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Biomechanical studies on transverse olecranon and patellar fractures: a systematic review with the development of a new scoring method

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Introduction: Several methods of transverse patellar and olecranon fixation have been described. This article compares biomechanical studies of various fixation methods using a newly developed scoring method.

Source of data: The databases PubMed, Web of Science, Science Direct, Google Scholar and Google were searched for relevant studies.

Areas of agreement: Fixation hardware failure remains a problem. Various materials and fixation techniques have been tested to provide an improved fixation of transverse olecranon and patellar fractures.

Areas of controversy: The difference in biomechanical testing setup between the studies makes it hard to compare different fixation techniques.

Growing points: The newly developed grading method was proved to be unbiased and reliable; however, extra specifications need to be added at some criteria when adopting the scoring method.

Areas timely for developing research: Non-metallic constructs may provide an improvement to the currently used metallic tension band wiring technique; however, clinical research is required.

Keywords: patellar fracture/olecranon fracture/internal fixation/tension band wiring

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Introduction

The olecranon

Transverse displaced olecranon fractures are the most common fractures that require operative intervention in the elbow in adults.[1–4] Olecranon fractures are commonly caused by a direct blow to the elbow, falls from a height >2 m, motor vehicle incidents or simple falls and are the most commonly observed orthopedic injuries in the emergency room.[2,5–7]

Various fixation techniques have been used for fixation of olecranon fractures, including tension-band wiring (TBW) in different configurations, TBW combined with Kirschner wires (K-wires),[1,6,8] cancellous screws,[9] plate and screw fixation,[7,10–12] Netz pins,[13] biodegradable pins[14] or absorbable sutures.[15,16] TBW is a commonly used method, first described by Weber and Vasey,[17] and recommended for transverse fractures by the Arbeitsgemeinschaft fur Osteosynthesefragen (AO).[2,3,8,18] With this technique, a high union rate and good functional recovery have been reported.[3,19]

However, complications occur with this technique, the most common one being prominence of the end of the K-wires which may cause skin irritation.[9,20,21] Skin penetration and infections are also observed, and delayed union can be a consequence of this infection. Migration of the wires can cause cartilage injury, soft-tissue problems, local pain and re-interventions. Loss of motion, extension and flexion are usually observed, and hardware removal is usually requested.[2,8,11,19,20] Therefore, adaptations and improvements have been made to overcome the complications when treating transverse olecranon fractures.[2,4,6,21]

The patella

The patella is the largest sesamoid bone in the skeletal system. Its subcutaneous and relatively superficial position makes the patella vulnerable to direct traumas. Fracture of the patella constitutes ~1% of all skeletal fractures.[22] Approximately 50–80% of patellar fractures are transverse fractures,[23] likely to disrupt the knee extensor mechanism. Surgical intervention is necessary either when the fracture gap exceeds 2–3 mm or in case of joint incongruence,[24,25] and when the continuity of the extensor mechanism of the knee is functionally compromised. Since the patella is continually subjected to strong tensile forces, patella fractures require rigid fixation with a perfect reduction of the fracture.[26] This can be achieved in different ways. The modified tension band wiring (TBW) technique is the most widely used and accepted treatment for displaced transverse patella fractures.[23,27–29] However, the use of the TBW technique is associated with prominent hardware and post-operative discomfort. Early loss of reduction of the fracture occurs in 22–30% of all cases.[30,31] Failure of fixation, K-wire migration, revision surgery and post-operative pain due to skin irritation are also not uncommon.[32,33] Overall, revision surgery with K-wire removal becomes necessary in up to 65% of all cases.[25,27,33]

Goals and objectives

Recently, non-metallic alternatives for both patella and olecranon fixation have been studied, which may lead to a decrease in discomfort and hardware failure. The current study assessed the published literature on fixation techniques and outcomes for patella and olecranon transverse fractures. In the published literature, two types of studies can be distinguished: clinical and biomechanical studies. For the latter type, no assessment method has yet been developed, contrary to clinical studies. In this study, a new scoring system is proposed for biomechanical studies and tested on the biomechanical studies on the topic at hand.

Methods

Search and selection

A literature search was performed using PubMed, ScienceDirect, Web of Knowledge, Scopus, Google Scholar and Google. The latter was included to find studies unpublished in academic papers, but already presented in lectures or congresses. The databases were searched using the keywords ‘patella’ or ‘olecranon’ and ‘fracture’, ‘internal fixation’ and ‘tension band wiring’. The date of the most recent search was 18 December 2012. No restriction to time period or language was applied. All titles relevant to the subject were retrieved and abstracts were scanned.

Studies in which no transverse fractures or olecranon or patella bones were studies were excluded, as were reviews, case reports, letters to the editor, book chapters and proceedings. The articles in Turkish, Korean, Italian and Chinese were also discarded. All other abstracts were categorized into patella and olecranon and subsequently divided into biomechanical and clinical studies, resulting in four groups of studies. Full text articles were obtained of all remaining studies. In this review, only the biomechanical studies were assessed (Fig. 1).

Scoring system

Since no score methodology has been developed to assess the quality of biomechanical studies, a new methodology was developed (Table 1). This

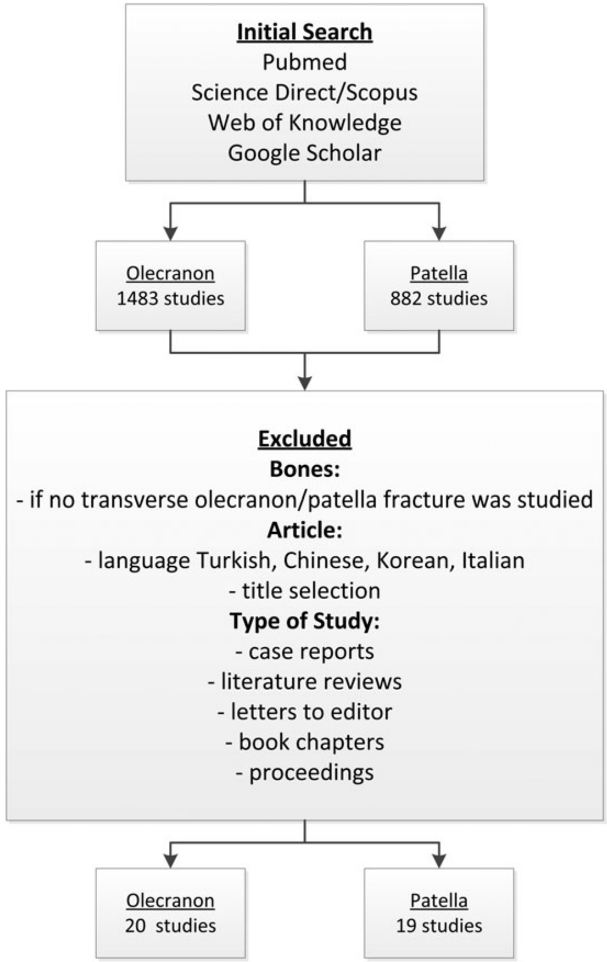

Fig. 1 Flow diagram of literature search.

scoring method consists of three parts: material specifications, experimental setup and results. A total of 100 points are available, with 100 points being a 'perfect' paper. Part 1, material specification, can gain a total of 25 points. The model system used can be of great influence on the results and should therefore be graded accordingly. Part 2, experimental setup, can gain a total of 45 points. A clear description of the experimental setup is necessary to understand the origin of the results and to make comparisons with other studies possible. Given the importance of this part it gains a high weighting factor in the scoring method. Part 3, results, can gain a total of 30 points. Description of the results and an evaluation of the model/experimental system used are of great importance in supporting conclusions drawn from the study. The studies were assessed twice by the four authors independently with an interval of 2 weeks, resulting in a total of eight assessments per each study.

Table 1 Scoring criteria.

	Score
Part 1: Material specifications	
Study size, number of assessed bones or joints	
>10	7
5–10	4
<5	0
Cadaver models	
Origin of assessed material	
Human cadaver material	5
Animal cadaver material with clinical relevance defined	3
Animal cadaver material without clinical relevance defined	0
Bone density of assessed material reported (including standard deviation)	
Defined with CT at sub 100-μm resolution	5
Defined with DXA	4
Defined with radiograph/CT	2
Undefined	0
Clinical/radiographical assessment of pre-testing state bone	
Examination performed on all bones, with exclusion criteria defined	2
Examination performed on all bones	1
Not stated, unclear	0
Matched pairs of bones from individual or individual bones	
Matched when two techniques are compared	2
Individual when multiple comparisons are made	2
Individual when two techniques are compared	0
Fixation method	
Fresh or frozen with 1 freeze/thaw cycle	4
Frozen with multiple freeze/thaw cycles	2
Formaldehyde/undefined	0
Synthetic model	
Mechanical properties defined of the synthetic system	
Per defined mechanical property important for the experimental setup: 4 points are given with a maximum of 12 points	
Geometry	
With clinical relevance	6
Without clinical relevance	0
Part 2: Testing methods	
Description of osteotomy given	
Adequate (preparation bone well described)	5
Fair	3
Unclear/unstated	0
Fixation method performed by	
Multiple surgeons	5
One surgeon (surgeon specified by # operations)	4
One surgeon (no specifications)	3
Undefined	0
Assignment of fixation method	
Random	5
Dominant arm/non-dominant joint specific	3
Not defined	0
Number of fixation techniques performed on one bone	
One fixation technique per bone only	5
Several	0

Continued

Table 1 *Continued*

	Score
Description of mechanical test method given	
Adequate	15
Fair	10
Unclear/unstated	0
Failure statement regarding displacement of the fracture defined	
Stated	5
Unstated	0
Statistical description data	
Complete description	5
Limited description	3
Unclear/unstated	0
Part 3: Description of results	
Outcome measurements clearly described	
Complete description	10
Limited description of outcome measurements	7
Unclear/unstated	0
Abrasions progression defined	
Stated	10
Unstated	0
Limitations of testing methods defined	
Complete description	10
Limited description	7
Unclear/unstated	0

Part 1: Material specifications

A larger study size confers greater validity than a case study; therefore, more bones assessed produce a higher score. Since the mechanical properties of a specific fixation method are influenced by the used models system, the properties of the model system should be stated explicitly. To ensure a fair grading method, cadaver models and synthetic bone models were considered separately.

For cadaver systems, the origin of the bones and the clinical relevance of them is an important factor. If the research mentions clinical relevance for animal cadavers it gains points, regardless of its relevance.

The properties of the bones should be clearly stated; a fixation method tested on brittle old bones could reveal other properties then when it is tested on strong young bones. If, after assessing the bones, some are excluded, the reasons for exclusions should be stated explicitly. Therefore, an important point is that one knows the properties of the material they are studying. This can be done by clinical and radiographical assessment of the bone. The bone density is the most important parameter which gives an idea of the strength of the bone[34]; this can be assessed with different techniques giving different accuracy.[35]

Obtaining sufficient donors to account for biological differences is difficult.[36] For the best comparisons, it is useful to match the bones from a cadaver. The difference then truly lies in the difference in technique tested, and not in the biological variation of the donors. If, however, multiple techniques are compared, this is not possible. In this instance, comparison of more than two techniques on individual bones is higher than using individual bones when comparing two techniques.

For synthetic bone models, it is important that the mechanical properties of the synthetic bones used are specifically stated. This makes the research reproducible. Four points can be gained per each property, for a maximum of 12 points. This criterion is of course subjected to some subjectivity, but all properties that are known about the synthetic bone should be mentioned.

The geometry of the used model should of course also been taken into account, as a geometry resembling clinical data is of greater relevance then a random geometry.

The number of tested bones/models is considered the most important criteria of material specifications. Therefore, it can gain a total of 7 points. The criteria which are of greatest influence on the characterization of the model system have an almost equal weight. They can gain a total of 14 points for the cadaver models and a total of 12 points for the synthetic models.

Part 2: Experimental setup

In this part the experimental setup is graded. There is much difference in the way biomechanical studies are performed. However, some basic points have to be satisfied.

First, how the procedures are undertaken can influence the outcome of the experiment. Therefore, a clear description of the osteotomy should be given. Description and position of the osteotomy and how it is introduced gain more points than only mentioning the position of osteotomy.

In clinical practice, the experience and expertise of the surgeon have a great influence on the outcome of the surgery. Therefore, the fixation method should be applied by multiple surgeons to exclude surgeon-dependent results. If the procedure is performed by one surgeon only, the experience of the surgeon should be taken into account. If it is unclear or not stated, no points should be given.

The assignment of the techniques should be undertaken randomly to avoid dominant/non-dominant specific results. No more than one technique should be used on one set of bones, as previous surgery may influence the mechanical properties of the bone.

The experimental setup should be described in such a way that it ensures reproducibility. The mode of failure should be explicitly stated.

Furthermore, data analysis should be described exhaustively. In this part, the description of experimental setup is considered to have a higher weight than the other criteria. Therefore, it can gain 15 points while every other criteria in this part can gain 5 points.

Part 3: Description of results

The outcomes and description of the results should be clearly stated. Again, there is the issue of subjectivity. In clinical studies, abrasions can cause side effects.[37–39] Therefore, the occurrence of abrasions should be stated. The limitations and drawbacks of the experiment should be clearly stated, as this can be taken into account when reproducing, improving or comparing studies. These three criteria are considered equally important, and each can gain 10 points.

Statistical analysis

The intra-class correlation coefficient (ICC) was used to determine the intra- and inter-rater reliability using a two-way mixed ANOVA model. For values ranging from 0.81 to 1.0, the reliability was considered excellent; from 0.61 to 0.80, very good; from 0.41 to 0.60, good; from 0.21 to 0.40, reasonable and, finally, from 0.00 to 0.20, poor.[40–42] The statistical analysis was performed using the SPSS® software, version 20.0 (Chicago, USA).

Results

Database searches

For the olecranon, 1483 studies were originally identified; 20 were relevant, and we assessed them using our scoring method. Two further studies were excluded due to structure incompatibility with the scoring method. The relevant studies were published from 1985 to 2012 in the USA (15), the UK (2), Switzerland (1), the Netherlands (1) and Taiwan (1). For the patella, 882 studies were found initially, of which 19 were included in this review after applying the exclusion criteria. The relevant patella studies were published from 1987 to 2012 in the USA (7), Germany (4), the UK (3), Turkey (2), Suisse (1) Ireland (1) and Greece (1).

Intra- and inter-rater reliability

Table 2 shows the intra-rater reliability of the scoring method. For the olecranon, one rater showed excellent agreement (0.92), two raters good agreement (0.70, 0.77) and one reasonable agreement (0.36). For the patella, two raters showed excellent agreement (0.85, 0.93), whereas the other two showed good agreement (0.76, 0.75).

Table 3 shows the inter-rater reliability of the scoring method. Both before and after consensus on the subjective criteria and correction of objective points the ICC values showed excellent agreement, ranging from 0.93 to 0.97.

Quality assessment

Tables 4 and 5 show the overall scores and their averages of all raters for the olecranon and patella studies. For the olecranon, the overall average score was 63.2, with scores ranging from 25.0[44] to 75.8.[49] Three studies

Table 2 Intra-rater reliability for each rater, for both olecranon and patella studies.

	Olecranon	Patella
Rater 1	0.92	0.76
Rater 2	0.70	0.85
Rater 3	0.77	0.93
Rater 4	0.36	0.75

Table 3 Inter-rater reliability for all raters for both olecranon and patella studies.

	Olecranon	Patella
Pre-consensus	0.93	0.95
Post-consensus	0.99	0.99

Table 4 Individual and average scores for all olecranon studies after consensus.

Study	R1 (1)	R1 (2)	R2 (1)	R2 (2)	R3 (1)	R3 (2)	R4 (1)	R4 (2)	Avg	St Dev
Brink *et al.*[43]	67	67	67	67	67	67	67	67	67.0	0.0
Candal Couto *et al.*[44]	25	25	25	25	25	25	25	25	25.0	0.0
Carofino *et al.*[80]	70	68	68	70	68	70	65	65	68.0	2.1
Catalano *et al.*[79]	39	39	39	39	39	42	39	42	39.8	1.4
Dieterich *et al.*[45]	72	72	67	70	72	72	67	67	69.9	2.5
Elliot *et al.*[46]	68	68	63	66	68	68	66	66	66.6	1.8
Fyfe *et al.*[47]	44	42	42	42	41	44	39	41	41.9	1.6
Grafinger *et al.*[48]	73	73	76	73	76	76	73	75	74.4	1.5
Hammond *et al.*[49]	75	76	76	75	76	76	76	76	75.8	0.5
Hutchinson *et al.*[50]	59	61	62	62	62	62	59	59	60.8	1.5
Kozin *et al.*[77]	62	62	59	60	57	62	60	60	60.3	1.8
Laliss and Branstetter[51]	71	74	73	73	73	76	69	71	72.5	2.1
Moed *et al.*[52]	70	73	68	71	73	75	70	70	71.3	2.3
Molloy *et al.*[53]	73	73	70	70	68	69	70	72	70.6	1.8
Neat *et al.*[54]	61	66	63	64	61	61	66	66	63.5	2.3
Paremain *et al.*[55]	68	68	71	68	70	70	68	70	69.1	1.2
Petraco[56]	75	75	74	74	75	75	72	72	74.0	1.3
Prayson *et al.*[57]	65	65	66	66	61	64	63	63	64.1	1.7
Sadri *et al.*[58]	67	72	72	72	72	70	67	67	69.9	2.5
Wu *et al.*[59]	61	60	60	60	58	63	57	62	60.1	2.0

With R1 is rater 1, R2 is rater 2, etc. and the first or second assessment given in brackets.

Table 5 Individual and average scores for all patella studies after consensus.

Study	R1 (1)	R1 (2)	R2 (1)	R2 (2)	R3 (1)	R3 (2)	R4 (1)	R4 (2)	Avg	St Dev
Baran *et al.*[60]	38	35	35	35	35	33	38	36	35.6	1.7
Baydar *et al.*[61]	62	59	56	54	59	64	62	62	59.8	3.4
Benjamin *et al.*[28]	50	48	48	48	45	47	45	45	47.0	1.9
Burvant *et al.*[62]	60	59	58	55	63	63	57	57	59.0	2.9
Ciocanel *et al.*[63]	29	26	29	29	29	29	26	26	27.9	1.6
Curtis[64]	54	52	49	49	49	48	49	52	50.3	2.1
Dargel *et al.*[36]	73	70	73	73	70	73	69	73	71.8	1.8
Fortis *et al.*[65]	55	55	53	53	55	54	56	56	54.6	1.2
Hughes *et al.*[64]	62	62	58	58	58	58	58	58	59.0	1.9
John *et al.*[67]	52	52	52	54	57	57	55	52	53.9	2.2
McGreal *et al.*[68]	52	52	49	49	49	52	51	49	50.4	1.5
Patel *et al.*[69]	66	66	61	61	66	64	66	66	64.5	2.3
Perry *et al.*[70]	55	55	52	52	52	52	52	52	52.8	1.4
Rothaug[71]	53	62	51	53	65	68	51	54	57.1	6.8
Schnabel *et al.*[72]	69	67	68	71	70	70	69	69	69.1	1.2
Thelen *et al.*[73]	71	71	73	69	73	73	73	71	71.8	1.5
Weber and Vasey[17]	50	50	45	50	50	50	49	48	49.0	1.8
Wild *et al.*[74]	71	71	69	69	71	73	73	73	71.3	1.7
Wild *et al.*[75]	36	37	37	37	62	62	40	43	44.3	11.2

With R1 is rater 1, R2 is rater 2, etc. and the first or second assessment given in brackets.

had a score below 50 and the remaining 17 studies had scores between 60 and 76. For the patella, the overall average score was 55.2, with scores ranging from 27.9[65] to 71.8.[75] Five studies had a score below 50. The remaining 15 studies had scores ranging from 50 to 72. All studies were reviewed, no matter what the score was.

Literature overview

Olecranon

With an average score of 64.0, the biomechanical literature on olecranon fracture fixation can be considered as fairly good quality. Fourteen of the 18 studies used cadavers in which transverse fractures were simulated. In one study[48] canine cadavers were used, whereas in all other 13 studies human cadavers were used. The remaining four studies[54,76–78] used bone models. The difference in experimental setup between the studies makes it hard to compare them. Fortunately, in almost every study two or more techniques were tested and compared.

Fixation placement

Several studies focused on the placement of the fixation. Candal-Couto *et al.*[44] concluded that the direction in which the wires are inserted is important. Fixation should be placed with the forearm in supination at 30°

of ulnar angulation. They recommend this technique to be adopted to avoid forearm rotation impairment. This study only received a grading of 27 points in its quality assessment making it the article with the lowest score. Catalano *et al.*[79] states that larger insertion angles of the K-wires might help avoid neurovascular injury when the insertion point is at or just proximal to the tip of the olecranon. In this study, the safe zone for the pin appeared to be 0–10° on the anterposterior view and on the lateral view 20–30°. In 1997, Prayson *et al.*[57] found that K-wire placement through the anterior cortex of the ulna appears to offer increased resistance to fracture displacement, and braided cable affords greater resistance than monofilament wire. However, the risk of injury is present due to nearby anterior neurovascular structures. Finally, Hammon *et al.*[49] concluded that the stability achieved with TBW fixation did not vary with the osteotomy location. They tested this by creating osteotomies at different locations in human cadaveric upper extremities, depending on the trochlear notch and testing. After TBW the specimens were fixed at 90° flexion and loaded through the triceps tendon. No statistical differences in fracture displacement were found between groups.

AO technique versus new TBW

Wu *et al.*[59] found no significant difference in fracture displacement between traditional AO and the new TBW technique. However, the new technique is technically easier and safer. In 1997, Paremain *et al.*[55] came to a similar conclusion, stating it unlikely that modified TBW would provide intrinsic static compression greater than that provided by the AO technique. No significant increase in resistance to gap formation was found.

Grafinger *et al.*[48] compared double loop (DL) TBW and dual interlocking single loop (DISL) TBW with the AO technique in canine cadaver forelimbs. Single load to failure was applied through the triceps tendon. At 0.5 mm of displacement, the DISL construct resisted more load than AO and DL constructs. At the critical fracture displacement the DL technique resisted more load than the AO technique. No significant difference between the DISL and AO TBW techniques was found in terms of fracture displacement.

Wiring

Several studies focused on alternatives to the steel wires normally used. Carofino *et al.*[80] studied a high-strength suture tension band, which appeared to have biomechanical properties equivalent to metal wire tension bands, when used with IMS fixation and K-wire constructs. Dickman *et al.*[76] studied titanium, monofilament wire and polyethylene by forming a single loop from each cable by wrapping it around a 25.4-mm diameter cylindrical mandrel. The ends were fastened using tensioning and crimping tools with techniques ‘identical to those used in clinical settings’.

Titanium had 7–90% of the ultimate tensile stress (UTS) of steel cables, while the UTS of polyethylene was similar to the steel cable. Titanium, steel and polyethylene were 100–600% stronger than monofilament wire. The polyethylene cable, finally, was abraded by the bone model used, whereas titanium and steel abraded the bone, a serious side effect. It must be noted that Dickman *et al.* did not use any bone model, but merely tested the cables of different material on a tensile testing apparatus. This made assessing this study with the grading method impossible.

In a study performed by Kozin *et al.*[77], neither monofilament wire or multifilament cable showed an increased stability. Also, the studied materials were more resistant to posterior than to an anterior load.

Stainless steel, FiberWire and EthiBond sutures were studied by Laliss *et al.*[51] FiberWire is made of a combination of ultra-high molecular weight polyethylene (UHMWPE) fibres and polyester fibres; EthiBond is made of polyester fibres only. They found that both stainless steel wire and FiberWire showed no failure (i.e. gap displacement of >2.0 mm), whereas No. 2 and some of the No. 5 EthiBond failed at 450 N. FiberWire may reduce the incidence of discomfort from the hardware and may thus be a good alternative to stainless steel. The author however stated that clinical trials are necessary. Not surprisingly, wire with a diameter of 1.5 mm is stronger than 1.0 mm wire[54]: the addition of a lateral wire improved fixation durability.

Elliot *et al.*[44] studied a more innovating material: tension band suturing with bioabsorbable materials. Transverse osteotomies were fixed with axial K-wires and TBW suturing utilizing: #1 PDS, #1 Panacryl and #2 Panacryl (all from Ethicon, Inc., Somerville, NJ, USA) and 18 gauge surgical wire. The specimens fixed with K-wires only, #1 PDS and #1 Panacryl tension band suturing failed to maintain osteotomy reduction. Only surgical steel and #2 Panacryl TBW maintained osteotomy reduction: both were found to be superior to the other fixation methods. The #2 Panacryl was concluded to be an excellent choice for a TBW construct; it retains 80% of its breaking strength at 3 months, is fully absorbed and maintains osteotomy reduction, overall a promising result.

TBW additions

In 2003, Hutchinson *et al.*[50] concluded that the fixation provided by TBW with screws is better than TBW or screws only. Sadri *et al.*[58] found that a new type of intra-medullary K-wires, with eyelets, provides similar stability as AO TBW with K-wires placed through the anterior cortex of the ulna. Staples combined with TBW however provided superior stability compared with TBW. Another technique, intra-medullary nails, studied by Molloy *et al.*[53], provided significantly stronger and stiffer fixation for transverse olecranon features than did the standard TBW technique. Petraco *et al.*[56] found no differences between: a transverse osteotomy with Kirschner wire and TBW, a chevron osteotomy with a cancellous lag screw and TBW and a oblique intra-articular osteotmy with a cancellous lag screw and TBW. In 1985, Fyfe *et al.*[47] studied TBW combined with other techniques. TBW with two tightening knots showed the least displacement at the fracture site even at high loads. Using intra-medullary screws gave erratic results, and adding TBW with a single knot was a little better.

A complete different addition is a post-operative exercise program, as studied by Brink *et al.*[43] By measuring compressive forces in human cadaveric models after TBW, no compressive forces were found in the osteotomy gap during active flexion. Extension, however, caused some (0.37–0.51 MPa) at the articular surface when comparing with active flexion (0.2 MPa). At the posterior site no significant pressure difference was observed between active flexion and extension. They concluded that 'post-operative exercise programmes should be modified in order to prevent loss of compression at the fracture site of a transverse olecranon fracture, treated with TBW when the elbow is mobilized'.

Alternative techniques

An alternative to the TBW technique is the olecranon sled, designed by TriMed, Inc., Valencia, CA, USA). Dieterich *et al.*[45] studied this fixation device, which consists of 'an outer wire loop (fixed to the ulna with a washer and two cortical screws) connected to two legs that are inserted into the fracture fragment and interdigitating intra-medullary within the ulna'. Testing it in osteotomies in cadavers lead Dieterich *et al.*[45] to conclude that the olecranon sled appears to provide as stable fixation as TBW for olecranon fractures.

In 2002, Moed *et al.*[52] studied proximal fragment excision as an alternative to TBW. This technique however resulted in abnormally elevated joint stresses, whereas TBW restored the normal biomechanics of the elbow joint. The elevated stresses may, over time, contribute to the development of elbow pain and osteoarthritis. TBW is thus concluded to be the preferred technique.

Conclusions: olecranon

The overall score of 64.0 of the literature on fixation of transverse olecranon fractures indicated a fairly good quality. The difference in experimental setup between the studies makes it hard to compare them. Fortunately, in almost every study two or more techniques were tested and compared. Hardware failure of TBW constructs still appears a yet unsolved problem.

Placement of the K-wires and angle of the forearm are of importance. An interesting conclusion might be that modified TBW is not better in terms of fracture displacement than the AO technique except at high loads; modified TBW is however technically easier to apply. EthiBond can be a good alternative to stainless steel in terms of fracture displacement, whereas monofilament cable was abraded by bone and titanium wire abraded the bone. A bioabsorbable material, No. 2 Panacryl, was also found to be an excellent choice for a TBW construct. TBW combined with screws appears to give better results, a combination with staples however gave even greater stability. The addition of tightening knots also increases fixation strength.

Patella

All graded articles are included in this overview. This is because the scoring was poor, and only 6 of 18 articles reached a score >60. Fifteen of the 18 studies used cadaver models, of which 12 used human cadavers, whereas 4 studies (Baran *et al.*,[60] Baydar *et al.*,[61] Dargel *et al.*[36] and Rothaug *et al.*[71]) used animal models. The remaining three studies (Hughes *et al.*,[66] John *et al.*[67] and Wild *et al.*[74]) used synthetic bone models.

Early motion

The benefits of early motion during rehabilitation are widely accepted. Weber *et al.*[29] first investigated the most common techniques and their functionality in a dynamic study. They compared circumferential wiring, Magnusson wiring, tension band wiring and modified tension band wiring. Tension band wiring and circumferential wiring showed separation of the fracture, and were insufficient. Magnusson wiring was found to fix the fracture until 10° of flexion, when a minimal displacement occurred. The modified tension band technique showed no change in fracture gap. The stability of the interface between the wire loop and bone (albeit through Krischner wires or not) results from better fixation.

Several studies showed the importance of flexion and extension on fracture fixation techniques. Burvant *et al.*[62] identified three regions in quadriceps tension in an extension experiment. Tension increased from 90° to 60°, followed by a nearly constant range from 60° to 30°. Then again an increase in quadriceps tension was observed. They found that the maximum fracture displacement did not occur at maximal quadriceps tension but rather in the constant range from 60° to 40°. Five years later, these observations were confirmed by McGreal *et al.*[68] They showed that the tendency to fracture separation occurred at 50–30°. These studies showed that not only the method of fixation was important in the evaluation, but that the experimental setup used will influence the results dramatically.

Tension band wiring and modifications

Many modification of tension band wiring have been investigated. Perry *et al.*[70] showed that the addition of a load sharing cable significantly reduced the incidence of failure in tension band wiring and screw fixation.

Fortis *et al.*[65] investigated the effect of a tension band wiring including a circular wire. They showed that tension band wiring with circular wire increased the tensile strain on the anterior surface, although this was not significant compared with intact bone and traditional tension band wiring. The increase in tensile strain on the posterior patellar surface with tension band wiring with circular wire however was significant compared with intact patella and normal tension band wiring. They stated this was enough proof that early passive motion is advisable in minimal displaced patellar fractures.

John *et al.*[67] investigated the effect of several figure-of-eight configurations in tension band wiring. In contrast to general used techniques, they found that a horizontal figure-of-eight with two twists in adjacent corners was significantly stronger than all other configurations with respect to interfragmentary compression. Also, a significantly more stable construct was gained with a horizontal figure-of-eight during cyclic loading. None of the constructs failed, and the fracture gap was smaller. These results were confirmed by the study of Baran *et al.*[60]

Hughes *et al.*[66] used a bone model with wheatstone bridge strain gauges to study a modified Wagoner's Hitch with braided polyester suture (no. 5 EthiBond). This technique produced less interfragmentary gap than the TBW techniques in Hughes' bone model.

Ciocanel *et al.*[63] showed that positioning the tension band at 1 cm from the patellar pole resulted in less fracture displacement after cyclic loading than positioning the tension bend adjacent to the patellar poles. However, no statistics were given.

Tension band wiring vs. other wire fixations

Benjamin *et al.*[28] argued that tension band wiring was superior to Magnusson and Lotke wire fixation. They however stated that wire fixation gives inconsistent results because of the difficulty of removing all excess wire length when bending the wires around turns and recommended screw fixation.

Patel *et al.*[69] found no statistical difference between fracture gaps of the Lotke technique and tension band wiring. They suggested that the position of the loop in tension band fixation could be slightly off, creating some slack in the loop causing fracture gap increase during the first loading cycle.

Curtis *et al.*[64] compared the AO technique with the Pyrford technique, a combination of TBW and cerclage wiring principles. By stressing repaired patellae to failure, it was found that the Pyrford technique gives greater strength of fixation, certainly enough to allow early mobilization. However, the AO technique is adequate for most cases. However, Burvant *et al*.[62] also studied the Pyrford technique, and found an increase in fracture displacement compared with modified TBW.

Tension band wiring vs. screw fixation

Screws can either be combined with TBW and other existing techniques, or used a stand-alone fixation technique. Burvant *et al*.[62] found that screws alone resulted in an increase in fracture gap, whereas screws in combination with TBW showed a significant decrease in fracture gap. Combined with the earlier described Pyrford technique, no significant decrease in fracture was found compared with modified TBW.

Using calf patellae, Bayder *et al*.[61] studied both Herbert screws in combination with TBW and malleolar screws (without TBW). Both these techniques were concluded to be more stable than modified TBW and having more resistance against the distraction forces. The authors state that comprehensive clinical trials are warranted to verify the results of their study.

Dargel *et al*.[36] studied a novel technique: the mini-screw fragment fixation system (FFS). The FFS consists of fine-threaded k-wires which allow for percutaneous fragment fixation as a one-step fixation device. Already successfully applied in their hospital department, they compared this technique with interfragmentary screw fixation and TBW. In terms of load to failure and fixation stiffness, the biomechanical performance of FFS was comparable to interfragmentary screw fixation and superior to TBW. Again, clinical trials are necessary.

Tension band wiring vs. staples

Schnabel *et al*.[72] studied the difference between tension band wiring and staple fixation in a cyclic model. During the first cycles no significant difference between groups was observed. At 1000 cycles, fracture displacement in the ventral aspect was significantly higher for the TBW group in both flexion and extension. Fracture displacement in the dorsal aspect was significantly higher for the TBW in flexion. No significant differences were seen in extension. The displacement amplitude at the dorsal aspect was significantly higher for the staple group. No significant differences in amplitude were found at the ventral side. The staple group had a higher survival probability than TBW. These results indicated that staples might be a promising fixation technique in transverse patella fractures.

Wiring material

Some authors have studied the effect of replacing stainless steel with polyesters. Polyesters have similar mechanical properties as stainless steel. They have a higher resistance to cyclic loading and are easier to handle.[71] McGreal *et al.*[68] investigated the difference between stainless steel and 7 metric braided polyester (Ti-cron). They showed that load to failure in polyester was less strong than wire. A single flexion/extension measurement showed minimal fracture separation for polyester. Prolonged loading showed no significant difference between stainless steel wire and polyester. Cyclic loading showed an equal performance of wire and polyester.

Patel *et al.*[69] found no statistical difference between seven metric braided polyester (No. 5 Ethibond) and 1.25-mm stainless steel in both tension band wiring and Lotke technique, suggesting that braided polyester sutures are a possible replacement for stainless steel wires.

Rothaug *et al.*[71] investigated the differences between a 1-mm UHMWPE and a 16-gauge stainless steel wire. UHMWPE withstood significantly greater loads to failure than wire in endoscopic cerlage. UHMWPE had significantly greater fatigue strength than stainless steel wire. Osteotomy gap was significantly less in constructs repaired by the suture technique than by endoscopic transfixed cerclage technique. No difference between UHMWPE cable and stainless steel wire was seen when evaluating the different techniques. This suggested that UHMWPE could be used for clinical applications and that the suture technique might lead to earlier recovery.

Fixed angle plates

Wild *et al.*[74] showed in a polyurethane model that fixed-angle plate fixation on the medial and lateral patella surface withstands a significantly higher load than cannulated screws (2×) and modified anterior tension wire (4×). Fixed-angle plate fixation displayed a significantly lower gap formation than anterior tension wiring and modified anterior tension wiring. The latter two did not show a significant difference. In a follow-up study,[75] they showed that this technique can be used in a clinical setting in a limited time, and is successful even in osteoporotic bones. Thelen *et al.*[73] compared the fixed-angle plate design with modified anterior TBW and cannulated leg with anterior tension wiring. They tested human cadaver knees by simulating knee motion from 90° flexion to full extension over 100 cycles. The TBW and lag screws with TBW showing significant fracture displacements of, respectively, 7.1 ± 2.2 and 3.7 ± 2.7 mm, larger than 2 mm which is clinically regarded as failure. The fixed-angle plate plates however showed no significant fracture gap displacement after 100 cycles: 0.7 ± 0.5 mm.

Conclusion: patella

The overall score in the patella articles of 55.6 was poor. Therefore, comparing the studies is hard since insufficient data are provided. This problem is aggravated by the differences in mechanical test setup and the limited amount of articles. Therefore, no comparison between fixation techniques will be made. However, it is possible to make a few observations. First, problems with wiring techniques (tension band, Lotke, Magnusson, Pyford) are partially caused by the difficulty of fixating the wire. It is especially difficult to remove all the excess wire when bending the wire around turns and fixating it. Handling the wire can also cause abrasions, which result in earlier failure of the wire. Because of the relative ease and its outstanding mechanical properties, the use of UHMWPE is recommended.

Secondly, many modification of the tension band wiring technique have been investigated. Two separate studies showed that applying the horizontal figure-of-eight results in higher interfragmentary gap compression and better resistance to cyclic loading.

Scoring system evaluation

In the next section, problems and inconsistencies encountered during the grading process will be discussed point by point. Adjustments to the grading will be stated and possible ways of avoiding these problems in the future will be discussed.

Part 1: Material specifications

Study size

Surprisingly, some articles do not include their sample size. In the current grading, these studies were considered to have a study size smaller than 5, since no points could be given. The grading method is adjusted to include articles which do not state their sample size.

In studies using a synthetic model, the number of models is not always mentioned (2:5; Hughes, John). In these cases, the number of cables used was taken as the study size. Remarkable, this only occurred in the patella group. This, however, is not the desired method of describing study size. Uncertainty about reusing the models for independent cable testing could be graded as insufficient, since the effect the cables have on the model itself are unknown. In our reasoning, this argument is indirectly graded by the ‘mechanical properties defined’ and ’the number of fixation techniques per bone’ criteria, and, to prevent double grading of one criteria, it is not considered.

Origin of the models/bone models

Biological differences in cadaver bones make mechanical testing subjective to varying parameters. Though reproducibility is very important in scientific research, many papers do not specify the properties of their bone models properly. Even though our grading method incorporates the most common denominators of biological significance, we noticed that assumptions still had to be made.

Some papers do not specify which cadaver model is used. In these cases we assumed a human cadaver model unless graphs suggested otherwise. It could be argued that no points should be given.

After grading, it became clear that the clinical relevance of animal models should be better specified. All the five animal studies evaluated showed a discrepancy in the grading if it was clinically relevant or not. This was seen both intra- and inter-observer. The only exception was the article of Rothaug, where the intra-observations were the same for both observations for every observer. When performing animal studies better specifications should be made of what is considered clinically relevant, e.g. size, geometry, bone density.

Bone density is considered an important indicator for the health state of the bone. Mentioning bone density makes comparison with other studies and the clinic more reliable. Some articles stated the evaluation of the bone density without stating the method used. In this instance, no points could be given since the accuracy of the method was not known.

The 'clinical/radiographical assessment of the pre-testing state bone' also showed subjectivity. Therefore, in the future exclusion criteria should be better specified. During the process of obtaining consensus several issues aroused. We recommend that several statements should be categorized before starting the evaluation process: evidence of injury, pathophysiology and musculoskeletal disease. We categorized them as following: no evidence of injury was considered an insignificant exclusion criteria, no evidence of pathophysiology was considered a significant exclusion criteria as well as musculoskeletal disease. Another small observation was that not always all bones were assessed. The representation of only a few bones for the whole set is considered to be inaccurate. Therefore, this grading criterion is adjusted to give 0 points.

Limb comparison

The criterion describing the method of matching of bones proved to be insufficient. Additional criteria have been added to complete the criteria. The grading has been partially based on the statistical desirability of the method chosen. The criteria added are: 'individual bones when properties are defined' and 'matched when multiple techniques are compared'. If the matched bones are not treated as matched pairs, in the statistical analysis when multiple techniques are compared, full points should be given.

Fixation method

In our initial criteria embalmment of bones was not considered. Since there are several ways to embalm which have different effects on mechanical properties of the bone,[81,82] embalming is graded as undefined since the effect on bone is not specified.

Part 2: experimental set-up

Description of osteotomy

As expected this criterion resulted in differences between observers. Of all articles, seven showed a maximal difference between observers. However, when obtaining consensus these differences were easily diminished.

Surgeon

In our grading criteria the experience of the surgeon was only taken into account if the number of surgeries performed by that surgeon was specifically stated. This was never the case. There were however articles which state the experience in a more subjective term, e.g. senior surgeon. When adapting this scoring method, careful consideration should be made whether or not these terms describe the experience of a surgeon. If they are taken into account, it should be specified which terms are eligible to gain 4 points.

Assignment of fixation method

This criterion also proved to be insufficient. Several studies assign fixation methods to left or right limb, probably assuming dominance in the right arm/leg. Therefore, this criterion is adjusted to include this by given the same scoring as studies which specify dominance.

Assigning method of fixation to models, which perform several fixation methods on one bone proved to be difficult as well. While obtaining consensus, this criterion has been formulated to earn maximum points when the assignment of several fixation methods to one bone has been done randomly. If several fixation methods are performed in a standardized order they gain no points.

We also observed little mention of assignment method in synthetical models. Even in these models it is important that the assignment method is specified. Also, especially foam models could be subjected to bias.

Number of fixation techniques per bone

Although it was not stated specifically before evaluation, all observers considered one fixation technique per bone with multiple cable tests as multiple fixations.

Description of mechanical test methods given

As expected, this criterion resulted in differences between observers. A total of five articles showed a maximal difference between observers.

However, when obtaining consensus these differences were easily diminished.

Failure statement

Studies should mention the size of the gap which they use as failure statement. Some articles mentioned this indirectly, e.g. quoting from other articles. In this way, it was not always clear whether they only mentioned the maximum gap size (usually leading to osteoarthritis) or also really took it into account when performing the study. Before starting evaluation, this item must be secured. In most papers, it was also not clear whether experiments continued after reaching failure.

Statistical analysis

A total of four articles showed a maximal difference between observers. When obtaining consensus, these differences were easily settled. Articles should at least specify the statistical method used, *post hoc* analysis when necessary and the *P* value, earning full points for a complete description.

Part 3: description of results

Outcome

Even though this criterion was expected to be subjective, no maximal differences were found between observers. Obtaining consensus was done easily.

Abrasions

None of the articles state the progression of abrasion. This is a serious limitation since it has been shown to lead to complications in a clinical setting.

Limitations

A maximal inter-observer difference in this criterion could be seen in 11 articles. When obtaining consensus, these differences were easily settled.

Article structure issues

Several articles showed multiple experiments in different fashions. If these differences are clearly described in both setup and results than an article can be graded as a whole. However, in the case of Parent *et al.*,[78] the differences in the experimental setup between different test methods and the results presented in the paper were so confusing that no clear grading could be given. Therefore, it was excluded from analysis. This raised the

Table 6 Adjusted grading method.

	Score
Part 1: Material specifications	
Study size, number of assessed bones or joints	
>10	7
5–10	4
<5/*unstated*	0
Cadaver models	
Origin of assessed material	
Human cadaver material	5
Animal cadaver material with clinical relevance defined	3
Animal cadaver material without clinical relevance defined	0
Bone density of assessed material reported (including standard deviation)	
Defined with CT at sub 100-μm resolution	5
Defined with DXA	4
Defined with radiograph/CT	2
Defined without defining method/undefined	0
Clinical/radiographical assessment of pre-testing state bone	
Examination performed on all bones, with exclusion criteria defined	2
Examination performed on all bones	1
Not stated, unclear	0
Matched pairs of bones from individual or individual bones	
Matched when two techniques are compared	2
Individual when multiple comparisons are made	2
Individual when no comparisons are made, but properties are defined	2
Individual when two techniques are compared	0
Matched when multiple techniques are compared	0
Fixation method	
Fresh or frozen with 1 freeze/thaw cycle	4
Frozen with multiple freeze/thaw cycles	2
Formaldehyde/*embalmed*/undefined	0
Synthetic model	
Mechanical properties defined of the synthetic system	
Per defined mechanical property important for the experimental setup: 4 points are given with a maximum of 12 points	
Geometry	
With clinical relevance	6
Without clinical relevance	0
Part 2: Testing methods	
Description of osteotomy given	
Adequate (preparation bone well described)	5
Fair	3
Unclear/unstated	0
Fixation method performed by	
Multiple surgeons	5
One surgeon (surgeon specified by # operations)	4
One surgeon (no specifications)	3
Undefined	0
Assignment of fixation method	
Random	5
Dominant arm/non-dominant joint specific *or right/left joint specific*	3
Not defined/*multiple fixation techniques per bone*	0
Number of fixation techniques performed on one bone	
One fixation technique per bone only	5

Continued

Table 6 *Continued*

	Score
Several	0
Description of mechanical test method given	
Adequate	15
Fair	10
Unclear/unstated	0
Failure statement regarding displacement of the fracture defined	
Stated	5
Unstated	0
Statistical description data	
Complete description	5
Limited description	3
Unclear/unstated	0
Part 3: Description of results	
Outcome measurements clearly described	
Complete description	10
Limited description of outcome measurements	7
Unclear/unstated	0
Abrasions progression defined	
Stated	10
Unstated	0
Limitations of testing methods defined	
Complete description	10
Limited description	7
Unclear/unstated	0

Adjustments are shown in italics.

question if articles should be graded as a whole, or per experiment performed in such article. We recommend to grade articles as a whole. Often the discussion and conclusion are based on the total results of the experiments. If an article separates everything: method, result, discussion and conclusion, then separate gradings can be given.

Bias

An important property of a new scoring method should be that it creates unbiased values. We believe that our scoring method is unbiased, as the intra-rater reliability was high (>0.90), even before reaching consensus.

Conclusion grading method

The grading method developed has proved to be unbiased and reliable (Table 6). When adopting it, several points have to be modified for the intention for which the method is used. These extra specifications have to be made at the following criterion: clinical relevance of animal models, selection criteria at the clinical/radiographical assessment, pre-testing state bone and surgeon experience.

Conclusions

The literature on the fixation of transverse olecranon fractures was with an overall score of 64.0 of fairly good quality. Hardware failure appears a yet unsolved problem, with non-metallic materials EthiBond and No. 2 Panacryl as possible alternatives for metallic constructs. With a score of 55.6, the literature on transverse patella fracture fixation was poor. The problems with wiring techniques are partially caused by the difficulty of fixating the wire. UHMWPE was recommended as non-metallic construct. The horizontal figure-of-eight technique results in better fixation. In both olecranon and patella, comparison of fixation techniques was hard due to differences in biomechanical setup between the studies. The newly developed grading method has proved to be unbiased and reliable; however, some issues need to be addressed when adopting it.

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