagreement between the reviewers about the quality assessment was again resolved by discussion with another independent reviewer (RM).

Data extraction and analysis

Included studies were ranked according to their levels of evidence. The study characteristics, including design, type and positions of plate used for fixation and follow-up time were also taken into account.

Complications following the plate fixation of DMCF were identified and broken down into the following categories, if possible; bone-healing problems (nonunion and symptomatic malunion), infection (deep or wound), implant related problems (breakage, mechanical failure, irritation, angulation), plate debridement, removal or revision, neurovascular problems (transient or persistent brachial plexus symptoms, regional pain syndrome), refracture after plate removal and other complications. These categories were further subcategorized into two groups; major and minor complications. Major complications are characterized as a complication that needs another surgery to either remove or revise the plate as a result of the complication presented. Major complications are: nonunions, symptomatic malunion, deep infections, mechanical failure, irritation, breakage of the implant, angulation and refracture after plate removal. Minor complications are characterized as a complication that does not need another surgery and where a small intervention (i.e. oral antibiotics) may suffice. Minor complications are: wound infection and neurovascular problems. To avoid misinterpretation, the definitions of various complications stated in the reviewed studies were used in our analysis as much as possible.

Results

A total of 196 articles were identified, of which 27 were potentially relevant after screening the title and abstract and excluding doubles (Fig. 1). Full text screening resulted in 11 studies eligible for final quality assessment. There was no disagreement between the reviewers about the selection of the 11 final articles.

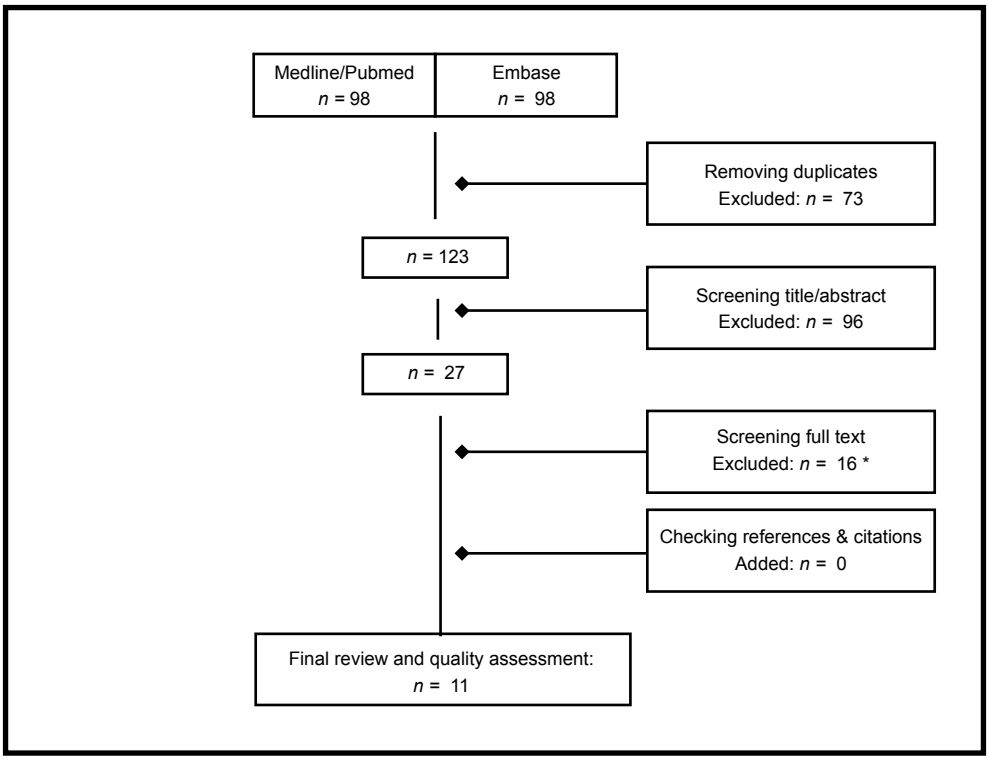

Figure 1. Flowchart demonstrating the article search and appraisal process. Search was conducted on April 6th 2011. *Asterisk* excluded were one case report [29] and two studies in which there was no clear distinction made between postoperative complications after acute fractures and nonunions [9, 14]. Seven studies included complicated fractures and made no distinction with uncomplicated fractures when describing complications [3, 8, 15, 18 - 20, 32]. One study was a surgical technique paper [2], one study only reported outcomes and no complications [28], two studies had no clear definition of indication for surgery [1, 38] and finally, two studies included different kinds of clavicle fractures (pathological, distal and nonunions) [11, 26].

Level of evidence

Three studies were designed as randomized controlled trials and marked with the highest LoE (Table 1) [5, 10, 33]. All three studies report considerable wound infection rates (5–22%) [5, 10, 33]. In addition, Shen et al. [33] report high nonunion rates of 13% in comparison to Ferran et al. [10] and the COTS [5], 0 and 3%, respectively. They [5, 10], on the other hand, report significant rates of implant-related problems requiring plate debridement, removal or even revision fixation, 10 and 53%.

One study was graded LoE II, being designed as prospective cohort study [16] and reported complications were mainly implant related (Table 2). A total of four studies were designed as retrospective cohort studies and therefore labelled as LoE III [7, 21, 35, 36]. Again the main complications reported in these four studies were implant-related problems (Table 3). Finally, three studies were assigned to LoE IV, all of them being retrospective case series [4, 31, 37]. The majority of complications again concerned the used implants (Table 4).

A total of 10 of the 11 assessed studies reported the usage of superior position for plate fixation [4, 5, 7, 10, 16, 21, 31 33, 35, 36]. Anterior or anterior inferior plate positioning was analysed in three studies [4, 16, 37]. The reconstruction plate and the low-contact dynamic compression plate (LCDCP) were the two most commonly used types for plate fixation.

Quality assessment

The majority of studies had well-defined in- and exclusion criteria, interventions and outcome measures. Adequate duration of follow-up was considered a minimum of 1 year which applied to most studies (Table 5). The study by the Canadian Orthopaedic Trauma Society [5] was graded the strongest of selected studies and of highest scientific quality.

Table 1. Studies graded level of evidence I according to the Oxford Centre of Evidence Based Medicine (http://www.cebm.net))

	COTS [5]	Ferran et al. [10]	Shen et al. [33]
Study characteristics			
Design	RCT: plating versus nonoperative treatment	RCT: plating versus pin fixation	RCT: 'normal' plating versus 3D-aided plating
Number of plate fixations	*n* = 62	*n* = 15	*n* = 133
Type of plate (times used)	LCDCP (44), reconstruction plate (15), precontoured plate (4), other (4)	LCDCP (15)	Reconstruction plate, 'Normal' plating (66), 3D-aided plating (67)
Plate positioning	Superior	Superior	Superior
Mean time to follow-up in months (range)	12	12 (5-28)	12
Complication rate			
Bone-healing problem			
Nonunion	2 (3%)	0 (0%)	8 (12%) versus 1 (1%)
(Symptomatic) Malunion	0	n/a	
Infection			
Wound	3 (5%)	3 (20%)	12 (19%) versus 2 (3%)
Deep	n/a	n/a	n/a
Implant breakage/failure/irritation			
Irritation	6 (10%)	3 (20%)	n/a
Mechanical failure	n/a	n/a	n/a
Plate debridement/removal/revision	6 (10%)	8* (53%)	n/a
Neurovascular problems			
Brachial plexus symptoms	8 (13%)	1 (7%)	n/a
Regional pain syndrome	0	1 (7%)	n/a
Refracture after plate removal	0	n/a	n/a
Other	4 (6%)	n/a	0

***RCT* randomized controlled trial, *LCDCP* limited contact dynamic compression plate, *3D* 3-dimensional, *n/a* not applicable (complication not mentioned in study)**

*** One plate was removed because the patient was a high level athlete**

Table 2. Studies graded level of evidence I according to the Oxford Centre of Evidence Based Medicine (http://www.cebm.net))

	Kuhlshrestha et al. [16]
Study characteristics	
Design	RCT: plating versus nonoperative treatment
Number of plate fixations	*n* =45
Type of plate (times used)	Reconstruction plate (45)
Plate positioning	Superior (15), anterior inferior (30)
Mean time to follow-up in months (range)	12
Complication rate	
Bone-healing problem	
Nonunion	0
(Symptomatic) Malunion	2 (4%)
Infection	
Wound	n/a
Deep	n/a
Implant breakage/failure/irritation	
Irritation	4 (9%)
Mechanical failure	n/a
Plate debridement/removal/revision	4 (9%)
Neurovascular problems	
Brachial plexus symptoms	n/a
Regional pain syndrome	n/a
Refracture after plate removal	0
Other	4 (9%)

***n/a* not applicable (complication not mentioned in study)**

Table 3. Studies graded level of evidence III according to the Oxford Centre of Evidence Based Medicine (http://www.cebm.net))

	Vanbeek et al. [36]	Cho et al. [7]	Liu et al. [21]	Thyagarajan et al. [35]
Study characteristics				
Design	Retrospective cohort study: noncontoured plating versus contoured plating	Retrospective cohort study: reconstruction plating versus reconstruction locking plating	Retrospective cohort study: plating versus pin fixation	Retrospective cohort study: plating versus pin fixation versus nonoperative treatment
Number of plate fixations	*n* = 42	*n* = 41	*n* = 59	*n* = 16
Type of plate (times used)	Noncontoured (14), DCP (4), LCP (2), LCDCP (4), reconstruction plate (4), precontoured (28), locking clavicle plate (28)	Precontoured: reconstruction plate (19), reconstruction LCP (22)	Reconstruction LCP (59)	LCDCP (16)
Plate positioning	Superior	Superior	Superior	Superior
Mean time to follow-up in months (range)	12	13 (7-35) versus 12 (7-24)	12	6 (4-11)
Complication rate				
Bone-healing problem				
Nonunion	0 versus 1 (4%)	0	6 (10%)	1 (6%)
(Symptomatic) Malunion	n/a	0	2 (3%)	n/a
Infection				
Wound	0 versus 1 (4%)	0	6 (10%)	1 (6%)
Deep	n/a	0		1 (6%)
Implant breakage/failure/irritation				
Irritation	9 (64%)* versus 9 (32%)	0	12 (20%)	2 (13%)
Mechanical failure	n/a	0	4 (8%)	n/a
Plate debridement/removal/revision	3 (21%) versus 3 (11%)	n/a	14 (24%)	2 (13%)
Neurovascular problems				
Brachial plexus symptoms	n/a	n/a	n/a	4 (25%)
Regional pain syndrome	n/a	2 (11%) versus 1 (5%)	n/a	6 (38%)
Refracture after plate removal	0 versus 1 (4%)	0	n/a	n/a
Other	0 versus 2 (7%)	7 (39%) versus 5 (23%)	n/a	1 (6%)

***LCDCP* limited contact dynamic compression plate, *n/a* not applicable (complication not mentioned in study)**

*** Removed noncontoured plates included DCP (1), LCDCP (1) and reconstruction plate (1)**

Table 4. Studies graded level of evidence IV according to the Oxford Centre of Evidence Based Medicine (http://www.cebm.net))

	Russo et al. [31]	Verborgt et al. [37]	Bostman et al. [4]
Study characteristics			
Design	Retrospective case series	Retrospective case series	Retrospective case series
Number of plate fixations	*n* = 43	*n* = 39	*n* = 103
Type of plate (times used)	Mennen-plate	Precontoured: reconstruction plate (?), LCDCP (?)	DCP (57), Reconstruction plate (46)
Plate positioning	Superior	Anteroir	Anterior (57), Superior (46)
Mean time to follow-up in months (range)	12	3	23 (6-53)
Complication rate			
Bone-healing problem			
Nonunion	2 (5%)	2 (5%)	3 (3%)
(Symptomatic) Malunion	n/a	n/a	12 (12%)
Infection			
Wound	0	4 (10%)	3 (3%)
Deep	0	3 (8%)	5 (5%)
Implant breakage/failure/irritation			
Irritation	0	n/a	n/a
Mechanical failure	0	2 (5%)	16 (16%)
Plate debridement/removal/revision	13* (30%)	7 (18%)	14 (14%) + 54 (52%)**
Neurovascular problems			
Brachial plexus symptoms	10 (23%)	3 (8%)	2 (2%)
Regional pain syndrome	n/a	n/a	n/a
Refracture after plate removal	n/a	2 (5%)***	1 (1%)
Other	2 (5%)	n/a	n/a

***LCDCP* low contact dynamic compression plate, *DCP* dynamic compression plate, *n/a* not applicable (complication not mentioned in study)**

*** 11 patients requested removal of the plate for cosmetic reasons**
**** 54 patients underwent routine plate removal**
***** Refractures both after LCDCP plates**

Table 5. Quality assessment outcome of all analyzed studies according to the modified version of the Cochrane Bone, Joint and Muscle Trauma Group's former quality assessment tool (QAT, http://www.cochrane-handbook.com)

	Allocation concealment	Intention to treat analysis	Assessor blinding	Comparable baseline characteriscs	Participant blinding	Treatment provider blinding	Care program comparability
COTS et al. [29]	2	2	0	2	0	0	2
Kulshrestva et al. [32]	2	2	0	2	0	0	2
Ferran et al. [30]	2	2	0	2	0	0	2
Shen et al. [31]	2	2	2	2	2	0	0
Liu et al. [35]	0	0	0	2	0	0	2
Cho et al. [34]	0	0	0	1	0	0	2
Vanbeek et al. [33]	0	0	0	2	0	0	2
Russo et al. [37]	0	0	0	0	0	0	0
Bostman et al. [4]	0	0	0	0	0	0	0
Thyagaranjan et al. [36]	0	0	0	2	0	0	0
Verborgt et al. [38]	0	0	0	0	0	0	0

	Defined in- and exclusion criteria	Well-defined interventions	Well-defined outcome measures	Clinically useful diagnostic tests	Adequate duration of follow-up	QAT score
COTS et al. [29]	2	2	2	2	2	**18**
Kulshrestva et al. [32]	2	2	2	1	2	**17**
Ferran et al. [30]	2	2	2	1	2	**17**
Shen et al. [31]	1	2	0	0	2	**15**
Liu et al. [35]	2	2	2	2	2	**14**
Cho et al. [34]	1	2	2	2	1	**11**
Vanbeek et al. [33]	2	1	2	2	0	**11**
Russo et al. [37]	1	2	2	2	2	**9**
Bostman et al. [4]	2	2	2	1	1	**8**
Thyagaranjan et al. [36]	2	1	2	0	0	**7**
Verborgt et al. [38]	1	1	2	1	2	**7**

***QAT* quality assessment tool**

Bold values indicate that the higher the value, the better methodological quality and least chance of bias, with a maximum score of 24

Discussion

The goal of this systematic review was to document the (prevalence of) complications after plate fixation of DMCF. To obtain the best available evidence, relevant studies were scored on scientific methodology and the LoE they provide. We attempted to find an answer to the following questions; what is the incidence of minor and major complications after surgical plate fixation of acute DMCF? What is the value of reported complications in terms of the scientific level of evidence at which they are presented? What are the frequency and severity of the long-term consequences of major complications after plate fixation? And what conclusions may be drawn from these findings and how may it influence treatment of midshaft clavicle fractures? In response to our second question, we found that only three of the eligible studies provided the highest LoE [5, 10, 33]. Two of these studies included a sample size calculation [5, 10]. One study was a prospective cohort study but scored very well on quality assessment [16]. Based on their quality of methodology, we believe the studies by the COTS [5] and Kulshrestha et al. [16] to provide the best available evidence.

In search of an answer to our first question, we found nonunion rates were no higher than 10% in all analysed studies but one [4, 5, 7, 10, 16, 21, 31, 33, 35, 36]. If reported on infection rates, both wound and deep infections were also below 10% in all but two studies [4, 5, 7, 10, 21, 31, 33, 35, 36]. The vast majority of these infections were wound infections, reportedly treated successfully with oral antibiotics. Neurovascular complications included brachial plexus symptoms and regional pain syndromes and ranged in prevalence from 0 to 38%, all reportedly were transient [4, 5, 7, 10, 31, 35, 37]. Based on these figures, the incidence of minor complications (wound infections and neurovascular problems) is low.

Regardless of the LoE provided, the vast majority of complications seem to be implant related, with irritation or failure of the plate being consistently reported on in almost every study, on average ranging from 9 to 64% [5, 10, 16, 21, 33, 36]. This is a point of concern, considering that, even in the better designed studies, a second operation with plate debridement, removal or revision was required at best in one out of every ten patients treated, in some studies even up to one out of every two patients [4, 5, 10, 16, 21, 31, 35, 36]. There is a relatively small risk of refracture after plate removal, between 1 and 5% [4, 31, 36]. However, it must be noted that only three of the 11 analysed studies report on these numbers. In one study, two refractures after plate removal were reported [31]. This study compared LCDCP plates and reconstruction plates, and both refractures occurred after removal of

LCDCP plates. Another study had a refracture after removal of a precountoured plate; the Locked Clavicle Plate [33]. The last refracture was reported after removal of an eight-screw dynamic compression plate [4]. The numbers presented above provide us with an answer to our third question. We conclude, based on the figures of plate debridement, removal or revision that the incidence of major complications is high, ranging up to 64%. Major complications require another surgery, but this surgery does treat the condition and complication and no long-term consequences are expected portraying low severity.

In light of our last question, this review points out that implant-related problems occur frequently. It is possible that the positioning of the plate anteriorly can decrease the number of complications. However, only one study mentioned that they felt that plate position initially influenced the outcome and complications of their treatment [16]. Additionally, plate type and pre-contouring to the anatomic shape of the clavicle may also have an influence. However, the current numbers available are too small and study designs to different to make any assumptions.

Although not optimal with regards to methodological qualities, we included retrospective case series in our analysis. In some studies, the complications were well documented and the reported complication rates were too high to ignore. In particular in the studies by Russo et al. [31] and Bostman et al. [4], the authors gave detailed descriptions of encountered complications and the complication rates are high. There are some limitations to this review. Proceedings from annual meetings (conferences) were not included in this review. Only PUBMED, EMBASE and the Cochrane databases were used for search. Therefore, some valuable information might be lost. However, at proceedings mostly interim analyses are reported and these results might differ from the final results. PUBMED and EMBASE are the largest medical databases. We thoroughly screened the studies and submitted them to a quality assessment which results in an evidence-based conclusion to what extend complications can be attributed to plate fixation. Because of the different study designs and characteristics, data could not be pooled and the data were summarized separately per study. We used the definitions of complications set forth in the analysed studies to divide the complications into six main categories. However, different authors may have used different definitions for complications i.e. deep, superficial and wound infections. In the future, improvements can be made concerning definitions of complications. Actual complication rates might be higher than many authors report, based on distinctions made between minor and major complications and overlap in definitions (e.g. failure or infection may result in removal, debridement or revision).

Based on the overall low numbers of reported nonunion and symptomatic malunion, we conclude and answer our final question that plate fixation is a safe treatment option for DMCF. However, this review also points out that complications related to the implant material are frequent often requiring removal, revision or debridement of the plate. The quantity of high LoE studies to support this is limited. More prospective trials with well-defined complications as outcome measurements are needed to make more specific recommendations with regard to optimum plate position, the type of plate and possible postoperative complications regarding plate fixation for DMCF.

Appendix I

PUBMED/MEDLINE search string

(((((((((midshaft[Title/Abstract]) OR shaft[Title/Abstract]) OR shafts[Title/Abstract]) OR mid[Title/Abstract]) OR midclavicle[Title/Abstract]) OR middle[Title/Abstract]) OR mid-third[Title/Abstract]) OR diaphysis[Title/Abstract]) OR diaphyseal[Title/Abstract])

AND

(((((((clavicular[Title/Abstract]) OR clavicula[Title/ Abstract]) OR claviculae[Title/Abstract]) OR clavicle[Title/Abstract]) OR clavicles[Title/Abstract]) OR collarbone[Title/Abstract]) OR collarbones[Title/Abstract])

AND

(((((plating[Title/Abstract])OR plate[Title/Abstract]) OR plate-osteosynthesis[Title/Abstract]) OR plates[Title/ Abstract]) OR plate-fixation[Title/Abstract])

AND

(((fractures[Title/Abstract]) OR fracture[Title/Abstract]) OR fractured[Title/Abstract])

Embase search string

midshaft:ab,ti OR shaft:ab,ti OR shafts:ab,ti OR mid:ab,ti OR midclavicle:ab,ti OR middle:ab,ti OR third:ab,ti OR diaphysis:ab,ti OR diaphysial;ab,ti AND (clavicular:ab,ti OR clavicula:ab,ti OR claviculae:ab,ti OR clavicle:ab,ti OR clavicles:ab,ti OR collarbone:ab,ti OR collar- bones:ab,ti) AND (plating;ab,ti OR plate:ab,ti OR plate-osteosynthesis:ab,ti OR plates:ab,ti OR plate-fixation:ab,ti) AND (fractures:ab,ti OR fracture:ab,ti OR fractured:ab,ti) AND [embase]/lim

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Chapter 4

Systematic review of complications after intramedullary fixation for displaced midshaft clavicle fractures

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Abstract

Background

The number of displaced midshaft clavicle fractures treated surgically is increasing, and open reduction and intramedullary fixation is an emerging surgical treatment option. The study quality and scientific levels of published evidence in which possible complications of this treatment are presented vary greatly.

Methods

We performed systematic computer-based searches of EMBASE and PubMed/MEDLINE. Studies included for review reported complications after intramedullary fixation alone or in comparison to either treatment with plate fixation and/or nonoperative treatment. The Level of Evidence rating and Quality Assessment Tool were used to assess the methodological quality of the studies. Included studies were ranked according to their levels of evidence.

Results

Six articles were eligible for inclusion and final quality assessment; 3 studies were graded the highest level of evidence. Major complications like bone-healing problems and deep infections requiring implant removal were reported at a rate no higher than 7%. Reported rates for minor complications, such as wound infection and implant irritation that could be resolved without further surgery, were as high as 31%.

Conclusion

The noted rates for major complications requiring additional surgery were low, but implant-related problems that require additional surgery might present with high prevalence. Owing to routine implant removal, treatment with intramedullary fixation often requires an additional surgical procedure.

Introduction

Fractures of the clavicle account for 5% of all fractures, and 80% of these fractures are located in the middle third of this S-shaped bone [1–4]. The incidence of surgical treatment for completely displaced midshaft clavicle fractures (DMCF) is rising owing to poor results reported after nonoperative treatment for this specific subset of patients in recent years [5–10].

Intramedullary fixation has emerged as a promising alternative to traditional open reduction and internal plate fixation [11]. Advantages of this minimally invasive treatment option include maintaining the fracture hematoma and keeping the periosteum intact, which positively influences bone formation and improves cosmetics owing to the small incisions used [11, 12]. Different techniques and examples of intramedullary fixation devices have been reported and include the Hagie [9] Knowles [13] and Rockwood [14] pins and titanium elastic nails (TEN) [15].

A spectrum of possible postoperative complications, including pin migration, implant failure, deep and superficial infections, refractures and mal- or nonunions has been reported [11, 16] In the current literature, however, the scientific level of evidence for reported complications from intramedullary fixation of DMCF and the quality of the studies reporting them varies. The aim of this systematic review was to answer the following questions:

1. What is the incidence of major and minor complications associated with intramedullary fixation of acute displaced midshaft clavicle fractures?

2. What interventions are available for resolving major or minor complications?

3. What is the value of reported complications in terms of the scientific level of evidence and the quality at which they are presented?

Methods

Search strategy

A computer-based search for relevant studies was carried out on June 1, 2011, on EMBASE and PubMed/MEDLINE online databases. We consulted the Cochrane Handbook (www.cochrane-handbook.com) for an optimal search strategy. Using the first 2 phases of this strategy in combination with a subject-specific search, a study database was obtained. To ensure inclusion of all relevant studies, reference and citation tracking were performed.

Inclusion and exclusion criteria

Studies were included for quality assessment if they reported on acute, isolated, displaced midshaft clavicle fractures treated with intramedullary fixation. Comparative studies in which intramedullary fixation was compared with other treatment modalities were also eligible for inclusion.

Exclusion criteria were studies written in languages other than English, German, Dutch or French. Also, case reports, biomechanical studies, surgical technique studies, review papers and studies involving fewer than 10 patients were excluded. Studies reporting on intramedullary fixation as a treatment for open fractures, pathological fractures, multitrauma, floating shoulders, nonunions or malunions and without a clear distinction in complication rates between these and isolated DMCF were also excluded.

Selection of studies

After completion of the initial search strategy, 2 researchers (F.-J.G.W., O.A.J.v.d.M.) screened the titled and abstracts of potential studies against the inclusion criteria. Studies were then thoroughly read to assess them for final eligibility. Disagreement between the reviewers was resolved by discussion with another independent reviewer (R.M.H.).

Quality assessment

Quality assessment was performed by 2 researchers (F.-J.G.W., O.A.J.v.d.M.) on the final study selection without masking the source or authorship of trial reports. Studies were first labelled according to their level of evidence (Oxford Centre of Evidence Based Medicine, www.cebm.net). The level of evidence rating is divided into 4 levels: level I indicates high-evidence studies, level II moderate, level III low and level IV very low-evidence studies.

To further interpret methodological study quality, we used the modified version of the Cochrane Bone, Joint and Muscle Trauma Group's former quality assessment tool (QAT, www.cochrane-handbook.com). The QAT is a tool with 11 items (7 on internal validity and 4 on external validity) that can be used to score a study on methodological qualities. Scores can range from 0 to 24. Disagreement between the reviewers about the quality assessment was resolved by discussion with another independent reviewer (R.M.H.).

Data extraction and analysis

Studies were ranked according to their level of evidence. The study characteristics, including design, type of intramedullary fixation and follow-up time were also noted. Complications of intramedullary fixation were identified and categorized for each study. The categories included implant-related problems (medial/lateral protrusion, visible or palpable presence of the implant, migration/telescoping, displacement of intramedullary device with or without displacement of the fracture parts), infection (wound or deep), bone-healing problems (nonunion, delayed union and symptomatic malunion), mechanical failure (angulation or breaking of intramedullary device and corresponding irritation), refractures, nonroutine intramedullary device removal and other complications.

These categories were further subdivided into 2 groups: major and minor complications. Major complications were those requiring additional (nonroutine) surgery to either remove or revise intramedullary fixation devices as a result of the complication presented. Major complications included nonunions, symptomatic malunions, deep infections requiring implant removal, breakage of the implant, angulation of the implant with persistent symptoms requiring removal and refractures after device removal. Minor complications were those not requiring additional (non-routine) surgery but requiring nonoperative treatment to resolve (i.e., antibiotics in case of an infection). These included wound infections, deep infections not requiring implant removal or irrigation/debridement, irritation, migration and telescoping, angulation of the implant without persistent symptoms and neurovascular problems. Irritation, migration and telescoping of the intramedullary device can often be resolved by minimally invasive shortening of the device under local anesthesia [11]. Neurovascular problems have the tendency to be self-limiting over time [11, 17, 18]. To avoid misinterpretation, the definitions of various complications stated in the reviewed studies were used in our analysis as much as possible.

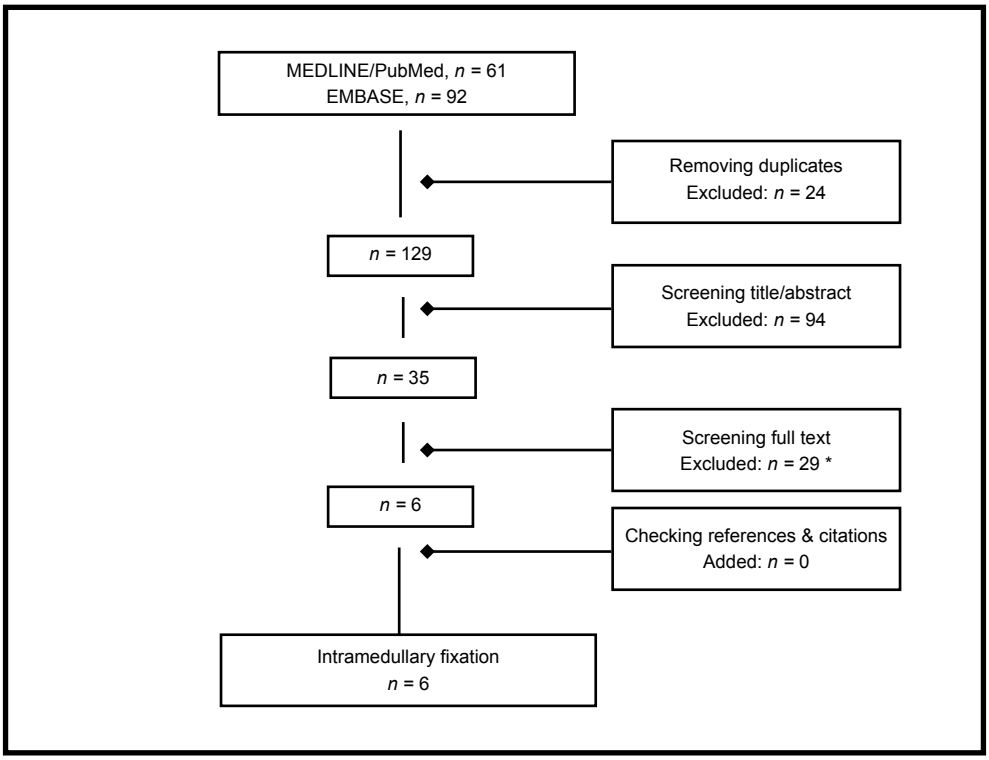

Figure 1. Literature search and final article selection.The search was conducted 7-1-2011. Excluded were 1 review paper [19] 4 studies in which there was no clear difference in postoperative complications made between closed and open clavicle fractures [13, 20–22] and 11 studies that included additional morbidity (e.g., floating shoulders or rib fractures) but in which the authors made no distinction between complications after isolated clavicle fractures and fractures with additional injury [14, 23–32]. In addition, 6 studies included treatment of nonunions or delayed unions and did not make a distinction with the treatment of acute fractures when describing the complications [16, 33–37] 2 studies were surgical technique papers [38, 39] 1 study reported on plate fixation [40] 1 study lacked a definition for dislocation [41] 1 study did not make a distinction between angulation and comminution [42] 1 study included fewer than 10 patients [15] and in 1 study [11] authors reported on a previously reported patient population [43].

Results

The search in PubMed/MEDLINE identified 61 articles; the search in EMBASE identified 92 articles. After checking for double entries, we excluded articles based on title and abstract content; 35 articles remained for full text screening. Finally 6 articles were eligible for inclusion and final quality assessment (Fig. 1). There was no disagreement between the reviewers about the selection of the 6 final articles.

Level of evidence

Three studies were assigned the highest level of evidence (Table 1) [18, 43, 44]. The rates of major complications like bone-healing problems and refractures were no higher than 7% in these 3 studies [18, 43, 44]. Judd and colleagues [18] reported 1 nonunion that required open reduction and plate fixation and 1 refracture after pin removal that was treated successfully with nonoperative treatment. Two studies reported a total of 3 delayed unions that all healed without further intervention [18, 43].

Regarding minor complications, Judd and colleagues [18] reported an implant-related irritation rate of 31% resulting in the early removal of 3 intramedullary devices owing to wound infections (10%), but the authors made no mention of further treatment for the remaining 21% of patients. Smekal and colleagues [43] reported a rate of 20% for device protrusion, which was treated with shortening of the intramedullary device under local anaesthesia.

The study by Witzel [45] was assigned level II evidence (Table 2). There were no major or minor complications reported in that series of 35 patients. One retrospective cohort study was assigned level III evidence (Table 3) [17]. This study reported 1 nonunion, 2 delayed unions and 4 malunions, but the authors did not describe treatment for these major complications. In addition, a 30% radiographic migration rate of the intramedullary fixation devices was reported in this study; most patients, however, remained asymptomatic and did not require any additional treatment [17].

Finally, 1 retrospective case series was assigned level IV evidence (Table 4) [46]. In this study, Chen and colleagues [46] reported a rate of 7% for malunions, which did not require additional surgery. Most of the complications encountered were minor and involved a 20% rate of irritation, which was treated by device shortening under local anaesthesia.

Table 1. Level I evidence studies

	Smekal et al. [43]	Ferrant et al. [46]	Judd et al. [18]
Design	RCT: intramedullary fixation v. nonoperative treatment	RCT: intramedullary fixation v. plate fixation	RCT: intramedullary fixation v. nonoperative treatment
Number of intramedullary fixations	60	17	29
Type of intramedullary fixation	Titanium endomedullary nail	Rockwood pin	Hagie pin
Mean time to follow-up in months (range)	24 (22-27)	12 (5-28)	3 (1-12)
Major complication rate			
Bone-healing problem			
Nonunion	0	0	1 (3)
Delayed union	2 (3)	0	1 (3)
(Symptomatic) malunion	0	0	n/a
Infection, deep	n/a	n/a	2 (7)
Implant breakage/failure/irritation, mechanical failure	2 (3)	1 (6)	1 (3)
Refracture after pin removal	1 (2)	n/a	2 (7)
Minor complication rate			
Implant breakage/failure/irritation			
Irritation	5 (5)	1 (6)	9 (31)
Migration/telescoping	7 (12)	n/a	n/a
(Medial/lateral) protrusion	12 (20)	n/a	n/a
Infection, wound	1 (2)	0	4 (14)
Routine nail removal	n/a	17 (100)	26 (90)
Nonroutine nail removal	0	0	3 (10)
Neurovascular problem			
Brachial plexus symptoms	0	2 (12)	1 (3)
Regional pain syndrome	0	0	n/a
Intramedullary fixation device shortening	12 (20)	n/a	n/a

***n/a* not applicable (complication not mentioned in study), *RCT* randomized controlled trial**

Finally, in 4 of the 6 included studies, all of the intramedullary devices were routinely removed according to the standard treatment guidelines in the authors' practices [17, 18, 44, 45].

Quality assessment

The randomized controlled trials by Smekal and colleagues [43] and Ferran and colleagues [44] both scored 18 out of the maximum 24 points on the quality assessment tool (Table 5).

Table 2. Level II evidence study

	Witzel et al. [45]
Design	RCT: intramedullary fixation v. nonoperative treatment
Number of intramedullary fixations	35
Type of intramedullary fixation	Prévot pin
Mean time to follow-up in months (range)	19 (8-26)
Major complication rate (%)	
Bone-healing problem	
Nonunion	0
Delayed union	0
(Symptomatic) malunion	0
Infection, deep	0
Implant breakage/failure/irritation, mechanical failure	0
Refracture after pin removal	0
Minor complication rate (%)	
Implant breakage/failure/irritation	
Irritation	0
Migration/telescoping	0
(Medial/lateral) protrusion	0
Infection, wound	0
Routine nail removal	n/a
Nonroutine nail removal	n/a
Neurovascular problem	
Brachial plexus symptoms	0
Regional pain syndrome	0
Intramedullary fixation device shortening	n/a

***n/a* not applicable (complication not mentioned in study), *RCT* randomized controlled trial**

Table 3. Level III evidence study

	Chen et al. [17]
Design	Retrospective case-control study: intramedullary fixation v. plate fixation
Number of intramedullary fixations	57
Type of intramedullary fixation	Titanium elastic nail
Mean time to follow-up in months (range)	24
Major complication rate (%)	
Bone-healing problem	
Nonunion	1 (2)
Delayed union	2 (3)
(Symptomatic) malunion	4 (7)
Infection, deep	n/a
Implant breakage/failure/irritation, mechanical failure	3 (5)
Refracture after pin removal	1 (2)
Minor complication rate (%)	
Implant breakage/failure/irritation	
Irritation	4 (7)
Migration/telescoping	17 (30)
(Medial/lateral) protrusion	n/a
Infection, wound	1 (2)
Routine nail removal	n/a
Nonroutine nail removal	n/a
Neurovascular problem	
Brachial plexus symptoms	1 (2)
Regional pain syndrome	0
Intramedullary fixation device shortening	n/a

***n/a* not applicable (complication not mentioned in study)**

Table 4. Level IV evidence study

	Chen et al. [46]
Design	Prospective case series: intramedullary fixation
Number of intramedullary fixations	41
Type of intramedullary fixation	Titanium elastic nail
Mean time to follow-up in months (range)	24 (7-24)
Major complication rate (%)	
Bone-healing problem	
Nonunion	n/a
Delayed union	n/a
(Symptomatic) malunion	3 (7)
Infection, deep	0
Implant breakage/failure/irritation, mechanical failure	0
Refracture after pin removal	0
Minor complication rate (%)	
Implant breakage/failure/irritation	
Irritation	8 (20)
Migration/telescoping	0
(Medial/lateral) protrusion	1 (2)
Infection, wound	0
Routine nail removal	41 (100)
Nonroutine nail removal	0
Neurovascular problem	
Brachial plexus symptoms	2 (5)
Regional pain syndrome	n/a
Intramedullary fixation device shortening	n/a

***n/a* not applicable (complication not mentioned in study)**

Table 5. Quality assessment tool

	Smekal et al. [43]	Ferran et al. [44]	Witzel et al. [45]	Judd et al. [18]	Chen et al. [17]	Chen et al. [46]
Measure						
Allocation concealment	2	2	2	2	0	0
Intention-to-treat analysis	2	2	0	0	0	0
Assessor blinding	0	0	0	0	0	0
Comparable baseline characteristics	2	2	2	2	2	2
Participant bliding	0	0	0	0	0	0
Treatment-provider blinding	0	0	0	0	0	0
Care program comparability	2	2	2	2	0	1
Defined inclusion and exclusion criteria	2	2	2	2	2	2
Well-defined interventions	2	2	2	2	2	0
Well-defined outcome measure	2	2	2	2	2	2
Clinically useful diagnostic tests	2	2	2	2	2	2
Adequate duration of follow-up	2	2	2	2	2	2
Score	18	18	16	16	12	11

Discussion

Our systematic review aimed at answering several questions regarding complications after intramedullary fixation of DMCF. What is the incidence of major and minor complications? What interventions are available for resolving major or minor complications? And, finally, what is the value of reported complications in terms of the scientific level of evidence and the quality at which they are presented?

Reported rates for major complications like bone healing problems and deep infections requiring implant removal were no higher than 7% [17, 18, 43–46]. In addition, only 4 refractures after pin removal were reported in a total of 3 studies [17, 18, 43]. Therefore, overall, the rate of major complications requiring additional surgical treatment was low. Most complications were implant failures, breakages, irritations or implant migrations. Reported rates of minor complications were as high as 31%.

Major complications require an additional surgery (e.g., corrective osteotomy). Minor complications are resolved with antibiotics for wound infections or shortening of the intramedullary device under local anaesthesia. Treatments for minor complications are non- or minimally invasive and therefore easy to resolve. Irritation is one of the main effects of migration, telescoping or protrusion. Three interventions seem to resolve most of these irritation related complications: shortening of the intramedullary device, removal of the device or revision osteosynthesis. Migrating, telescoping or protruding devices may remain asymptomatic without requiring additional treatment, yet most intramedullary fixation techniques require routine surgical device removal once fracture healing has occurred [18, 44–46]. The vast majority of patients require additional surgical interventions, although these interventions are minor. An option for reducing medial protrusion (and thus irritation) might be the use of medial end caps. Frigg and colleagues [47] reported a reduction in medial protrusion rates by using an End Cap for TEN.

The level of evidence and quality assessment tools were used to assess studies on methodological quality. Only 6 studies met our inclusion criteria, 3 of which provided the highest possible level of evidence. Therefore, studies on this specific subject with high-level evidence are scarce.

The optimal surgical technique to accomplish intramedullary fixation is anecdotally harder to master than more traditional surgical fixation techniques. Reported operative outcome may be influenced by learning curves of the

involved surgeons. Only 1 study included in our review mentioned the involved surgeon's experience with intramedullary fixation [45]. In addition, depending on the intramedullary device used, the degree of open fracture reduction varies. Theoretically, this may negatively affect infection rates due to increased exposure, cosmetic outcome due to an increase in incision length and fracture healing due to disruption of the periosteum and fracture hematoma. For instance, fixation with the Rockwood pin, requires open reduction [44], whereas TEN fixation reportedly allows for closed reduction in 60%–85% of cases. In addition, the type of intramedullary device may influence the rate of complications. Unfortunately, the current numbers available are too small and study designs too different to permit a thorough analysis.

Discussion of whether more complex fractures should then be treated with intramedullary fixation may arise. The included studies did not answer that question. However, other studies that did not meet our inclusion criteria indicated that intramedullary fixation might also be suitable for fixation of more complex fractures [11, 24, 32].

In 3 of the studies included in our review, the intramedullary devices were routinely removed upon fracture healing [18, 44, 46] Device removal requires additional surgery with corresponding risks and complications (e.g., infection or refracture). However, it should be noted that these additional surgical procedures only require small incisions and have short durations [17, 44].

Limitations

The study design carries the risk of certain limitations. Only the PubMed/MEDLINE and EMBASE databases were used for our search. Proceedings of annual meetings were not taken into the account; therefore, valuable information might have been lost. However, usually only preliminary results are presented at (annual) meetings and may differ from the final study results.

Owing to the different study designs and characteristics, data could not be pooled and were summarized separately per study. Available studies were only included if they reported on the treatment of isolated clavicle fractures. This strict inclusion criterion was chosen to avoid the possible influence of comorbidities on reported outcomes and complications. It has to be noted that studies reporting on a combination of clavicle fractures and lower extremity or rib pathology [35, 36] were accordingly excluded, although the impact of the mentioned comorbidities on the outcome of the clavicle fracture treatment may not be severe.

Several different complication groups were defined for analysis of the selected studies. However, there are differences in definitions of complications among the studies (e.g., deep, superficial and wound infections may have been present). Future studies would benefit from improvements in defining complications when determining outcome parameters. Furthermore, our review focused solely on the spectrum of complications of intramedullary fixation; therefore, no comparisons with complications after open reduction and internal plate fixation or nonoperative treatment were made.

Finally, the applicability of the quality assessment tools used should be addressed. With regards to the levels of evidence, a “high” level of evidence referred to the manner in which different treatment options were compared, but not necessarily to the way in which data were collected. In general, prospectively collected data are more reliable than retrospective data. However, when drawing conclusions on the incidence and consequences of adverse events of a single therapeutic intervention, data can be extracted from both case series and comparative studies. It is uncertain that the level of evidence of data from comparative studies is greater than that of data from prospective case series. Therefore, the quality assessment tool was added and used to strengthen the quality assessment of different studies included in our review.

Conclusion

Reported rates of major complications requiring additional surgery (e.g., corrective osteotomy) after intramedullary fixation were low, but implant-related problems that also required additional surgery might present with high prevalence. Owing to (routine) implant removal, treatment with intramedullary fixation often requires an additional surgical procedure.

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Chapter 5

Complications after plate fixation and elastic stable intramedullary nailing of dislocated midshaft clavicle fractures: a retrospective comparison

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Abstract

Purpose

The incidence of operative treatment of dislocated midshaft clavicle fractures (DMCF) is rising due to unsatisfactory results after nonoperative treatment. Knowledge of complications is important for selection of the surgical technique and preoperative patient counselling. The aim of this study is to compare complications after plate fixation and elastic stable intramedullary nailing (ESIN) with a titanium elastic nail (TEN) for DMCF.

Methods

A retrospective analysis of our surgical database was performed. From January 2005 to January 2010, 90 patients with DMCF were treated with plate fixation or ESIN. Complications were evaluated in both treatment groups and subsequently compared.

Results

Seven implant failures occurred in six patients (14%) of the plate group and one implant failure (2%) was seen in the ESIN group (p=0.051). Major revision surgery was performed in five cases in the plate group (11%) and in one case (2%) in the ESIN group (p=0.100). Three refractures (7%) were observed in the plate group after removal of the implant against none in the ESIN group (p=0.105). Six minor revisions (13%) were reported in the ESIN group and none were reported in the plate group (p=0.027).

Conclusions

Compared to other studies we report higher rates of refracture (7%), major revision surgery (11%) and implant failure (14%) after plate fixation. The frequency of implant failures differed almost significantly for patients treated with plate fixation compared to ESIN. Furthermore, a tendency towards refracture after implant removal and major revision surgery after plate fixation was observed.

Introduction

Clavicle fractures occur commonly; between 2.6 and 10% of all fractures are clavicle fractures [1]. Operative treatment for dislocated midshaft clavicle fractures (DMCF) is increasing due to reported unsatisfactory results after nonoperative treatment [2–4]. Two recently published randomized trials have proven the superiority of both plate fixation and elastic stable intramedullary nailing (ESIN) over nonoperative treatment for DMCF in terms of functional outcome and pain relief [5, 6].

The two most commonly used techniques for operative treatment of DMCF are plate fixation and ESIN [7]. Plate fixation results in a biomechanically stable construction allowing early mobilization and providing for fracture compression. Long-term outcome and experience with this procedure have been well documented [8]. Complications associated with plate fixation are refracture of the clavicle after implant removal and wound infection [9, 10].

ESIN is a relatively new and technically more demanding technique [7]. If closed fracture reduction is possible, ESIN has the advantage of maintaining an intact fracture hematoma, which could speed up fracture healing. If open fracture reduction is necessary, surgical incisions are in general smaller in comparison to plate fixation resulting in improved cosmetic results. In addition, smaller incisions may result in lower infection rates [6, 11]. Possible disadvantages of ESIN are medial nail protrusion and the need for implant removal requiring a second operation [11, 12].

Knowledge of possible complications is essential on the appropriate surgical technique and preoperative patient counselling. A recent Cochrane review showed that comparative studies of different techniques for operative treatment of DMCF are lacking [13]. The aim of this study is to retrospectively compare complications after plate fixation and ESIN with a titanium elastic nail (TEN) for DMCF.

Materials and methods

A retrospective analysis of data from the surgical database at our hospital was performed. The Diakonessenhuis is a level 2 trauma centre and a regional teaching hospital. All monotrauma patients who underwent operative treatment for a DMCF between January 2005 and July 2010 were eligible for inclusion. This inclusion period allowed for another year of follow-up postoperatively. Dislocation was defined as at least one shaft width difference in height between the fracture parts, regardless of the reduction.

The following exclusion criteria were used: (1) patients with pre-existent morbidity concerning the arm, shoulder or hand, (2) open fractures, (3) pathological fractures, (4) presence of neurovascular injury and (5) fractures older than one month or nonunions.

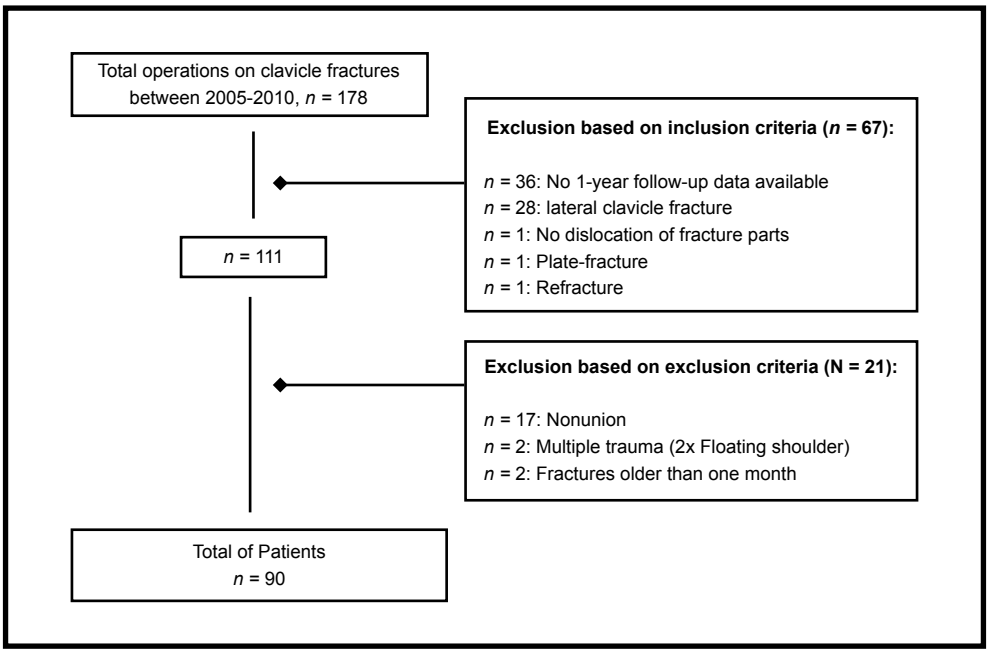

Figure 1. Flowchart: selection of patient group

Operative treatment

The operations were performed or supervised by one of the trauma surgeons (DL, KO, GJC, EV). The choice of the procedure was based on either the surgeon's or patient's preference.

Operative technique: plate fixation

Patients were treated according to the principles set by the AO Foundation. Patients were administered prophylactic antibiotics. A compression plate with additional interfragmentary lag screws or a bridging plate in cases of severe comminution were used for different kinds of fracture types. A transverse incision was made over the fracture site and in all cases the plate was positioned on the anterior superior surface of the clavicle. Different types of plates were used, which were provided by Synthes® (Zeist, Netherlands). In the beginning of the study period reconstruction plates with the corresponding screws were used, later on small fragment locking plates with the corresponding screws became available and for the remaining time of the study these plates and screws were used.

Operative procedure ESIN

Patients were administered prophylactic antibiotics. A small skin incision was made approximately 1 cm lateral to the sternoclavicular joint. For ESIN a Synthes® TEN was used. A TEN was inserted with a diameter varying from 2 to 3.5 mm, depending on the width of the bone. Closed reduction, initially fixed with two percutaneously pointed reduction (Weber) clamps, was performed and confirmed by fluoroscopy. If closed reduction failed, an additional small incision was made above the fracture site for direct manipulation of the main fragments. After complete introduction of the TEN into the lateral fragment, the fracture was compressed and the TEN was cut as short as possible at the medial end.

Postoperative management

The choice of postoperative management was based on the surgeon's preference, but patients generally received a sling while being encouraged to start early mobilization if pain permitted.

The complications were divided into two groups: major and minor complications.

Major complications

The following complications were regarded as major (Table 1): nonunion, symptomatic malunion, refracture after implant removal, deep infections or breakage of the implant.

Nonunion was defined as an unsuccessful healing of the bone after six months that clinically could be associated with pain and was visible on the radiograph as a gap between the fracture parts. Symptomatic malunion was defined

as an incorrect anatomical position of the clavicle in comparison to the (healthy) side resulting in pain symptoms or a loss of function of the shoulder. Implant-related problems such as breakage were determined on the radiographs. Deep infection was defined as infection requiring implant removal. Refracture was defined as a fracture of the clavicle after implant removal and diagnosis was based on clinical symptoms and radiographs.

Minor complications

The following complications were considered as minor (Table 1): (oral) antibiotics for a wound infection or cutting the protruding end of the TEN under a local anaesthetic in case of medial irritation or skin perforation. Other minor complications were deep infections not requiring implant removal or debridement, migration and telescoping (for ESIN), angulation of the implant without persistent symptoms and neurovascular problems.

Infection was defined as redness, swelling, purulent discharge, a positive wound culture and/or when prescription of antibiotics was given. Irritation (of the skin) was assessed clinically and caused by prominence of the implant material or in case of the TEN medial or lateral protrusion. Migration was defined as the medial or lateral displacement of the TEN without movement of the fracture parts also resulting in medial or lateral protrusion. Telescoping was defined as displacement of the fracture parts and the TEN. Pain was considered significant if it was still present after six months.

Table 1. Major and minor complications

Major complications	Minor complications
Nonunion	Superficial infection
(Symptomatic) malunion	Pain after 6 months
Implant fracture (breakout)	Temporary brachial plexus lesion
Major revision surgery	Hyperaesthesia
Deep infection	Plate irritation
Refracture after implant removal	Medial TEN protrusion
	Lateral TEN protrusion
	Minor revision surgery (shortening of TEN)

Table 2. Baseline characteristics, follow-up duration and time to removal for both treatment groups

		Plate group *n* = 43	ESIN group *n* = 47	*p*-value
Age, years (mean ± SD)		39,4 ± 14,1	33,1 ± 15,6	*p = 0,049*
Gender, *n* (%)	Male	33 (77)	33 (70)	*p* = 0,48
	Female	10 (23)	14 (30)	
Fracture side, *n* (%)	Right	20 (47)	19 (40)	*p* = 0,56
	Left	23 (54)	28 (60)	
AO Classification, *n* (%)	A1	-	-	*p* = 0,11
	A2	11 (26)	22 (47)	
	A3	8 (19)	7 (15)	
	B1	1 (2)	0	
	B2	17 (4)	14 (30)	
	B3	2 (5)	4 (9)	
	C1	1 (2)	0	
	C2	3 (7)	0	
	C3	-	-	
Trauma mechanism, *n* (%)	Traffic accident	9 (21)	12 (26)	*p* = 0,81
	Sports	18 (42)	18 (38)	
	Fall	13 (30)	12 (26)	
	Unknown*	3 (7)	5 (11)	
Neurovascular injury, *n* (%)		0	2 (4)	*p* = 0,23
	Unknown*	3 (7)	9 (19)	
Imment skin perforation, *n* (%)		1 (2)	2 (4)	*p* = 0,61
	Unknown	3 (7)	9 (19)	
Follow-up time, months (median, IQR)		8 (2-13)	6 (5-12)	*p* = 0,76
Time to removal, months (median, IQR)		11 (7-15)	5 (4-6)	*p < 0,001*

***TEN* titanium elastic nail, *SD* standard deviation, *AO classification* Muller AO classification for fractures-long bones, *ESIN* elastic stable intramedullary nailing**

*** Was not reported in documentation**

When treated with ESIN the TEN was always removed after four months and/or if consolidation was achieved. Plate fixation was only considered for removal after consolidation and if patients experienced irritation or nuisance caused by the implant, or by explicit request of the patient. Consolidation and appropriate time of removal were determined by the treating surgeon by examining radiographs and the clinical condition of the patient.

Statistical analysis

Descriptives were reported as mean and standard deviation (SD) or as median and interquartile range (IQR), depending on normal or non-normal distributions of the data, respectively. An independent samples *t* test was performed to assess differences in age between groups; the Mann–Whitney U test was performed in case of total follow-up duration; the chi-square test was used in

case of gender, fracture side, trauma mechanism and ≥1 irritation(s); and Fisher's exact test was used in case of AO Classification, neurovascular injury, imminent skin perforation, ≥1 implant failure(s), major surgical revision, refractures, superficial infection and minor revision surgery. Kaplan-Meier survival analysis was performed to assess differences in time to removal of TEN or plate fixation, with non-removal considered as censored observation. The level of significance was set at $p<0.05$. Statistical analyses were performed using SPSS software (version 17.0.0, Chicago, IL, USA).

Approval

In accordance with the legal department of the Diakonessenhuis Utrecht and the local Ethics Commission, individual patient approval was not required due to full anonymity of the included patients and the retrospective study design.

Table 3. Major and minor complications in both treatment groups

	Plate group *n* = 43	ESIN group *n* = 47	*p*-value
Major complications			
At least 1 implant failure*, *n* (%)	6 (14)	1 (2)	*p* = 0,051
Major revision surgery, *n* (%)	5 (12)	1 (2)	*p* = 0,100
Refracture after implant removal, *n* (%)	3 (7)	0	*p* = 0,105
Minor complications			
Superficial infection, *n* (%)	1 (2)	4 (9)	*p* = 0,363
At least one irritation, *n* (%)	19** (44)	29** (62)	*p* = 0,096
Pain after 6 months, *n* (%)	4 (9)	2 (4)	
Temporary brachial plexus lesion, *n* (%)	0	2 (4)	
Hyperaesthesia, *n* (%)	3 (7)	0	
Plate irritation, *n* (%)	17 (40)		
Medial TEN protrusion, *n* (%)		23 (49)	
Lateral TEN protrusion, *n* (%)		3 (6)	
Minor revision surgery (shortening of TEN), *n* (%)	0	6 (13)	*p = 0,027*

Results

According to the inclusion and exclusion criteria 90 patients could be included in the analysis (Fig. 1); 43 patients were treated by plate fixation and 47 patients were treated using ESIN. On average, patients in the plate group were 39.4 (SD 14.1) years of age and older (p=0.049) than patients in the ESIN group, who were 33.1 (SD 15.6) years of age (Table 2). In the ESIN group closed fracture reduction was performed in seven cases (15%), and open fracture reduction was performed in the remaining 40 patients (85%). The median follow-up time of all patients was seven months (IQR 4–13 months). The plate group had a median follow-up time of eight months (IQR 2–13 months). A median follow-up time of six months (IQR five to 12 months) was observed in the ESIN group.

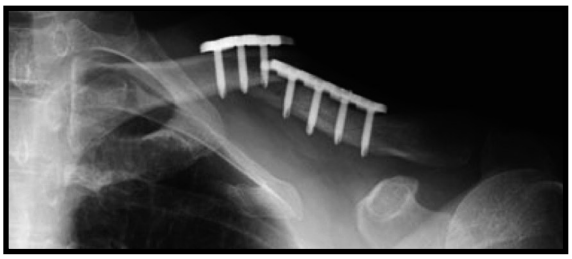

Figure 2. **Example of a broken 3.5-mm reconstruction plate**

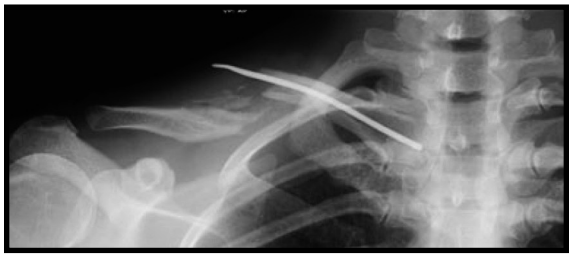

Figure 3. **Example of implant failure of a TEN**

Major complications

Implant failure

Seven implant failures occurred in six patients (14%) of the plate group. One implant failure was seen in the ESIN group (2%) (p=0.051, Table 3). All implant fractures occurred within three months of the primary surgical procedure (Fig. 2).

Three of these broken plates were revised with plate fixation and supplementary cancellous bone graft. The remaining four implant failures in the plate group were treated conservatively in all cases after removal of the implant. One of these patients recovered with a slightly impaired shoulder function, and the other patients all healed uneventfully. The implant failure in the ESIN group (Fig. 3) was revised using plate fixation and supplementary bone graft and healed uneventfully.

Major revision surgery

Major revision surgery was performed in five cases in the plate group (12%), and one major revision surgery was performed in the ESIN group (2%) (p=0.100, Table 3). Three revision operations were performed in the plate group as mentioned above due to implant failure (see *Implant failure*). One major revision operation in the plate group was the treatment of a refracture after removal of the implant (see *Refractures*). The last major revision operation was performed due to a complicated removal of the implant, requiring the use of a carbide drill in an additional operation. The major revision surgery in the ESIN group was due to implant failure and revised with plate fixation and spongiosa transplantation (see *Implant failure*).

Refractures

Three refractures (7%) were observed in the plate group after removal of the implant against none in the ESIN group (p=0.105, Table 3). All refractures occurred within 2 months after removal of the implant. Two refractures were treated conservatively and one refracture was treated with plate fixation (see *Major revision surgery*); all three healed uneventfully.

Other major complications

No other major complications such as bone healing problems or deep infections occurred.

Minor complications

Six minor revisions (13%) were reported in the ESIN group and none were reported in the plate group (p=0.027, Table 3). The definition of minor revisions is cutting the protruding medial end of the TEN under a local anaesthetic. These procedures were performed as a result of irritation of the implant (three patients) and medial skin perforation (three patients). One of the patients with medial skin perforation was also diagnosed with superficial wound infection, which was treated with oral antibiotics and healed uneventfully.

Removal

In the ESIN group 45 TEN of the total 47 TEN were removed. In the plate group 27 patients (total of 43 patients) underwent removal of the implant material. The median time until removal in all 72 patients was six months (IQR 4–11). In the ESIN group the implants were removed at a median of five months (IQR 4–6). Plates were removed at a median of 11 months (IQR 7–15) ($p<0.001$, Table 2).

Discussion

Implant failure just fell short of being significantly more frequently observed after plate fixation (p=0.051). Similarly, refracture after implant removal and major revision surgery just tended to prevail more often after plate fixation. Moreover, 80% of the revision procedures were due to implant failure. Minor revision surgery on the other hand was more frequently observed after ESIN (p=0.027).

Compared to other studies we report higher rates of refracture (7%), major revision surgery (12%) and implant failure (14%) after plate fixation. Ferran et al. reported no implant failures [14]. The Canadian Orthopaedic Trauma Society reported one (2%) case of early mechanical failure, Chen et al. reported 7% implant failure and Liu et al. reported an implant failure rate of 9% [5, 15, 16]. Our results are comparable with the results of Böstman et al., who reported an implant failure rate of 15% [17]. Implant removal after plate fixation resulted in refracture in 1–5% [10, 17–19].

Similar results have been found in the literature regarding minor complications in plate fixation [20], and the incidences of major and minor complications after ESIN seem to comply with estimates from literature elsewhere [21].

Theoretically, complications after plate fixation differ from complications after intramedullary fixation. Plate fixation provides a rigid fixation, originally intended to achieve primary bone healing. Fracture healing occurs without much periosteal ossification, and after fracture healing the plate might still contribute to the mechanical strength of the fixation. Therefore, implant removal might reduce mechanical strength which could explain the slightly increased refracture rates. Another explanation for the tendency of slightly more refractures might be the screw holes after implant removal. These weak spots could potentially initiate a refracture in small clavicles.

Fixation using an intramedullary device results in secondary bone healing. Secondary bone healing is achieved through periosteal ossification, and after fracture healing the intramedullary device does not continue to contribute to the mechanical strength of the fixation. Therefore, intramedullary fixation might show less refractures after removal of the implant.

Implant failures can also be explained by this mechanism. An intramedullary device moves along with the slight movements of the bone and will restore it to its original form. Plate fixation is rigid and does not move. When

excessive movement occurs, the plate might bend or break.

The main problem after ESIN is medial protrusion causing irritation or skin perforation resulting in minor revision surgery. In the literature, medial protrusion is reported in the range of 5–39% [6, 15, 22, 23]. This minor complication can be prevented by anatomical reduction and fixation of the fracture to prevent telescoping. Early abduction of the arm should also be considered as a cause of medial protrusion of the TEN. Patients should be advised not to abduct the arm over 90° in the first two weeks postoperatively. Another option of reducing medial protrusion is the use of medial end caps. Frigg et al. showed a reduction in medial protrusion rates by using an end cap for TEN [23].

For plate fixation a larger incision is made, which results in a higher risk of infection and probably less cosmetic satisfaction. In this study no significant differences in infection rates between the two groups were observed.

This study is limited by its retrospective design, resulting for instance in an older patient group receiving plate fixation. The impact of the plate fixation group being older could not be assessed in this relatively small patient group. Further, shoulder function and cosmetic appearance were not adequately documented. Therefore, results after both procedures regarding shoulder function and cosmetic appearance could not be compared. However, according to comparative studies on this subject, no significant differences in shoulder function and cosmetic appearance have yet been reported between both techniques [16, 17, 24].

During the study period, different types of plate fixation were used according to fracture type or surgeon's preference. This might limit the general application of the complications in the plate group. The reason for using different plates was the availability of the types of plates. At the start of this study period reconstruction plates were used, and later the small fragment locking plates became available and were used. However, the main goal of this study was to compare complications after two principles of osteosynthesis for DMCF: plate fixation and intramedullary fixation with ESIN.

Moreover, the retrospective study design may have hampered a complete record of complications that may have occurred during follow-up, but were treated and followed up elsewhere, at another hospital. Due to the surgeon's preference of treatment method and the retrospective design we also encountered a difference in treatment policy for different types of fractures. Simple fractures (i.e. A2 or B2, Table 2) had a greater possibility of being treated with ESIN than complex fractures.

Currently a randomized controlled study is being performed at the Diakonessenhuis Utrecht comparing plate fixation and intramedullary fixation in DMCF (POP-study [25]). The goal of this study is to provide a better insight into results and the complications after both treatments [26]. In this study the frequency of implant failures differed almost significantly for patients treated with plate fixation compared to ESIN. Furthermore, a tendency towards refracture after implant removal and major revision surgery after plate fixation was observed.

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Chapter 6

Rationale and design of the plate or pin (POP) study for dislocated midshaft clavicle fractures: study protocol for a randomized controlled trial

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2011: 15:12:177

Abstract

Background

To describe the rationale and design of a future study comparing results of plate fixation and Elastic Stable Intramedullary Nailing (ESIN) with a Titanium Elastic Nail (TEN) for adults with a dislocated midshaft clavicle fracture.

Methods/Design

Prospective randomized multicentre clinical trial in two level 1 and one level 2 trauma centres. 120 patients between 18 and 65 years of age will be included. They are randomized to either plate fixation or ESIN with a TEN with a one year follow-up. Sixty patients will be treated with plate fixation and 60 patients will be treated with ESIN. Primary outcome parameter is the Disabilities of the Arm, Shoulder and Hand score after 6 months. Secondary outcome parameters are Constant Shoulder Score, complications, experienced pain, radiologic consolidation and cosmetics after both procedures.

Discussion

Prospective randomized studies comparing operative techniques for treatment of dislocated midshaft clavicle fracture are lacking. By studying shoulder function, complications, quality of life, radiographic union, cosmetics as well as experienced pain, a complete efficacy assessment of both procedures will be performed.

Trial registration

The POP study is registered in the Dutch Trial Register (NTR2438).

Background

Clavicle fractures in adults occur commonly and account for approximately 5% of all fractures. Around 80% of the clavicle fractures involve the midshaft and over half of these fractures are dislocated [1,2]. Historically, clavicle fractures were treated conservatively, mostly with sling or figure-of-eight bandage [3,4]. Consolidation was achieved within a few weeks, even with severe dislocation.

Recently, poor results were described of conservatively treated dislocated midshaft clavicle fractures (DMCF) [5-10]. The number of nonunions after conservative treatment appeared to be much higher than previously assumed [5]. Furthermore, the clinical importance of clavicle malunion was discovered with symptoms like persistent pain, permanent loss of strength, rapid fatigability of the shoulder joint and disappointing cosmetic results [6-8]. Altogether these symptoms result in decreased patient satisfaction scores after conservatively treated DMCF [9,10].

Two commonly used operative techniques for treatment of DMCF are plate fixation and Elastic Stable Intramedullary Nailing (ESIN) [11]. In recently reported prospective randomized studies, functional results after both techniques proved to be superior compared to conservative treatment of DMCF [12,13]. Furthermore, a recent meta-analysis demonstrated a significantly lower nonunion rate after surgical treatment in general [8].

Prospective randomized studies comparing operative techniques for treatment of DMCF are lacking [14]. The aim of this article is to describe the rationale and design of a prospective randomized study comparing results of plate fixation and ESIN with a Titanium Elastic Nail (TEN).

Methods and Design

Study design

Prospective randomized multicentre study involving three hospitals in The Netherlands, including Diakonessenhuis, Utrecht (level 2 traumacenter); Medisch Centrum Haaglanden, The Hague and St. Elisabeth Hospital, Tilburg (both level 1 traumacenters). Patients with DMCF, defined as at least one shaft width difference in height between the fracture parts regardless of the reduction, are allocated to either plate fixation or intramedullary fixation with ESIN through randomization. A flow chart of the study is shown in Figure 1.

Patient population

A total number of 120 patients will be included in the trial (see *sample size considerations*). Patients will be recruited at the emergency room (ER) of the participating hospitals. Patients are screened for eligibility according to the criteria listed in table 1. Patients with a DMCF on one side and no contraindications for general anaesthesia are eligible for inclusion in the study.

Intake

Ultimately within 1 week, an appointment with an orthopaedic trauma surgeon and the investigator will take place. If informed consent is obtained, the patient is included in the study, patient data are obtained by the investigator (table 2) and the patient is randomized.

Randomization

Patients are randomized prior to surgery in the doctor's office by computerized block randomization for either plate fixation or ESIN. The block varies between 2, 4, 6 and 8 patients. In each block the two operative techniques are equally represented. This randomization procedure will be stratified by participating hospital. After randomization, follow-up of patients will take place according to the intention-to-treat principle.

Interventions

After randomization the patient will be scheduled for surgery as soon as possible but ultimately 4 weeks after the initial trauma.

Operative procedure plate fixation

Patients are administered prophylactic antibiotics. With general anaesthesia, the patient is positioned in a beach-chair semi-sitting position. The involved shoulder is prepared and draped, and an incision is made just under the fracture site. If possible, supra-clavicular nerves are identified and spared. The fracture site is identified. In simple fractures, the fracture is reduced and a small fragment, low contact compression plate is fixed upon the anterosuperior surface of the bone starting medially using bicortical, non-angular stable screws. On the outer sides of the plate angular-stable screws are placed. In oblique or complex fractures interfragmentary lag screws can be placed to obtain compression. In case of severe comminution only bridging plate is performed. The fascia and the skin are closed in layers.

Operative procedure ESIN using a TEN

Patients are administered prophylactic antibiotics. With a general anaesthetic, the patient is placed in supine position. A small skin incision is made approximately 1 centimetre lateral to the sternoclavicular joint. The anterior cortex is opened with a sharp pointed reamer while care is being taken to not accidentally perforate the thorax. A TEN is inserted (the diameter varies from 2 to 3,5 mm, dependent on the width of the bone). Closed reduction, eventually supplemented with two percutaneously introduced pointed reduction clamps, is performed under fluoroscopic control. If closed reduction fails, an additional incision will be made above the fracture site for direct manipulation of the main fragments. After complete introduction of the TEN in the lateral fragment, the fracture is compressed and the TEN will be cut as short as possible at the medial end. The fascia and the skin are closed in layers.

Postoperative management

If possible, surgery is performed as a day case. Post-operatively, patients are given a sling but are encouraged to start with pain-dependent mobilisation immediately and to discard the sling as soon as possible. Load bearing is not recommended before osseous consolidation. Patients are advised to take pain medication when necessary. The type and amount of analgesics should be kept in the pain diary.

Follow-up

The patient is requested to record - on a daily basis during the fortnight immediately following surgery - the pain experienced as well as the type and amount of analgesics used. Experienced pain is assessed with a 10-point Likert scale (0 = no pain and 10 = extremely painful).

All patients are reviewed in the outpatient department by the treating surgeon and investigator at 2 and 6 weeks, 3 and 6 months and 1 year after surgery. All visits include standardized clinical evaluation and registration of possible complications by the treating surgeon and the investigator (table 3).

At the 2 weeks outpatient visit the pain diary is discussed by the researcher with the patient. Radiographs will be taken in order to check implant position and, at subsequent follow-up visits until radiographic union. Radiographic union is defined as complete cortical bridging between proximal and distal fragments on both radiographs as determined by the treating surgeon.

The Disabilities of the Arm, Shoulder and Hand (DASH) and Constant scores will be gathered at the 6 weeks, 3 and 6 months and 1 year postoperative visits by the investigator [15-17].

The DASH questionnaire is a self administered region-specific outcome instrument developed as a measure of self-rated upper extremity disability and symptoms. The DASH questionnaire consists mainly of a 30-item disability/symptom scale, scored 0 (no disability) to 100 (= completely disabled upper extremity) [15,16]. To prevent bias, the DASH questionnaires will be completed in absence of the operating surgeon, before the clinical assessment.

The Constant score includes an analysis of pain, shoulder motion, strength, and function. From a perfect score of 100, it reserves 35 points for patient-reported subjective assessment, including the presence of pain and the ability to perform basic activities of daily living, and 65 points for objective measurement. For the latter, 40 points are allocated to range of motion and 25 points are allocated to strength [17].

The cosmetic result after 6 weeks, 3 and 6 months, and 1 year is assessed by eliciting a patient satisfaction score on a 0 (= very unsatisfactory) to 10 (= very satisfactory) Likert scale.

After 6 months and 1 year the patient is asked to complete the SF 36 questionnaire again (see table 2) [18]. The SF 36 is a validated questionnaire designed to measure health related quality of life.

End Points

The primary endpoint is the DASH score 6 months after surgery. Secondary endpoints are listed in table 4.

Implant removal

Implant removal is scored as a re-operation if it occurs within the first 6 months and is due to implant related problems (listed in table 3). Implant removal according to the patient's wish will be granted after consolidation.

Safety measures

Surgeons operating patients for this study must have extensive experience with both plate fixation and ESIN with a TEN. It is assumed that every surgeon must have performed over 20 procedures in both techniques to operate on patients who participate in this study. The cut-off value of 20 operations is established on personal experience by one of the authors (MHJV), who participated in the Content-study in which conservative treatment of DMCF was compared to ESIN with a TEN (results not published yet). In this study the learning curve for ESIN with a TEN was passed after 20 procedures.

Sample Size and Power

The primary outcome measure in this study is the DASH score. Initially, a minimum difference of 10 points in DASH score can be considered as clinically relevant [16]. However the DASH score rates the whole upper extremity and a smaller difference should be considered as clinically relevant when focusing on clavicular function in particular.

Unfortunately, no studies comparing plate fixation and ESIN for dislocated midshaft clavicle fractures with power calculation are available [14]. Therefore we performed a power calculation based on the following rationale. A DASH score of a 'normal' upper extremity varies between four and eight [15]. The DASH score of the group of patients who were conservatively treated for DMCF after 24 weeks was 14 [12]. We consider the difference of six points between this latter DASH score and the worst score (eight) within the normal range as the clinically relevant margin. This coincides well with a recently online published protocol for treatment of wrist fractures in which a comparable margin in DASH score for local function (five points) is considered clinically relevant (Design Minimax studie: http://www.cruamc.nl/Minimax). With an expected standard deviation of 11 points in the DASH score, a two sided alpha of 0.05 and a power of 0.80, 53 patients in each group are needed (total

106) to show a difference of at least 6 points in DASH score after 6 months. Considering that an interim analysis is planned (see below), it is assumed that 2 sequential tests are made using the O'Brien-Fleming spending function to determine the test boundaries. Further assuming a 10% loss to follow-up, 120 patients should be included.

Statistical Methods

Data will be analysed according to the intention-to-treat principle. The difference between the operative techniques at the end of the follow-up period in DASH (primary out- come) and Constant scores will be tested for significance using the Student's T-test or the Mann-Whitney U test, depending data distributions. A general linear random effects model will be applied to assess differences during the follow-up period in DASH, Constant, pain, and SF-36 scores to account for repeated measures within patients. The difference in the frequency of complications during follow-up will be assessed with Poisson regression, whereas the Chi-square test or Fisher's exact test will be used to test for differences in proportion of re-operated patients. Differences in cosmetic satisfaction will be tested using the Mann-Whitney U-test. Time to radiological consolidation will be assessed by Kaplan-Meier analysis. A p-value of < 0.05 will be considered statistically significant in all analyses. SPSS software will be used for statistical analysis.

Data and safety monitoring board and interim analysis

A data and safety monitoring board (DSMB) is established existing of two surgeons and one methodologist. The DSMB will perform an interim analysis after one year. In the interim analysis discrepancies in a) major complications, b) minor complications and c) DASH scores between both procedures are calculated.

Major complications are defined as intra-operative nerve or vessel damage resulting in prolonged hospital admission, persistent injury or death, and re-operation due to an unsatisfying result. Minor complications are the other complications listed in table 3.

After one year, 72 patients (36 patients in each arm) will be included if inclusion is moving on as expected. The following stop criteria are defined:

- an established difference in patients with major complications of 13.5% (1% in one arm against 14.5% in the other) with a two-sided *p*-value of 0.1, 80% power, and assuming a negligible mortality rate, or
- an established difference in patients with minor complications of 37.1% (15.5% in one arm against 52.6% in the other arm) with a two-sided *p*-value of 0.01 and 80% power, or
- an established difference in DASH-score with an effect size of 0.55 with a two-sided *p*-value of 0.003 and 16.5% power (reflecting the first of the 2 sequential tests for the primary outcome using the O'Brien-Fleming spending function), or
- a potential difference in mortality, at the discretion of the DSMB.

Current status

This study has been approved by the Medical Ethics Committee of the Diakonessenhuis Utrecht. Approval of the local Ethical Boards of the other two participating hospitals is currently requested. This study is performed in accordance with the ethical standards of the Declaration of Helsinki. Recruitment of patients started in January 2011 in the Diakonessenhuis, Utrecht and will start in April 2011 in the Medisch Centrum Haaglanden, The Hague and St. Elisabeth Hospital, Tilburg. To date 25 patients have been included in the study. After a start-up phase the speed of the inclusion is expected to increase steadily and, depending on the number of patients needed to be included in the trial (see sample size considerations), recruitment of the 120th patient is currently expected in July 2012. Analysis and reporting is subsequently expected one year later to be complete (July 2013). The POP-study is registered in the Dutch Trial Register (NTR 2438).

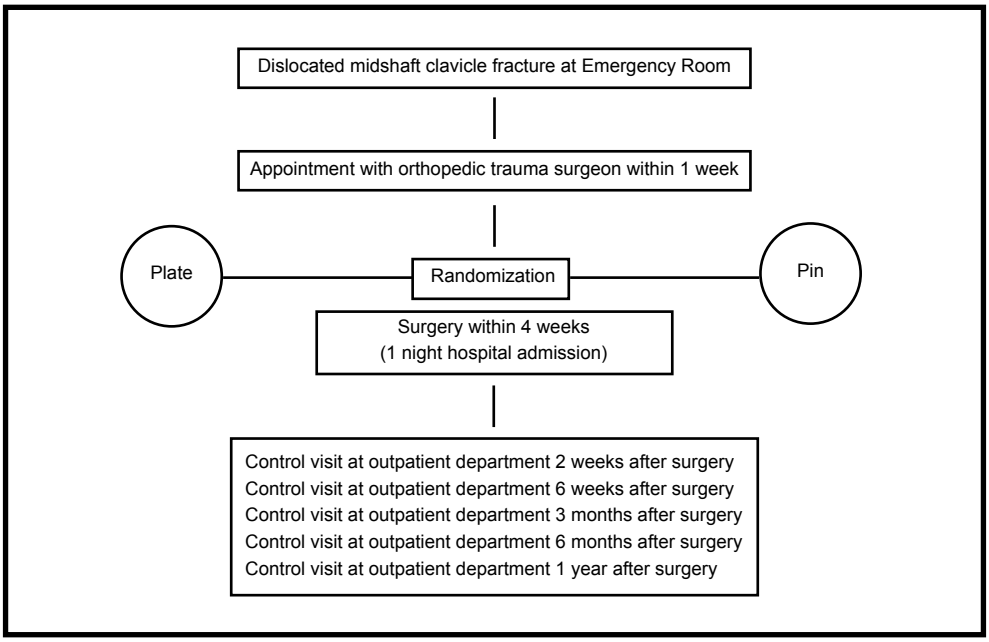

Figure 1. Flowchart of POP-study

Table 1. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Unilateral dislocated midshaft clavicular fracture • No medical contraindications to general anaesthesia • Provided informed consent	• Age < 18 years or > 65 years • Multitrauma patients • Open fracture • Pathological fracture • Fracture > 1 month old • Neurovascular disorders • Glasgow Coma Scale < 12 (moderate to severe head injury) • Inability to comply with follow-up (for example due to an inability to read or complete forms) • Pre-existing shoulder pathology in affected side (rotator cuff lesion, acromioclavicular pathology or previous shoulder surgery)

Table 2. Preoperative data

Preoperative data
• Age
• Gender
• Dominant arm
• Trauma mechanism (sports, traffic, accident, etc)
• Sports (if yes: at what level? Recreational or professional)
• Occupation
• Smoking
• Medical history
• Medication
• SF-36 Questionnaire [18]
• Body Mass Index
• AO Classification of fracture*

*** This classification exactly concurs to the OTA classification of midshaft clavicular fractures**

Table 3. Complications

Intra-operative complications	Post-operative complications
• Nerve/vessel damage	• Wound healing disorders (infection, hypertrophic scar, dehiscence)
• Other operative complications	• Transient brachial plexus laesion (defined as paresthesia of the arm, and weakness of the pink and index finger)
	• Irritation of the implant (post-operative pain/itch/irritation)
	• Migration of the implant
	• Breakage of the implant
	• Nonunion (defined as lack of radiographic healing with clinical evidence of pain and motion at the fracture site after 6 months)
	• Malunion (defined as union of the fracture in a shortened, angulated, or displaced position with weakness, easy fatigability, pain with overhead activity, neurologic symptoms, and shoulder asymmetry)
	• Other complications

Table 4. Primary and secondary endpoints

Primary Endpoints	Secondary Endpoints
• DASH score after 6 months	• Constant Score after 6 months • DASH and Constant Score after 6 weeks, 3 months and 1 year • Complications: intra-operative, post-operative period (2 weeks) and after 6 weeks, 3 and 6 months and 1 year • Re-operation after unsatisfying result in a time horizon of 1 year (including implant removal) • Time to radiological consolidation, with a maximum time horizon of 6 months • Pain score, until 2 weeks postoperative • Cosmetic satisfaction after 6 months and 1 year

Discussion

No comparative prospective or randomized study has been published comparing outcome of plate fixation with ESIN with a TEN of DMCF. The study aim is to provide and compare results of plate fixation and ESIN with a TEN.

Traditionally DMCF were treated conservatively. This policy was based on good results from large cohort series from the sixties: nonunion rates were < 1% [3,4].

These series, however, were all very mixed with regard to age, clavicle fracture site, displacement and fracture classification. Children, who have better bone healing and remodelling mechanisms, were also included. Malunion was not yet accepted as a clinical entity. Outcome was surgeon based contrary to present-day patient based outcome tools like DASH and Constant scores.

Surgical treatment however, has its own drawbacks. Wound healing disorders, infections, loss of fixation and nonunions do also occur as listed in table 3 [12,13,19-22]. In addition, a second surgical procedure might be required to remove the implant. Nevertheless, recently published studies reporting lower nonunion rates, improved functional outcome, faster mobilization and (perhaps therefore) increased patient satisfaction initiated a tendency towards surgical treatment of DMCF [8,12,13,22].

Theoretically, both plate fixation and ESIN have their own advantages. A biomechanical study shows that plate fixation provides a more rigid stabilization compared to ESIN. Therefore plate fixation may provide a stronger construct for early rehabilitation protocols [23]. Plate fixation is technically easy to perform which provides another advantage.

On the other hand, ESIN is less invasive, results in lesser implant prominence and implant removal can be done with minimal dissection [22]. If closed reduction is possible, this technique has the advantage of an intact fracture hematoma, which could speed up the healing process. However, minimally invasive techniques exert certain specific risks that can lead to complications (e.g. for the clavicle iatrogenic brachial plexus injury have been described) [20]. The primary endpoint of this study is the DASH score 6 months after surgery. After 6 months the nonunion rates can be calculated and therefore 6 months is the first possible endpoint to determine the success rate of the surgery. Patients will be followed for a 1 year period, mainly to assess the follow-up of nonunions or other implant-related complications.

The main goal of this study is to compare two principles of osteosynthesis: plate fixation and ESIN. Therefore the operating surgeon is free in his choice of plate regarding compression or angular stable locking. The operating surgeon is also free to decide the location of the plate, both superior and anterior/inferior plating are allowed. If plate fixation proves to be superior, a following study should be initiated to compare different methods of plate fixation.

There are some limitations of this study. Due to different incisions blinding is not possible. However, by using a self administered outcome instrument, the investigator-related bias is minimized for the primary endpoint. In this study the DASH score is used as primary endpoint. The DASH score does not specifically focus on clavicular function. However, a score which solely assesses clavicular function is lacking. In our opinion the DASH score provides the most reliable result for rating upper extremity disability and symptoms. To provide a complete overview of shoulder function the Constant score is used as a secondary endpoint.

A limitation of multicentre studies in general is that patient follow-up is often performed by multiple doctors resulting in decreased consistency of the clinical evaluation (interobserver bias) and increased loss to follow-up. In this study the same investigator (FJW) will be present during all patient visits at the outpatient department. Therefore, the consistency of the results will be improved and loss to follow-up rates should be reduced.

This prospective randomized multicentre study is designed to compare plate fixation and ESIN with a TEN for DMCF. As shoulder function, complications, quality of life, radiographic union, cosmetics and experienced pain are assessed, this study will provide a complete efficacy assessment of both procedures.

List of Abbreviations

POP: Plate Or Pin; ESIN: Elastic Stable Intramedullary Nailing; TEN: Titanium Elastic Nail; DMCF: Dislocated Midshaft Clavicle Fracture; ER: Emergency Room; DASH: Disabilities of Arm, Shoulder or Hand; DSMB: Data and Safety Monitoring Board.

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Chapter 7

A randomized controlled trial comparing plate fixation versus intramedullary fixation for dislocated midshaft clavicle fractures: short term results

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Submitted

Abstract

Background

Open reduction and internal plate fixation and Elastic Stable Intramedullary Nailing are commonly used operative techniques for dislocated midshaft clavicle fractures (DMCF). The best operative technique, however, remains a topic of debate. The aim of this article is to compare short-term results of plate fixation against ESIN with a Titanium Elastic Nail (TEN) for dislocated midshaft clavicle fractures.

Methods

A prospective multicentre randomized controlled trial was performed in four different hospitals throughout the Netherlands. From January 2011 until September 2012 a total of 120 patients were included and treated following randomization with either plate fixation or ESIN for DMCF. Operative time, post-operative pain, shoulder function scores and complications were documented up until six weeks post-operatively.

Results

The plate-group had a mean DASH-score of 11.36 (SD 11.04), the ESIN-group had a mean DASH score of 15.07 (SD 13.54) six weeks after surgery (p=0.096). The mean Constant-Murley score six weeks after surgery was 91.05 in the plate-group and 84.08 in the ESIN-group (p=0.004). The mean operative time in the plate-group was 53.96 minutes and in the ESIN-group 43.08 minutes (p=0.005). A total of sixteen protrusions causing nuisance and irritation were reported in the ESIN-group.

Conclusion

Better functional results in the plate-group six weeks after surgery are observed. Slightly more complications are found in the ESIN group but time of surgery is significantly shorter. Therefore, short-term results favour plate fixation for DMCF.

Background

Eighty percent of all clavicle fractures are located in the midshaft. Half of these fractures are displaced more than one shaft width. Patients are usually young, predominantly male, working and active in sports [1, 2]. The treatment for dislocated midshaft clavicle fractures (DMCF) remains controversial. Over the years conservative management was increasingly criticized due to unsatisfactory results resulting in a tendency towards surgical treatment for DMCF [3-7].

The two most used operative methods are open reduction using plate fixation and Elastic Stable Intramedullary Nailing (ESIN) [11]. Plate fixation provides a relatively more stable construct which could improve faster return to work and sports. ESIN has the possible advantage of an intact fracture hematoma if closed reduction is successful, which in turn could benefit the fracture healing and cosmetics. However, there is no high level evidence available which of these two techniques is superior [12]. In the young and active group of patients early functional recovery is of utmost importance regarding return to work and sports. The aim of this article is to compare short-term results of plate fixation against ESIN with a Titanium Elastic Nail (TEN) for dislocated midshaft clavicle fractures.

Methods

This study reports the short-term follow-up of the POP-trial (Plate or Pin trial for DMCF) and the design was recently published [13]. Changes regarding this study protocol were the addition of an extra participating centre (St Antonius Hospital Nieuwegein, Netherlands, a level 2 trauma centre and teaching hospital) and extension of the follow-up to one year. Approval was obtained from all ethic boards prior to the start of this study (Initial Ethical Board: VCMO, Nieuwegein, The Netherlands, correspondence number: R-10.18D).

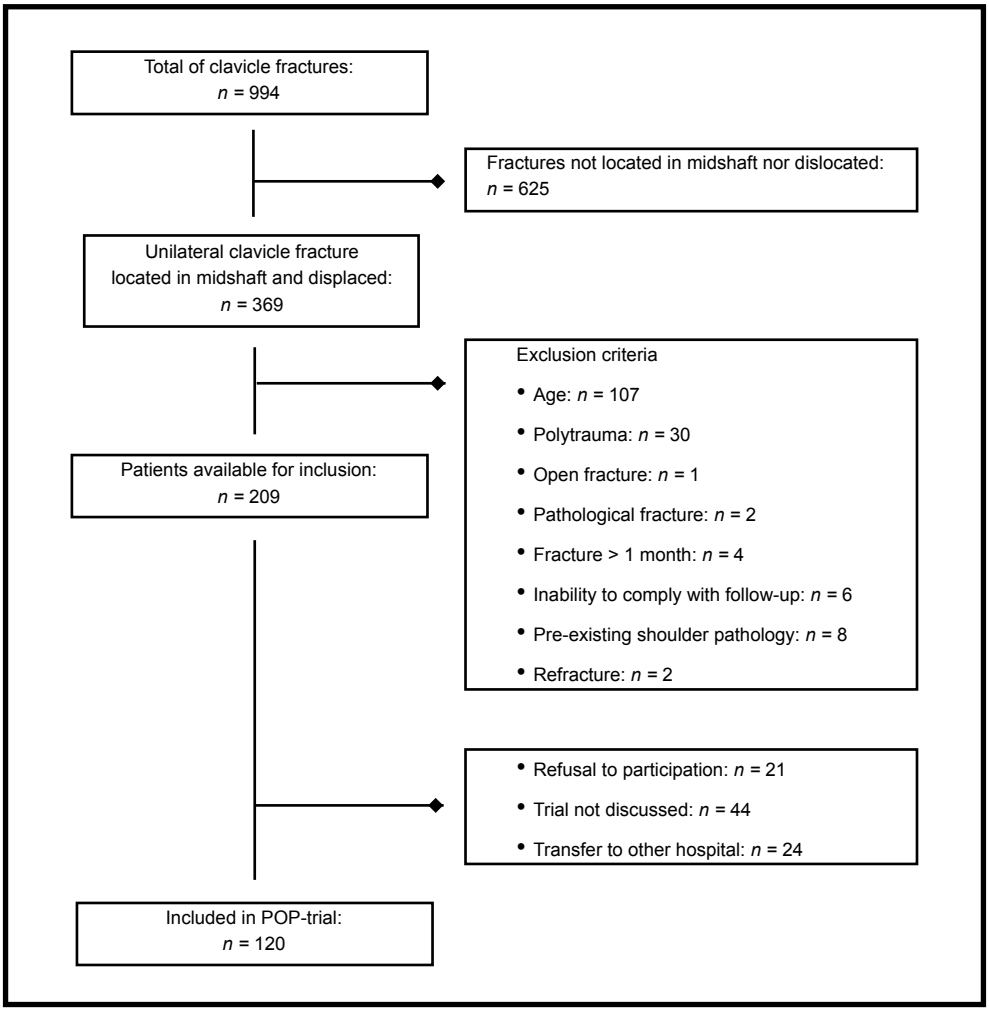

Figure 1. Flowchart of POP-trial

In- and Exclusion Criteria and Sample Size Calculation

Patients were recruited at the emergency room (ER) or the outpatient clinic of the participating hospitals. In- and exclusion criteria and a specific calculation of the sample size are shown in figure 1 and the published study protocol [13].

Pre-operative data collection

Baseline characteristics were gathered from patients prior to randomization. Age, weight, length, right or left hand dominance, fracture side, medication, disease history, ethnicity, level of sports and gender were documented. Furthermore we documented trauma mechanism, smoking habits (yes or no) and if there was an abuse of alcohol and/or regular usage of drugs present (yes or no). A radiograph was examined by the investigator and treating surgeon to determine the classification of the fracture.

Randomization

The randomization procedure was described in the study protocol [13]. After randomization, follow-up of patients took place according to the intention-to-treat principle.

Operative technique plate fixation

Patients were administered prophylactic antibiotics once. In simple fractures, the fracture was reduced and a small fragment, low contact compression plate was fixed upon the anterosuperior surface of the bone starting medially using bicortical, non-angular stable screws. On the outer sides of the plate locking screws were placed. In oblique or complex fractures interfragmentary lag screws were placed (if possible) to obtain compression. In case of severe comminution a bridging plate was placed. Different types of plates were used according to the surgeon's preference, i.e. the LCP plate, the lateral clavicle plate, the preformed clavicular plate and the DC-plate. Plates in all four participating hospitals were provided by DePuySynthes® (Zeist, the Netherlands). The fascia and the skin were closed in layers.

Operative technique intramedullary fixation

Patients were administered prophylactic antibiotics. A small skin incision was made approximately 1 centimetre lateral to the sternoclavicular joint. TEN's in three hospitals were provided by DePuySynthes® (Zeist, the Netherlands)

and in one hospital (Medisch Centrum Haaglanden, The Hague) by Stryker® (Waardenburg, the Netherlands). A TEN nail was inserted (the diameter varied from 2.0 to 3.5 millimetre, dependent on the width of the bone marrow). Closed reduction, was performed under fluoroscopic control. If closed reduction failed, an additional incision was made above the fracture site for direct manipulation of the main fragments. After complete introduction of the TEN in the lateral fragment, the fracture was compressed and the TEN was cut as short as possible at the medial end. During each surgery the complications and data were monitored and reported directly afterwards.

Post-operative follow-up

All patients were reviewed in the outpatient clinic by the treating surgeon and investigator (F.J.G.W.) at two and six weeks post-operatively. All visits included standardized clinical evaluation, registration of possible complications and evaluation of radiographs in two directions in order to check implant position.

Endpoints

All intra- and post-operative data were monitored and recorded for further analyses. The patient was requested to fill out a validated Dutch translation of the Disability of Arm Shoulder and Hand (DASH) form provided at the outpatient clinic during the six weeks follow-up visit [14, 15]. The Constant-Murley Score was assessed by the investigator during the outpatient visit [16]. The patient was also requested to record - on a daily basis during the fortnight immediately following surgery - the pain experienced as well as the type and amount of analgesics used. Experienced pain was assessed with a 10- point Likert scale (0 = no pain and 10 = extremely painful). Nerve or vessel damage and other intra-operative complications were registered during intra-operative data collection.

Intra-operative ratings

During each surgery the treating surgeon scored the operation in one of the following three difficulty levels: ‘easy’, ‘normal’ or ‘difficult’. The satisfaction with the final result of the surgery was also scored by the same treating surgeon rating the operation into three different categories: bad result, medium result or good result.

Post-operative complications

At the outpatient visits complications were reported if they occurred. Implant related complications such as breakage of the implant were determined on the radiograph. Superficial wound infection was defined as redness, swelling, purulent discharge, a positive wound culture and/or when prescription of antibiotics was given. The definition of deep infections was an infection that needed implant removal. Hyperesthesia was defined as an increased and/or abnormal painful feeling in the area of incision. Irritation (of the skin) was assessed clinically if caused by prominence of the implant material. The definition of transient brachial plexus lesion was a paraesthesia of the arm, and/or weakness of the pink and index finger. Hematoma and a desensitized feeling of the skin below the incision were also documented.

Statistical Analysis

Data were analysed according to the intention-to-treat principle. Differences at baseline were tested using the Student's T-test for continuous parameters (or Mann-Whitney U-test in case of unequal variances) and Pearson's Chi-square for categorical parameters. The differences between the operative techniques in DASH and Constant scores were tested for significance using the Student's T-test or the Mann-Whitney U-test in case of unequal variances. A general linear model for repeated measures within patients was applied to assess differences in daily pain scores during the first post-operative fortnight. The difference in the frequency of complications during surgery was assessed with Poisson log linear model. Difference in difficulty of surgery was assessed using the extended Mantel-Haenszel test for trend, while the exact linear-by-linear association was assessed for satisfaction with the surgical result. The impact of missing follow-up data for DASH, Constant and daily pain scores was assessed through a worst case scenario. In this scenario missing data in the plate and ESIN groups respectively were imputed with the worst observed score from the same group at the time of measurement. A p-value below 0.05 was considered statistically significant in all analyses. SPSS software and PEPI software were used for statistical analysis.

Results

Between January 2011 and September 2012 a total of 120 patients were enrolled in the study; fifty-eight patients were randomized to the plate-group and sixty-two patients were randomized to the ESIN-group (Figure 1). There are no significant differences regarding the baseline characteristics between both treatment groups (Table I). No differences were found between treatment groups regarding disease history and medication usage (data not shown). Three patients were lost to follow-up during the first six weeks post-operatively.

Table I. Baseline characteristics

	Plate-group *n* = 58	ESIN-group *n* = 62
Age (years: mean ± SD)	38,31 (14,61)	39,05 (13,15)
Gender		
Male	53 (91%)	60 (97%)
Female	5 (9%)	2 (3%)
Dominance (*n*, %)		
Right	50 (86%)	55 (89%)
Left	8 (14%)	7 (11%)
Trauma mechanism (*n*, %)		
Traffic accident	28 (48%)	25 (40%)
Sports	18 (31%)	29 (47%)
Fall from stance/height/other	12 (21%)	8 (13%)
Smokers (*n*, %)		
Yes	19 (33%)	20 (32%)
No	38 (67%)	42 (68%)
Alcohol/drugs (*n*, %)		
Yes	7 (12%)	7 (11%)
No	51 (88%)	55 (89%)
Ethnicity (*n*, %)		
Caucasian	57 (98%)	61 (98%)
Black/Asian/Other	1 (2%)	1 (2%)
Sports (*n*, %)		
No	17 (29%)	20 (32%)
Yes	41 (71%)	42 (68%)
BMI (kg/m2: mean ± SD)	24,71 (3,47)	23,73 (4,17)
Fracture side (*n*, %)		
Right	30 (52%)	29 (47%)
Left	28 (48%)	33 (53%)
AO Classification (*n*, %)		
A (Simple fractures)	27 (47%)	24 (39%)
B (Wedge fractures)	29 (50%)	34 (55%)
C (Complex fractures)	2 (3%)	4 (7%)

***BMI* body mass index (kg/m2), *AO classification* Muller AO classification for fractures- long bones, *SD* standard deviation, *ESIN* elastic stable intramedullary nailing**

Endpoints

The plate-group had a mean DASH-score of 11.36 (SD 11.04), the ESIN-group had a mean DASH score of 15.07 (SD 13.54) six weeks after surgery (*p*=0.096) (Table II). The Constant score six weeks after surgery was 91.05 (SD 12.19) in the plate-group and 84.08 (SD 15.89) in the ESIN-group (*p=0.004*). The mean post-operative pain scores over time are shown in Figure 2. The difference in favour of the plate-group (overall mean 3.02 versus 3.45 in the ESIN-group) was non-significant (*p*=0.163). No differences were found in analgesic use between both treatment groups (data not shown). The operative time in the plate-group was 53.96 (SD 16.55) minutes and in the ESIN-group 43.08 (SD 23.89) minutes (*p=0.005*) (Table II). No difference was observed concerning the level of difficulty of the surgical procedures (p=0.106). Of the 'difficult' rated surgical procedures in the ESIN-group the mean operating time was 65 minutes (SD 26.3), the 'difficult' plate-group procedures had a mean operating time of 60.55 minutes (SD 16.24) (*p*=0.613). The 'normal'-rated ESIN procedures had a mean operating time of 33.36 minutes (SD 9.72), the 'normal'-rated plate procedures had a mean operating time of 55.31 minutes (SD 15.53) (p<0.001). Satisfaction with the surgical result tended to be more favourable in the plate-group (*p*=0.055).

Conversions

A total of six conversions took place intra-operatively. Five TEN's were converted to plates and one plate was converted to TEN (*p*=0.107) (Table II). The five conversions in the ESIN-group were one simple fracture (A), three wedge fractures (B), and one complex fracture (C). The one conversion in the plate-group was a cross sectioned fracture (A).

Intra-operative complications

One patient in the ESIN-group remained with a slight gap between the medial and distal fracture parts, which was visible on the intra-operative radiograph. In one patient the TEN was accidentally pushed through the lateral cortex of the clavicle. No intra-operative vascular damage or plexus damage was reported in both groups.

Table II. Endpoints

	Plate-group *n* = 58	ESIN-group *n* = 62	*p*-value
6 weeks data			
Missing	3	0	
DASH Score (mean, SD)	11,36 (11,05)	15,23 (13,54)	0,096*
Constant Score (mean, SD)	91,05 (12,19)	84,08 (15,89)	0,004#
Intra-operative data			
Missing	1	2	
Difficulty surgery			0,106***
Easy (*n*, %)	7 (12%)	6 (10%)	
Normal (*n*, %)	39 (68%)	33 (55%)	
Difficult (*n*, %)	11 (19%)	21 (35%)	
Satisfaction surgeon			0,055##
Bad result (*n*, %)	0	1 (2%)	
Medium result (*n*, %)	1 (2%)	6 (10%)	
Good result (*n*, %)	56 (98%)	53 (88%)	
Time of surgery in minutes (mean, SD)	53,96 (16,55)	43,08 (23,89)	0,005*
Conversion (*n*, %)	1 (2%)	5 (8 %)	0,107**

***DASH* disability of arm, shoulder and hand, *ESIN* elastic stable intramedullary nailing, *SD* standard deviation**

*** Student's T-test**
**** Chi-square test**
***** Extended Mantel-Haenszel test for trend**
 # Mann-Whitney U-test
Exact linear-by-linear association

Post-operative complications

In the plate-group (*n* = 55) eleven patients (20%) had one complication. In the ESIN-group (*n* = 62) sixteen patients (26%) had one complication and three patients (5%) had two complications. The difference in protrusion rate was responsible for a nearly significant difference in postoperative complications in favour of the plate-group (p=0.09). Medial protrusion of the TEN was seen in twelve patients and none were reported in the plate-group. Medial protrusion was seen in seven simple fractures and five wedge fractures and none in the complex fracture group. One of these patients underwent treatment by cutting the protruding end of the TEN because the TEN broke through the skin. Other complications are shown

in Table III. Two patients underwent major revision surgery in the ESIN-group. The first patient experienced a post-operative lateral protrusion of the TEN that eventually was treated with removal of the TEN. In the second patient telescoping and shortening of the clavicle occurred when the patient switched over from the operating table to the hospital bed. This shortening resulted in medial protrusion which was so invalidating that a revision needed to be performed a week after initial surgery (Table III).

Worst case scenario analysis

Imputation of missing DASH, Constant and pain scores under the worst case scenario resulted in difference scores (mean for the plate group minus mean for the ESIN group) of -2.13 in case of DASH (p=0.385), 4.39 in case of Constant (p=0.138), and -0.62 in case of pain scores over time (p=0.086).

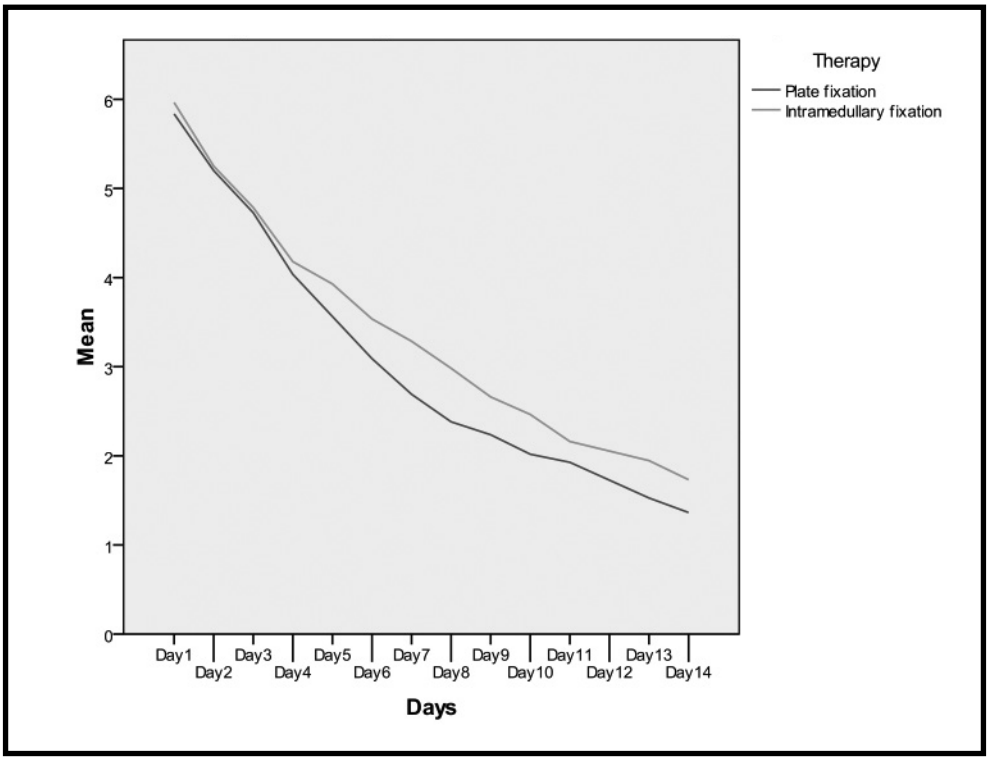

Figure 2. **Mean pain scores for both treatment groups**

***n* plate fixation = 55 (3 missing)**
***n* intramedullary fixation = 56 (6 missing)**

Table III. Complications in both treatment groups

	Plate-group *n* = 58	ESIN-group *n* = 62
Missing	1	1
Intra-operative complications (*n*, %)	**0**	**2 (3%)**
Vascular damage (*n*, %)	0	0
Plexus damage (*n*, %)	0	0
Gap between fracture parts (*n*, %)	0	1 (2%)
Lateral cortex perforation (*n*, %)	0	1 (2%)
Missing	3	0
Post-operative complications	**11 (20%)**	**19 (31%)***
Implant breakage (*n*, %)	0	0
Superficial wound infection (*n*, %)	3 (6%)	0
Deep infection (*n*, %)	0	0
Hyperesthesia (*n*, %)	2 (4%)	2 (3%)
Plate irritation (*n*, %)	3 (6%)	0
Protrusion of TEN (medial/lateral) (*n*, %)	0	16* (26%)
Transient brachial plexus laesion (*n*, %)	2 (4%)	0
Hematoma (*n*, %)	0	1 (2%)
Desensitized skin under incision (*n*, %)	1 (2%)	0
Major revision surgery (removal of revision of implant) (*n*, %)	**0**	**2 (3%)***
Minor revision surgery (shortening of TEN) (*n*, %)	**0**	**1 (<1%)***

***SD* standard deviation, *TEN* titanium elastic nail, *ESIN* elastic stable intramedullary nailing**

*** Three patients underwent medial protrusion and minor revision surgery (*n* = 1), or lateral protrusion and removal of TEN (*n* = 1), or directly post-operative shortening with invalidating medial protrusion and therefore revision of TEN (*n* = 1)**

Discussion

Better functional results in the plate-group six weeks after surgery were observed. Slightly more complications (especially protrusions) were found in the ESIN-group, but time of surgery was significantly shorter.

The worst case scenario to account for missing data in the intention-to-treat analysis showed that the functional results should be interpreted with some caution. All differences in functional results still favoured the plate-group. These differences were less pronounced in case of the DASH and Constant scores but more pronounced for pain scores over time.

This is the first prospective randomized study that compared plate fixation and ESIN. DASH and Constant scores after six weeks were slightly better in the plate-group compared to the study of the Canadian Orthopaedic Trauma Society [8]. DASH-scores of the ESIN-group were comparable with the results of Smekal et al. after six weeks [9]. The better functional results in the plate-group can be explained because of the relatively better stability plate fixation offers in comparison to ESIN [17]. Patients reported a stable feeling in the shoulder which encouraged them to extend shoulder movement in the early post-operative phase.

Time of surgery and closed/open reduction rates were comparable with the study of Bohme et al., who reported a mean operative time of 43 minutes for ESIN, 61 minutes for plate fixation and a 25% closed reduction rate for TEN [18]. Despite the fact that ESIN is widely seen as a more difficult technique, the operating time was shorter in comparison to plate fixation, even with an 80% open reduction rate. Closed reduction resulted in short operating time. There was no difference in operating time when the procedure was labelled ‘difficult’. However, in the ‘normal’ group the ESIN-group showed a significantly shorter operating time. When a procedure is likely to be ‘normal’ (simple, not comminuted fracture pattern, no additional problems and a ‘fresh’ fracture) a shorter operating time can be achieved using ESIN.

Medial protrusion after ESIN was a major problem in this study. Frigg et al. reported problems with the medial end of the TEN in 13 out of 18 patients and in our previously published retrospective study 23 of 47 patients complained of medial protrusion [19, 20]. Medial protrusion could be the result of post-operative shortening of the clavicle because the medial end of the TEN is not secured. Post-operative shortening was expected to be more likely in multi-fragmentary fracture patterns because of the lack of cortical contact and supporting surface. However, protrusion was seen in seven simple fractures

and five wedge fractures. None were observed in the complex fracture group. Frigg et al. already showed that complications with the medial end of the TEN can be reduced by using an End-Cap [19]. Future research is needed to determine if medial protrusion can be resolved by using End-Caps.

Conversions were not correlated to fracture pattern. The main reason for conversion from TEN to plate was the incapability to enter the distal fragment of the clavicle even if the fracture site was opened. Even the smallest TEN's in diameter (2.0 mm) could, in some cases, not be introduced into the distal fragment. All five conversions were fractures that were located in the lateral part of the midshaft, which raises the question whether or not these fractures are suitable to be treated with ESIN. A communication error was the reason for the conversion from plate to TEN.

This is the first prospective multicentre randomized controlled trial that compares plate fixation with intramedullary fixation for dislocated midshaft clavicle fractures. To guarantee consistency in data collection and minimize loss of data and follow-up all pre- and post-operative data were collected by one investigator (FJW). By using the DASH-score as self-administering outcome measure, the investigator-related bias was minimized

This study has some limitations that need to be addressed. No blinding was possible due to the incision made. As seen in the flowchart, there was a large group of potential patients (n = 44) that were not included because the trial was not discussed. This number was consistent with the prior number mentioned in our study protocol regarding the learning curve. Our protocol stated that a learning curve of 20 procedures for both techniques was needed for a surgeon to participate in this trial [13]. Some surgeons did not meet these criteria and therefore the trial was not discussed with some patients. Age, co-morbidity and fracture pattern of these excluded patients were retrospectively compared with our study population and no significant differences were found.

Results of this study are of high clinical relevance when dealing with young patients who are fully active in work and sports. The priorities of these patients are fast recovery and fast improvement of shoulder function. The long term follow-up will clarify if additions or changes to our short-term conclusions need to be made in the comparison between the two techniques. Taking in consideration complications and fast functional recovery, treatment with plate fixation for dislocated midshaft clavicle fractures is recommended. Results regarding this trial's total follow-up of one year will be expected early 2014.

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Chapter 8

General discussion

Introduction

Eighty percent of clavicle fractures are located in the midshaft and half of these fractures are dislocated at least one shaft width [1, 2]. Operative treatment is preferred for dislocated midshaft clavicle fractures (DMCF) based on better functional results of the shoulder, reduction of nonunions, reduction of postoperative pain, less physical therapy, less usage of pain medication and earlier resumption to work [3-10]. The two most commonly used operative techniques are plate fixation and intramedullary fixation [11]. High quality evidence regarding superiority of one of these techniques is lacking [11,12]. This thesis contributes to the decision making process which operative treatment is best for dislocated midshaft clavicle fractures.

Definitions used in this thesis.

The midshaft of the clavicle was defined as the middle 1/3rd of the clavicle as seen in figure 1. Dislocation was defined as one shaft-width distance between fracture parts with no cortical contact. Fracture parts without cortical contact are always at risk of shortening both in the traumatic as in the post-traumatic setting. Consequently the severity of shortening was not evaluated in this thesis.

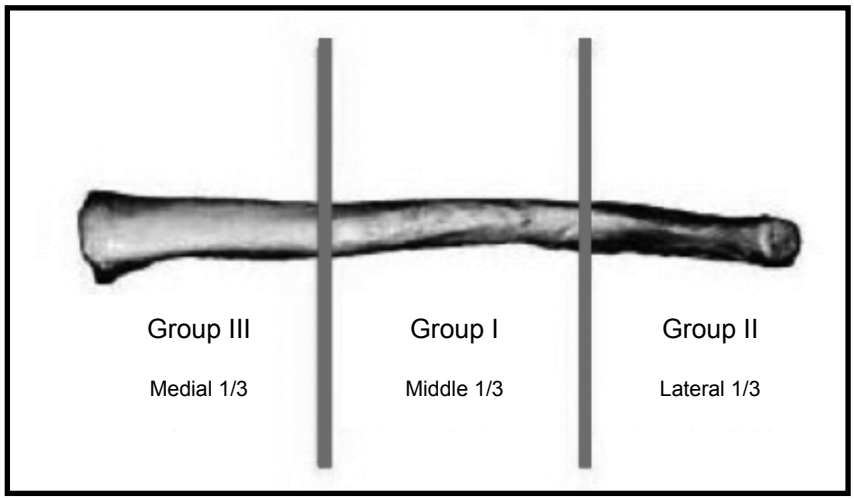

Figure 1. **The Allman Classification for clavicular fractures**

Complications in Chapters 3 and 4 were identified in all included studies and for each chapter complications were divided into a generalized set of major and minor complications. Definitions of major and minor complications were different for each type of treatment.

Assigning complications to different categories was needed to provide a clear overview of the complications and for easier comparison between included studies. However, different authors may have used different definitions for complications i.e. deep, superficial and wound infections. In the future, improvements can be made by using standardized definitions of complications for clavicle surgery. Actual complication rates might be higher than many authors report, based on distinctions made between minor and major complications and overlap in definitions (e.g. failure or infection may result in removal, debridement or revision).

Differences between plate fixation and intramedullary fixation

Plate fixation is based on the concept of primary bone healing, if anatomical reduction is achieved very few periosteal reaction is to be expected. Intramedullary fixation is based on secondary bone healing (and more periosteal reaction) because small movements between fracture parts is possible due to the flexible concept of this technique. The differences found between plate fixation and intramedullary fixation were as follows:

1. Primary bone healing is a more rigid and therefore less stable healing process compared to secondary bone healing. An intramedullary device on the other hand has the ability to move along with slight movements of the bone and has the possibility to return to its previous position and form. So plate fixation is more rigid and (excessive) movements of the clavicle could result in fatigue of the plate leading to breaking or bending.

2. When removal of the plate due to irritation or nuisance was indicated, refracture was seen in a small amount of patients. An explanation for the refracture rate after plate removal was the potentially weak spots of screw holes in the clavicle. These spots could hypothetically be the location of a refracture in small clavicles.

3. The main problem of Elastic Stable Intramedullary Nailing (ESIN) was medial protrusion resulting in nuisance or irritation following minor revision surgery. Around 25% of patients suffered from a form of protrusion resulting in irritation or even in an intervention. The protrusion was associated with post-operative shortening of the clavicle. This shortening would be expected in multi-fragmentary fracture patterns because of the lack of cortical contact and supporting surface. However, the protrusion was also seen in simple fractures and wedge fractures, especially in the oblique type of fractures. Prevention of this complication is possible by precise anatomical reduction and fixation of the fracture to prevent this telescoping, this might be difficult to achieve using the technique of intramedullary nailing. Direct postoperative abduction of the arm could possibly be a risk factor for this protrusion and therefore patients should be advised to abduct the arm not further than 90 degrees in the first two weeks postoperatively to prevent this telescoping.

4. ESIN is widely seen as a more difficult operative procedure, which was mirrored with the 80% open reduction rate although the operative time of ESIN was significantly shorter compared to plate fixation. In 80% of cases an additional incision was placed eliminating the advantage of closed reduction (intact fracture hematoma and better cosmetic appearance). Another example of the difficulty of the ESIN procedure was the rate of conversions. A total of five conversions took place in the ESIN group. The main reason for conversion was the incapability to enter the distal fragment of the clavicle with the Titanium Elastic Nail (TEN) even if the fracture site was opened. Even the smallest TEN's in diameter (2.0 mm) could, in some cases, not be introduced into the distal fragment. The clavicle could be divided further down into two extra categories. The midshaft could be divided in a medial and lateral part as shown in figure 2. All five fractures resulting in conversions were located in the lateral part of the midshaft. This observation raises the question whether lateral part midshaft fractures are suitable to be treated with ESIN.

5. Better functional results after plate fixation were observed six weeks postoperatively. The better short term functional results reported in the plate group were explained by the stable construct plate fixation provides, this might encourage people to seek out their maximum potential.

Future perspectives

The final results of the POP-trial (Chapter 7) need to be awaited before any final conclusions can be drawn. However, it is already clear that future research is needed in search of the optimal way of preventing complications in both treatment groups. Both treatment groups frequently experience implant related complications causing nuisance and irritation. By eliminating these complications both surgical approaches look promising in achieving a stable construct with minimal major and minor complications. Examples of a solution for the complications presented are a different position of the plate or locking of the medial end of the TEN.

In the retrospective comparison (Chapter 5) and in the participating hospitals of the randomized controlled trial (Chapter 7) plates were positioned on the superior surface of the clavicle. The main problem of positioning the plate superiorly was irritation and nuisance, which usually resulted in removal of the plate. Nowadays, the locking plates have the possibility to be placed minimally invasive. With this technique, the so-called Minimal Invasive Plate Osteosynthesis (MIPO), the length of the incision can be equally short compared to intramedullary fixation [13]. Future research is needed to determine which position is best for plate fixation and if MIPO can reduce incision length to a comparable level of intramedullary fixation.

The main problem of ESIN is protrusion resulting in irritation. Protrusion is the result of migration of the nail or shortening of the clavicle. Hypothetically the cause of both migration and shortening could be the absence of a locking mechanism of the nail. By using an End Cap locking of the nail at the medial end of the clavicle can be achieved and irritation minimized because the End Cap is smooth and does not protrude in the skin [14]. This can also minimize the risk of shortening of the clavicle resulting in a decreased malunion risk. Future research is needed whether or not the usage of End Caps is preferred.

Treatment advice based on this thesis

If the fracture pattern is comminuted, plate fixation is recommended because this type of pattern is harder to operate on with an intramedullary device. An additional incision is more likely with this type of fracture pattern (which eliminates the advantage of closed reduction) and the risk of shortening (and therefore malunion and possibly protrusion or migration) is higher.

Midshaft clavicle fractures can be divided into two segments, a medial and a lateral half. If the fracture is simple (Type A in the AO-classification) and located in the lateral part of the midshaft plate fixation is probably better because of the small entrance and the more technically demanding procedure of intramedullary fixation. When the fracture is located in the medial part of the midshaft intramedullary fixation is recommended. This thesis shows that performing intramedullary fixation on a fracture in the lateral part of the midshaft is more difficult resulting in higher conversion rates. When the fracture is located in the medial part of the midshaft intramedullary fixation has a higher possibility of closed and anatomical reduction and less risk of shortening. When dealing with wedge fractures plate fixation is probably better. Manipulation of the fracture fragments is possible with open reduction and plate fixation which could possibly be an advantage regarding malunion and shortening. In the results of Chapter 7 shortening is observed when using intramedullary fixation in wedge fractures. With a stable construct like plate fixation the chance of shortening is minimized. These recommendations are based on the studies performed in this thesis. The final results regarding the total follow-up of one year need to be awaited to make additions or changes to our conclusions and recommendations.

Conclusions

1. No difference in functional outcome or complications after plate fixation and intramedullary fixation for dislocated midshaft clavicle fractures are found in recent literature. The quantity of high quality evidence to support these statements is low.

2. Plate fixation is a safe treatment option for dislocated midshaft clavicle fractures but implant related complications tend to be frequent resulting in removal of the implant.

3. Intramedullary fixation is a safe treatment option for dislocated midshaft clavicle fractures but implant related complications (medial protrusion) resulting in a minor intervention or premature removal of the implant are frequent.

4. Plate fixation is recommended if fast functional recovery is needed for dislocated midshaft clavicle fractures.

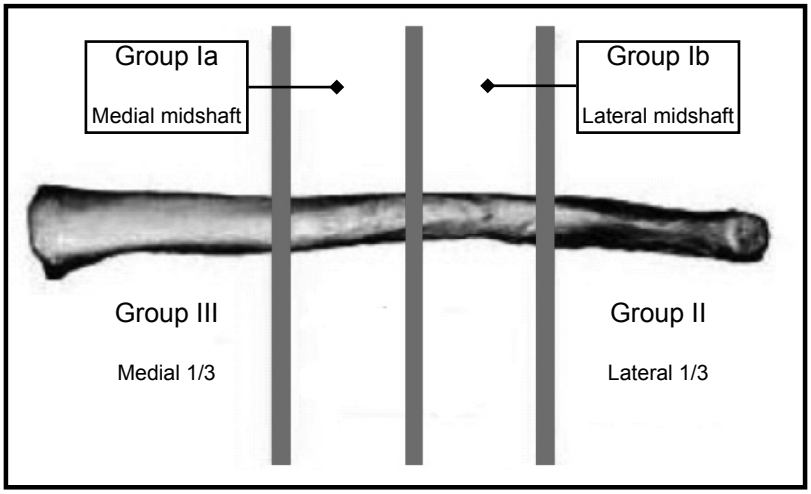

Figure 2. **Medial and lateral midshaft clavicle fractures**

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Chapter 9

English summary and conclusions

Summary and Conclusions

In this thesis literature research and clinical studies are presented to assist physicians in the decision making process for surgical treatment of dislocated midshaft clavicle fractures (DMCF).

In *Chapter 1* an introduction is given regarding the background, aim and outline of this thesis. The aims presented are:

1. A review of current literature about studies comparing plate fixation and intramedullary fixation for dislocated midshaft clavicle fractures.
2. Insight in complications after plate fixation and intramedullary fixation for dislocated midshaft clavicle fractures.
3. Providing the rationale and design of a prospective randomized multicentre study comparing plate fixation and intramedullary fixation for dislocated midshaft clavicle fractures (Plate Or Pin: POP-study).
4. Presenting the short-term results of the POP-study.

Chapter 2 is a systematic review comparing plate fixation and intramedullary fixation for DMCF. The quality of evidence of each included study is evaluated using two different quality-scoring systems: the modified version of the Cochrane Bone, Joint en Muscle Trauma Group's former quality assessment tool and the GRADE approach. The Cochrane tool is used to judge the internal and external validity of the included studies. The GRADE approach is a quality tool that specifies four levels of evidence (high, moderate, low, very low).

Four studies are eligible for inclusion; one study is considered high quality evidence while the other three are considered low quality evidence. All four studies report no significant difference in function or complications in a 6 to 13 months follow-up period. Typical complications after plate fixation are superficial wound infection, implant loosening or breakage, hypertrophic scars and refracture after implant removal. Complications after intramedullary fixation are migration and perforation of the intramedullary nail combined with irritation.

Despite the limited number and low quality of the available studies, there is no difference in shoulder function between patients treated with plate fixation or intramedullary fixation for DMCF. Complications after plate fixation and intramedullary fixation are different.

Chapter 3 specifically focuses on the complications after plate fixation. Another literature search is performed and a total of eleven studies are found. The Cochrane tool and the GRADE approach are used to qualify the included studies. Complications are divided into two groups: major and minor complications. Major complications are those requiring additional (nonroutine) surgery to either remove or revise the plate as a result of the complication. Minor complications are characterized as a complication that does not need another surgical procedure or when a small intervention (i.e. oral antibiotics) is sufficient.

Eleven studies are included with only three of high quality evidence. Nonunion and symptomatic malunion rates do not exceed 10% and deep infections are reported below 8%. The incidence of minor complications in all eleven studies is low. Superficial infections are reported below 10%.

The vast majority of the complications are implant related with irritation or failure of the plate being consistently reported in almost every study ranging from 9-64%. Plate fixation is a safe treatment option for DMCF but implant related complications are relatively frequent.

In *Chapter 4* the same approach is used to assess the complications following intramedullary fixation for DMCF. A total of six studies are included and analyzed. A similar distribution between major and minor complications is made as in Chapter 3. Minor complications (irritation, migration and telescoping) of the intramedullary device can often be resolved by minimally invasive shortening of the implant under local anaesthesia.

Six studies are included; three studies are graded with the highest level of evidence. Major complications like non- and symptomatic malunion and deep infections requiring implant removal do not exceed 7%. Implant failures are reported to be no higher than 6%. Rates of irritation following medial protrusion of the intramedullary device are reported up to 31%.

This chapter shows that intramedullary fixation is a safe treatment option for DMCF. The advantage of intramedullary fixation is that revision or removal of the implant can be performed minimally invasive with small incisions and short operating times. Minor complications (medial protrusion) occur frequently. As a result of routine implant removal, treatment with intramedullary fixation requires an additional surgical procedure.

In *Chapter 5* a retrospective comparison of plate fixation and intramedullary fixation using a titanium elastic nail (TEN) is presented focussing on complications. Records of 90 patients who were treated in a level 2 trauma centre (Diakonessenhuis) with either plate fixation or intramedullary fixation are reviewed and complications are reported. The complications are once again divided into two groups: major and minor complications.

Seven implant failures occurred in six patients (14%) of the plate group and one implant failure (2%) was reported after intramedullary fixation (p=0.051). Major revision surgery was performed in five cases in the plate group (12%) and in one case (2%) after intramedullary fixation (p=0.100). Three refractures (7%) were observed in the plate group after removal of the implant against none after intramedullary fixation (p=0.105). Six minor revisions (13%) were reported after intramedullary fixation and none were reported in the plate group (p=0.027). This chapter shows a tendency towards more major complications (implant failure and refracture after implant removal) after plate fixation in comparison with intramedullary fixation. Minor complications (medial protrusion) are more frequent after intramedullary fixation.

After comprehensive literature and retrospective research for the optimal surgical treatment of DMCF, *Chapter 6* presents the rationale and design of a multicentre prospective randomized trial comparing plate fixation with intramedullary fixation (pin or plate: POP-study).

Short-term results of the POP-study are presented in *Chapter* 7. From January 2011 until September 2012 a total of 120 patients were included and treated according to block-randomization with either plate fixation or intramedullary fixation using TEN. Operative time, post-operative pain, shoulder function scores and complications were documented up until six weeks post-operatively. The plate-group had a mean DASH-score of 11.36 (SD 11.04), the TEN-group had a mean DASH score of 15.07 (SD 13.54) six weeks after surgery (p=0.096). The mean Constant-Murley score six weeks after surgery was 91.05 in the plate group and 84.08 in the TEN-group (*p=0.004*). The mean operative time in the plate group was 53.96 minutes and in the TEN-group 43.08 minutes (*p=0.005*). Sixteen protrusions causing nuisance and irritation were reported in the TEN-group. This chapter reports better functional results of the shoulder six weeks postoperatively favouring plate fixation. More complications are seen in the TEN-group but the time of surgery is significantly shorter.

Future Perspectives

This thesis provides a solid basis for future research of the surgical treatment of DMCF. Both plate fixation and intramedullary fixation are safe treatment options for DMCF. However rates of implant related complications in both groups are relatively high. Future research should focus on minimizing implant related complications.

For plate fixation an alternative position can be an option for reducing irritation and implant removal. In the clinical studies of this thesis placement of the plate on the superior site of the clavicle is used. However, placement on the anterior-inferior site of the clavicle is another option. Future research comparing superior and anterior-inferior plating is needed to assess if the position has influence on the irritation (and consequently the removal) rate.

One of the disadvantages of plate fixation is the rather large incision that is made in order to position the plate. However, Minimally Invasive Plate Osteosynthesis (MIPO) is an upcoming technique where the plate is placed with a minimal incision reducing possible wound infections and improving cosmetics.

Medial protrusion is the most frequently reported complication after intramedullary fixation. An option for reducing medial protrusion is adding an End Cap over the medial protruding end of the TEN. This End Cap with it's smooth surface is placed over the medial end of the TEN and screwed into the bone. The use of End Caps might reduce irritation rates. Future research should compare intramedullary fixation with and without an End Cap to assess the differences in medial protrusion, irritation rates, cosmetics and functional results.

Overall the one year follow-up results of the POP-trial need to be awaited to draw further conclusions regarding functional results and complications after surgical management of dislocated midshaft clavicle fractures.

Conclusions

1. No difference in functional outcome or complications after plate fixation and intramedullary fixation for dislocated midshaft clavicle fractures are found in recent literature. The quantity of high quality evidence to support these statements is low.

2. Plate fixation is a safe treatment option for dislocated midshaft clavicle fractures but implant related complications tend to be frequent resulting in removal of the implant.

3. Intramedullary fixation is a safe treatment option for dislocated midshaft clavicle fractures but implant related complications (medial protrusion) resulting in a minor intervention or premature removal of the implant are frequent.

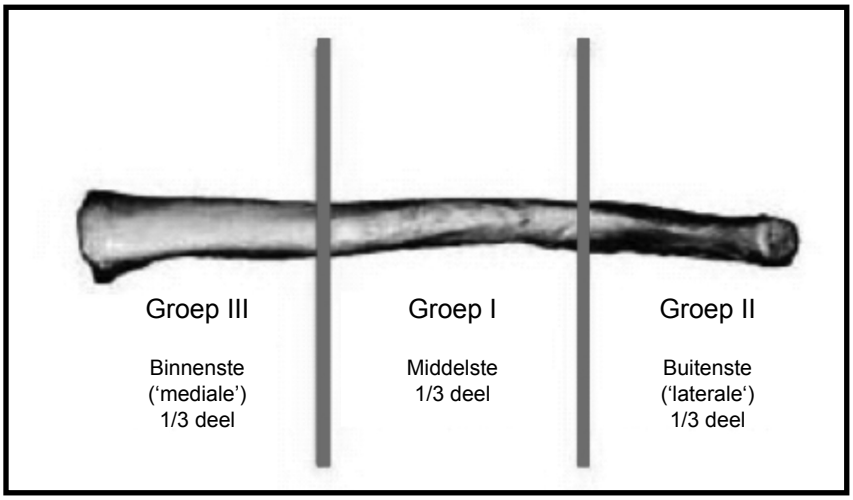
4. Plate fixation is recommended if fast functional recovery is needed for dislocated midshaft clavicle fractures.

Chapter 10

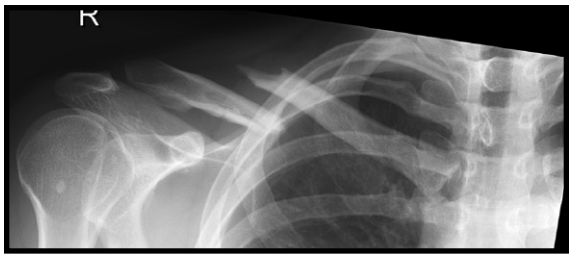
Nederlandse samenvatting en conclusies
(Dutch summary and conclusions)

Dit proefschrift gaat over de chirurgische behandeling van gedisloceerde midschacht claviculafracturen, oftewel de volledig verplaatste sleutelbeenbreuk in het middelste 1/3de deel van dit bot (zie figuren 1, 2 en 3). U kunt zich afvragen of dit een belangwekkend onderwerp is, maar, om maar eens iets te noemen, dit botje speelde destijds wel een belangrijke rol in de geschiedenis van het Verenigd Koninkrijk. In 1702 struikelde namelijk het paard van Zijne Majesteit de Koning Willem III van Oranje-Nassau over een molshoop nabij Hampton Court Palace in London waarbij de koning zijn sleutelbeen brak. Als gevolg van deze breuk ontwikkelde de berijder een longontsteking die hem uiteindelijk fataal werd. Omdat Willem III op dat moment geen kinderen had, werd de troonsopvolging gewijzigd en zitten sindsdien de Windsors in plaats van de Oranje Nassaus in het Verenigd Koninkrijk op de troon. Noem het maar een kleinigheid!

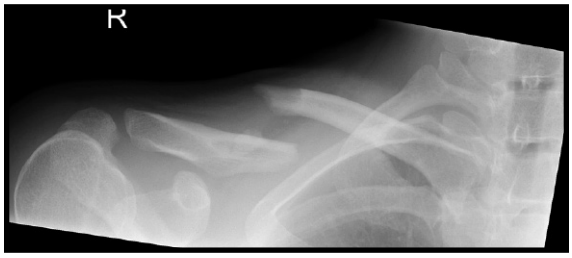
Een sleutelbeenbreuk (claviculafractuur) komt redelijk vaak voor en is meestal het gevolg van een directe klap op de schouder of een val met uitgestrekte armen. Het zal u dan ook niet verbazen dat dit letsel veel optreedt tijdens het wielrennen, met als belangrijkste voorbeeld de claviculafractuur die Lance Armstrong opliep na een val tijdens de ronde van Spanje. Hij werd direct met veel bombarie naar de VS gevlogen en tijdens een urenlang durende operatie kon dit sleutelbeen met platen en schroeven minutieus aan elkaar geschroefd worden, waarna hij enige weken later de Tour de France alsnog kon rijden.



Figuur 1. Indelingen van het sleutelbeen



Figuur 2. **Een gedisloceerde midschacht claviculafractuur in twee richtingen**



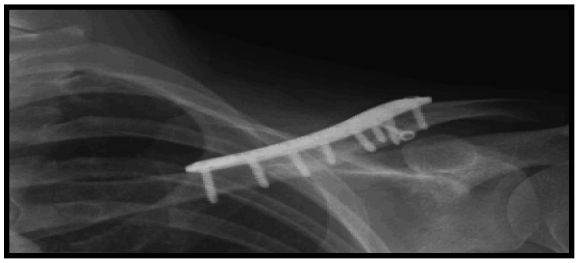
Figuur 3. **Een gedisloceerde midschacht claviculafractuur in twee richtingen**

Jarenlang is echter gedacht dat een breuk van de clavicula het beste conservatief (niet operatief) behandeld kon worden. Dit ging ook vaak goed. In een groot onderzoek uit de jaren ‘60 van de vorige eeuw werd al beschreven dat met een simpele mitella er nauwelijks problemen en complicaties optraden, zelfs niet bij breuken die volledig verplaatst waren. Het niet helen van de fractuur na een periode van 6 maanden (een zogenaamde nonunion) werd daarbij nauwelijks gezien (<1%). Het verkeerd aan elkaar groeien van het bot in een afwijkende stand (een zogenaamde malunion) werd wel regelmatig gezien maar leek op lange termijn niet tot veel (functionele) klachten te leiden.

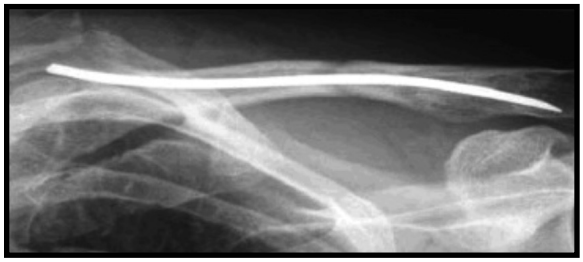
Er zijn wel enige kanttekeningen bij dit grote onderzoek te plaatsen. Een groot gedeelte van de breuken trad op bij kinderen en heel jonge patiënten, waarvan bekend is dat fractuurgenezing bijna nooit tot problemen, zoals een nonunion, leidt. Op jonge leeftijd groeit bot makkelijker en sneller weer aan elkaar vast. Bovendien werd in dit onderzoek niet gekeken naar het uiteindelijke functionele resultaat. Het bleek immers dat, ondanks de toen heersende gedachte dat de stand waarin genezing optrad er niet toe deed, er op termijn wel degelijk klachten konden ontstaan als een dergelijke malunion zich voor deed.

Toen er in de negentiger jaren dan ook een nieuw grootsopgezet onderzoek naar claviculafracturen werd verricht kwamen daar andere resultaten uit. Zo bleek het aantal nonunions beduidend hoger te liggen dan tot nu toe aangenomen werd, dit kon zelfs oplopen tot wel 15 procent. Daarnaast bleken dus de in malunion geconsolideerde fracturen op langere termijn niet zo asymptomatisch te zijn als tot dan werd aangenomen. Vanaf dat moment werd er meer en meer gekozen voor operatieve fixatie, met name bij patiënten in hun werkzame levensfase met een gedisloceerde claviculafractuur.

De twee meest gebruikte operatieve methodes voor claviculafracturen zijn fixatie door middel van een plaat (zie figuur 4) of door middel van een pen (zie figuur 5). Deze twee methodes werden reeds door verschillende onderzoekers met de conservatieve methode vergeleken. De conclusies van deze onderzoeken lieten zien dat een operatieve methode tot sneller herstel leidde vergeleken met de conservatieve methode. Daarnaast leek het dat er minder nonunions en malunions ontstonden na operatieve fixatie. Welke van de twee operatieve methodes beter was (plaat fixatie of fixatie d.m.v. een pen) is tot op heden echter niet goed bekend. Omdat operatieve behandeling meer en meer toegepast wordt is een onderzoek naar de beste operatie techniek noodzakelijk. Het doel van dit proefschrift is dan ook om een bijdrage te leveren in deze discussie zodat duidelijk wordt welke techniek superieur is.



Figuur 4. **Plaatosteosynthese**



Figuur 5. **Intramedullaire pen fixatie**

In *hoofdstuk 1* wordt een inleiding gegeven over de achtergrond, het doel en de opzet van dit proefschrift. De doelstellingen van dit proefschrift zijn:

1. Een overzicht van de huidige literatuur geven over onderzoeken waarin de plaat en de pen fixatie van claviculafracturen worden vergeleken.

2. Inzicht te krijgen in de complicaties zowel na plaat en pen fixatie bij claviculafracturen.

3. Het verstrekken van de achtergrond en het ontwerp van een onderzoek ter vergelijking van plaat en pen voor claviculafracturen (Plaat Of Pen studie, de zogenaamde POP studie).

4. De presentatie van de korte termijn resultaten van de POP-studie.

Hoofdstuk 2 is een literatuuronderzoek met als doel het vinden en bestuderen van onderzoeken die de plaat en de pen vergelijken voor claviculafracturen. De kwaliteit van het bewijs van alle geïncludeerde studie is geëvalueerd met behulp van twee verschillende systemen die de kwaliteit van de onderzoeken scoort. Elke studie afzonderlijk is beoordeeld op kwaliteit met een schaal lopend van ‘zeer laag’ tot ‘hoog’. Hoe hoger de kwaliteit van bewijs hoe beter de toepasbaarheid van de resultaten op een bepaalde geselecteerde patiëntenpopulatie. Uiteindelijk komen vier studies in aanmerking voor inclusie; één studie is volgens de kwaliteitsscores van hoge kwaliteit, terwijl de andere drie studies van lage kwaliteit zijn. De geanalyseerde onderzoeken laten geen verschil in schouderfunctie of complicaties zien in een periode van 6 tot 13 maanden na operatie. Typische complicaties van de plaat zijn oppervlakkige wondinfectie, loslating van het implantaat of breuk van het implantaat, hypertrofische (wild groeiende) littekens en refractuur (opnieuw breken van de fractuur op dezelfde plek) na verwijdering van het implantaat. Complicaties na de pen zijn migratie en perforatie (door de huid) van het implantaat in combinatie met irritatie aan het mediale uiteinde. Migratie is de verplaatsing van de pen in het bot. De mediale zijde is de zijde aan de kant van het borstbeen waar de pen ook wordt ingebracht. Ondanks het beperkt aantal beschikbare studies, is er geen verschil aantoonbaar in schouderfunctie van patiënten die met plaat of pen zijn behandeld voor claviculafracturen in een tijdsbestek van 6 tot 13 maanden na de operatie.

Hoofdstuk 3 richt zich specifiek op de complicaties van de plaat. Opnieuw is literatuuronderzoek uitgevoerd waarbij er uiteindelijk elf studies bestudeerd zijn. Complicaties zijn verdeeld in twee groepen: grote en kleine complicaties. Grote complicaties zijn de complicaties die een extra operatieve ingreep vereisen om de complicatie te verhelpen. Grote complicaties zijn nonunions 6 maanden na operatie, symptomatische malunions, diepe infecties waarvoor verwijdering van het implantaat noodzakelijk is, breuk van het implantaat en refracturen na het verwijderen van de plaat. De resultaten van deze studie tonen aan dat de aantallen nonunions en symptomatische malunions niet hoger dan 10% zijn in alle elf geanalyseerde studies (op een studie na). Diepe infecties komen in minder dan 8% van de patiënten voor in de bestudeerde studies. Hoewel het aantal kwalitatief goede studies laag is, lijkt de conclusie toch gerechtvaardigd dat de plaat een redelijk veilige methode is om een gedisloceerde claviculafractuur mee te behandelen.

In *hoofdstuk 4* is het bovenstaande herhaald maar dan met de beschikbare literatuur over de fixatie d.m.v. een pen. Grote complicaties, zoals nonunion, symptomatische malunion en diepe infecties waarvoor verwijdering van het implantaat nodig is, zijn niet hoger dan 7%. Falen van het implantaat (loslating van het materiaal, implantaatbreuk) komt in minder dan 6% van de gevallen voor. De belangrijkste kleine complicatie die alleen optreedt bij een fixatie met een pen is de migratie van de pen, waardoor irritatie optreedt. Dit is echter relatief gemakkelijk op te lossen, meestal door onder lokale anesthesie een gedeelte van de pen af te knippen. Concluderend is dan ook een intramedullaire pen een veilige behandelingsoptie voor een gedisloceerde claviculafractuur.

In *hoofdstuk 5* is een retrospectieve (d.w.z. terugblikkende) vergelijking van beide behandelingsgroepen uitgevoerd in een perifeer ziekenhuis (het Diakonessenhuis in Utrecht). De gegevens van 90 patiënten die zijn behandeld met ofwel een plaat of een pen werden beoordeeld en complicaties werden geanalyseerd. Bij zes patiënten (14%) traden problemen op zoals een breuk van de plaat en/of loslating van de schroeven. Slechts bij één intramedullaire pen werd een nonunion gezien (2%). Bij vijf patiënten moest vanwege het niet functioneren van de plaat een nieuwe operatie uitgevoerd worden, terwijl dat in de patiëntengroep die met een pen behandeld was slechts eenmaal hoefde te gebeuren.

Na verwijderen van de plaat traden drie refracturen (7%) op. Dit werd nooit gezien bij de patiënten die met een pen behandeld waren. Zes keer was het nodig de pen in te korten onder lokaal anesthesie wegens migratie van het implantaat. Toch kon er in dit onderzoek niet duidelijk een voorkeur voor één van de implantaten worden uitgesproken, omdat niet duidelijk was bij welke type breuk voor een plaat of voor een pen werd gekozen. Reden voor de start van een gerandomiseerd onderzoek waarbij diverse ziekenhuizen mee konden doen.

In *hoofdstuk 6* wordt het ontwerp van dit onderzoek gepresenteerd waarin de plaat wordt vergeleken met de pen voor gedisloceerde midschacht clavicula fracturen.

De eerste resultaten van dit onderzoek zijn gepresenteerd in *hoofdstuk 7*. Vanaf januari 2011 tot september 2012 zijn in totaal 120 patiënten gevraagd mee te doen aan dit onderzoek om vervolgens een plaat of een pen te loten. Operatieduur, pijn na de operatie, bewegingsuitslagen aan de hand van speciale scores en complicaties zijn gedocumenteerd tot zes weken na de operatie. De bewegingsuitslagen van de schouder, arm en hand zijn bepaald door middel van twee verschillende scores. Een daarvan is de DASH score. De DASH score (Disabilities of Arm Shoulder and Hand-score) is een score systeem waar aan de hand van 30 items de patiënt gevraagd wordt of algemene dagelijkse handelingen en bezigheden problemen opleveren. Zo wordt er bijvoorbeeld gevraagd of de patiënt moeite heeft met schrijven, een tas optillen of een lamp verwisselen. Aan de hand van een puntensysteem wordt er bepaald of de functionaliteit van de schouder slecht is (een score van 100) of dat de schouderfunctionaliteit perfect is (een score van 0). Een modaal gezond persoon heeft een score tussen de 0 en de 15. De plaat-groep heeft een gemiddelde DASH-functionaliteits-score van 11.36, de pen-groep heeft een gemiddelde DASH-functionaliteits-score van 15.07 zes weken na de operatie. Gezien deze cijfers doet de plaat groep het dus beter op basis van deze score. Een andere gebruikte score is de Constant-Murley score. Met deze score wordt er fysiek gekeken naar de bewegingsuitslagen van de patiënt, wat de patiënt maximaal kan tillen en of de patiënt nog pijn heeft bij deze bewegingen. Bij deze score zijn de uitslagen precies het tegenovergestelde. Een score van 100 is de best haalbare score, een score van 0 de slechtste. De gemiddelde Constant-Murley score zes weken na de operatie is 91,05 in de plaat-groep en 84,08 in de pen-groep. De gemiddelde operatietijd in de plaat-groep is 53,96

minuten en in de pen-groep 43,08 minuten. In totaal zestien patiënten melden irritatie bij het uitstekende deel van de pen nabij de insteekplaats dichtbij het borstbeen in de pen-groep. Concluderend rapporteert dit onderzoek betere functionele resultaten van de schouder zes weken na de operatie bij patiënten behandeld met een plaat voor gedisloceerde midschacht clavicula fracturen. De pen-groep heeft significant meer complicaties, maar de tijd van opereren in deze groep is korter.

Toekomstig onderzoek

Dit proefschrift legt de basis voor uitgebreid onderzoek over de chirurgische behandeling van gedisloceerde midschacht clavicula fracturen. Door middel van uitgebreid literatuur onderzoek en klinische studies zijn onze bevindingen dat zowel plaatosteosynthese als intramedullaire fixatie veilige behandelingsopties zijn voor een claviculafractuur.

Bij eerste analyse lijkt op korte termijn de plaat de beste optie. Na 6 weken zijn de functionele resultaten beter dan na operatie middels een pen. De uiteindelijke resultaten van de POP studie dienen te worden afgewacht om een uiteindelijke keuze tussen de twee technieken mogelijk te maken.

Chapter 11

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Chapter 12

About the author

Curriculum Vitae

Franciscus Jasper Gerardus Wijdicks was born on March 15, 1986 in Breda, the Netherlands. After graduating from high school (Mencia de Mendoza Lyceum Breda) in 2004, at first he started with the study Communications and Informational Sciences at Utrecht University. In 2007 he got accepted for the study Medicine at the Erasmus Medical University of Rotterdam.

During his study he was an active member of the Utrechtsch Student Corps and the Utrechtsch Studenten Roeivereniging Triton, with whom he participated in the Ringvaart Regatta in 2011. In 2011 he started a research project at the Department of Surgery at the Diakonessenhuis (Dr. G.J. Clevers) in Utrecht, what developed into a doctoral program under supervision of prof. dr. L.P.H. Leenen, Dr. E.J.M.M. Verleisdonk and Dr. R.M. Houwert. He temporarily interrupted his study of Medicine in order to work on his research project full time. During his doctoral program he received a prestigious grant from the AO foundation, a nonprofit organization specialized in the treatment of trauma patients. A full time period of 2 years work has resulted in this thesis. At the start of 2013 he resumed his Medicine study with his internships. He hopes to graduate from Medical school in the year 2014.