Fixation of Multifragmentary Patella Fractures Using a Bilateral Fixed-angle Plate

SIMON THELEN, MD; MARCEL BETSCH, MD; JOHANNES SCHNEPPENDAHL, MD; JAN GRASSMANN, MD; MOHSSEN HAKIMI, PhD; CHRISTIAN EICHLER, MD; JOACHIM WINDOLF, PhD; MICHAEL WILD, PhD

abstract

Full article available online at Healio.com/Orthopedics. Search: 20131021-29

This biomechanical study is the first to compare 3 fixation methods—bilateral fixed-angle plate, modified anterior tension wiring, and cannulated lag screws with anterior tension wiring—in multifragmentary distal patella fractures.

A T-shaped 3-part fracture simulating a multifragmentary articular distal patella fracture (AO/OTA 34-C2.2) was created in 18 human cadaver knee specimens. Three groups were created using homogenous ages and bone mineral densities based on the fixation method received. Repetitive testing over 100 cycles was performed by moving the knee against gravity from 90° flexion to full extension. Failure was defined as fracture displacement greater than 2 mm. In all patellae using fixed-angle plates, an anatomical fracture reduction could be maintained throughout cyclic testing, whereas anterior tension wiring and lag screws with tension wiring showed significant fracture displacement after 100 cycles, with mean fracture gaps of 2.0±1.3 and 1.9±1.6 mm, respectively. The differences in fracture gaps between the fixed-angle plate group and the other 2 groups were statistically significant. In both groups using tension wiring, half of the constructs (3 of 6 in each group) failed due to a fracture displacement greater than 2 mm. The bilateral fixed-angle plate was the only fixation method that sustainably stabilized a multifragmentary articular distal patella fracture during cyclic loading when compared with modified anterior tension wiring and cannulated lag screws with anterior tension wiring.

The authors are from the Department of Trauma and Hand Surgery (ST, MB, JS, JG, MH, JW), Heinrich Heine University Hospital Düsseldorf, Düsseldorf; the Department of Anatomy II (CE), University of Cologne, Cologne; and the Department of Trauma and Orthopedic Surgery (MW), Klinikum Darmstadt, Darmstadt, Germany.

The authors have no relevant financial relationships to disclose.

Correspondence should be addressed to: Marcel Betsch, MD, Department of Trauma and Hand Surgery, Heinrich Heine University Hospital Düsseldorf, Moorenstr 5, D-40225 Düsseldorf, Germany (marcel.betsch@gmx.de).

doi: 10.3928/01477447-20131021-29
With a reported prevalence of approximately 1% of all human fractures, patellar fractures often present with a heterogeneous fracture pattern. The transverse 2-part fracture is the most common type, accounting for 34% of all fractures, followed by multifragmentary distal patella fractures. Surgical treatment of patellar fractures is indicated in fractures with greater than 2 to 3 mm of displacement or articular incongruity and if the extensor mechanism is disrupted. Despite partially unsatisfactory long-term study results, modified anterior tension wiring with a vertical figure-of-eight pattern remains the most widely accepted procedure for the fixation of patellar fractures, followed by the combination of cannulated lag screws with tension band wiring.

Although recent biomechanical studies have investigated different osteosynthesis in simple transverse patella fractures, the current study is the first to biomechanically evaluate different fixation techniques for a 3-part fracture involving the articular surface of the distal part of the patella, which is the second most frequent fracture site. A bilateral fixed-angle plate specifically designed and developed for the stabilization of patellar fractures was compared with modified anterior tension wiring with K-wires and cannulated lag screws with anterior tension wiring. It was hypothesized that a bilateral fixed-angle plate, which demonstrated superior strength and sustainability in preliminary testing on transverse patella fracture types, would also be able to retain the reduction of a more fragmentary fracture pattern superior to the current standard techniques.

**Materials and Methods**

Eighteen knees were chosen from 76 human cadaveric specimens that were preserved in formalin-based dilution for more than 6 months. Those with radiographic alterations, such as precedent fractures, orthopedic implants, or advanced retropatellar arthritis, were excluded, and specimens of similar age and bone mineral density (BMD) were identified. Average cadaver age was 74.6±6.4 years (range, 61-87 years), and specimens included 6 women and 12 men. Bone mineral density was measured using a peripheral quantitative computed tomography (pQCT) scanner (XCT 3000; Stratec Medizintechnik, Pforzheim, Germany). Scans were performed at the previously marked transverse osteotomy line in the center of each patella. Mean BMD of the specimens, including cortical and cancellous bone substance of the patellae, was 483.9±23.2 mg/cm³. The selected specimens were divided into 3 groups of 6 specimens based on the type of internal fixation method each patella received. Age and BMD were distributed homogenously to minimize their influence on the results (Table 1).

The knees were dissected of soft tissue, leaving the knee joint capsule, ligaments, and extensor mechanism (including the medial and lateral retinaculum) intact. An articular T-shaped 3-part fracture (AO/OTA 34-C2.2) was created using an oscillating saw and osteotome by first horizontally osteotomizing the patellae in the previously marked center and consecutively by dividing the inferior part vertically into 2 halves. Subsequently, all fractures were anatomically reduced and stabilized according to their predetermined type of osteosynthesis. The modified anterior tension wire technique featured 2 parallel 2-mm stainless steel K-wires and a 1.25-mm stainless steel wire loop forming a figure-of-eight on the anterior patella surface. The wire was twisted manually until it straightened, achieving a stable osteosynthesis with anatomic reduction of the fracture gap. The cannulated lag screws with anterior tension wiring technique used 2 parallel cannulated lag screws (diameter, 4.0 mm; length, 36 mm; thread, 12 mm) (Synthes, Oberdorf, Switzerland) that were inserted over previously placed parallel K-wires before passing a 1.25-mm stainless steel wire through them and forming a figure-of-eight on the anterior patella surface. This was followed by tightening the tension band by twisting the 1.25-mm wire ends until a stable, anatomic reduced osteosynthesis was obtained. The bilateral fixed-angle plate technique used a 2.7-mm titanium fixed-angle plate (Königssee Implantate, Allendorf, Germany), which features 5 holes on either side, with each allowing for polyaxial fixed-angle screw placement (Figure 1). Both branches of the plate were bent in a semicircular shape and placed on the medial and lateral edge of the patellae in an 80° angle to its anterior surface, sparing the insertion of the quadriceps and patella tendon. The reduced fracture was stabilized by attaching the plate to the patella with four 3.5-mm angle-stable locking screws on each side.

The testing protocol for all techniques was set up to simulate knee joint motion

<table>
<thead>
<tr>
<th>Specimen Age and Bone Mineral Density</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variable</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Age, y</td>
</tr>
<tr>
<td>BMD, mg/cm³</td>
</tr>
</tbody>
</table>

Abbreviation: BMD, bone mineral density.
against gravity from 90° flexion to full extension. The distal femur was fixed horizontally on the base of a load frame. Tension was applied by seizing the proximal end of the quadriceps tendon into a metal clamp that was connected to the crossbar of a dynamic material testing machine (Model 5565; Instron Ltd, High Wycombe, United Kingdom) with a braided steel cable that was vertically deflected by a pulley (Figure 1). According to similar reports, the weight of the lower leg was simulated by a 3.2-kg iron disk floating along the axis of the tibia 25 cm below the distal patellar pole.3,17

All patellae were cyclically tested by simulating knee joint motion from 90° flexion to full extension (0°) by pulling the quadriceps tendon (Figure 1). A predefined tensile load was not applied. Instead, to ensure the desired range of motion was achieved, an initial calibrating cycle from 90° flexion to full extension was performed to define the individually required travel distance of the load frame, which was then adopted as the main parameter in each test cycle. In addition, the calibration cycle permitted measuring of the fracture gap after the first cycle. Each specimen underwent 100 cycles at a constant velocity of the load frame of 25 mm per minute until full extension was reached. Failure was defined as widening of the fracture gap more than 2 mm. The fracture gap was measured at the medial and lateral border of the transverse osteotomy line using a digital calliper. Measurements were conducted before and after the initial calibration cycle and after the last testing cycle. The original fracture gap before testing was 0 mm for all specimens, indicating successful anatomic reduction.

For specimens that did not fail during cyclic testing (ie, those with a fracture gap of more than 2.0 mm), a destructive loading to failure followed. On the basis of the destructive test setup of a preceding study,16 load to failure was applied by increasing the tensile loads on the tendons of the dissected patellae. A 60° knee flexion angle was simulated using an artificial femur condyle as a pivot point. Osteosynthesis failure in the destructive set-up was determined by a sudden load decrease of more than 20% in the load-displacement diagram.

The statistical interpretation included an analysis of variance for independent variables, which was conducted for fracture gap widening of the 3 groups. A post-hoc t test followed subsequently if overall differences between the groups could be observed. Statistical boundaries were a confidence interval of 95% and a significance level of P value less than .05.

## RESULTS

To achieve the required range of motion, each test cycle was controlled by the crossbar’s travel distance required to simulate knee joint range of motion from 90° flexion to full extension. The load measured to reach full extension during the calibration cycle was averaged over the 6 constructs of each group, resulting in a mean tensile load for each group. These mean tensile loads did not differ significantly between the groups during cyclic testing (P>.3) (Table 2, Figure 2).

All 18 specimens withstood 100 cycles of tensile loading without implant cut-out or fracture. The fracture gaps after testing were compared with the values of the anatomic reduced fracture site before the first cycle.

### Modified Anterior Tension Wire

A slightly widened fracture gap (mean, 0.9±0.6 mm) was found at a mean tensile load of 216.3±36.9 N in 5 of 6 specimens after the first cycle. Mean fracture gap measurement after 100 cycles was 2.0±1.3 mm (Table 2). Three of 6 specimens failed due to fracture gap widening of more than 2 mm, whereas the other 3 specimens went on to destructive testing. Mean load at failure was 1091±358 N (range, 744 to 1449 N).

### Cannulated Lag Screws With Additional Anterior Tension Wiring

A mean tensile load of 256.7±86.8 N was required to bring the 6 patellae from 90° flexion to full extension against gravity. Mean fracture gap measurement after the initial cycle was 0.7±0.8 mm. After 100 cycles, mean fracture gap measurements were 1.9±1.6 mm (Table 2; Figure 3). Three of 6 specimens in this group displayed a fracture gap exceeding 2.0 mm after 100 cycles, which was regarded as fixation failure. The other 3 specimens were loaded until destructive failure, reaching a mean load at failure of 768.3±170.4 N (range, 584 to 920 N).
Fixed-angle Plate

The specimens in the fixed-angle plate group showed distinguished characteristics compared with the above mentioned groups because all 6 maintained an anatomically reduced fracture gap of 0.0 mm throughout all 100 cycles of nondestructive testing (Table 2, Figure 3). The mean load required for the demanded range of motion was 242.0±74.0 N and did not differ significantly from the other two groups (Table 2 and Figure 2). Since none of the patellae with fixed-angle plate osteosynthesis failed during 100 cycles, a destructive loading to failure followed for all 6 specimens. Here, a mean tensile load of 1214.7±616.2 N (range, 623 N to 1909 N) was determined before it came to a sudden decrease in the load-displacement diagram indicating failure of the osteosynthesis.

Direct comparison of the 3 fixation methods after 100 repetitive cycles of nondestructive loading revealed that the fixed-angle plate resulted in significantly less fracture gap widening than modified anterior tension wiring (P<.01) and lag screws with tension wiring (P<.05) (Table 2, Figure 3). After the initial calibration cycle, no fracture displacement could be observed in the fixed-angle plate group compared with the 2 groups using the tension wire principle; however, these differences after the first load cycle were not significant (P=.05) (Table 2). No significant difference in fracture dehiscence after 100 cycles could be found between the combination of lag screws plus tension wiring and anterior tension wiring alone (Table 2, Figure 3). Concerning the subsequent destructive loading, no statements about significances can be made because only 3 specimens in the modified tension wiring and 3 in the screw plus tension wiring group were tested to failure compared with all 6 specimens of the fixed-angle plate group. Still, fixed-angle plates failed at the highest mean loads (1214.7±616.2 N) in comparison to the other techniques (Table 2).

### Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Modified Anterior Tension Wiring</th>
<th>Lag Screws + Tension Wiring</th>
<th>Fixed-angle Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean cyclic tensile load, N</td>
<td>216.3±36.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>256.7±82.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>242.0±74.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fracture gap before first cycle, mm</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Fracture gap after first cycle, mm</td>
<td>0.9±0.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.7±0.8&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fracture gap after 100 cycles, mm</td>
<td>2.0±1.3&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1.9±1.6&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.0&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mean destructive load at failure, N</td>
<td>1091±358&lt;sup&gt;f&lt;/sup&gt;</td>
<td>768±170&lt;sup&gt;f&lt;/sup&gt;</td>
<td>1215±616&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>No significant difference in mean tensile loads in all groups (P>.9).
<sup>b</sup>No significant difference after first cycle between any groups (P>.05).
<sup>c</sup>No significant difference after 100 cycles between tension wiring vs screws + tension wiring (P>.9).
<sup>d</sup>Significant differences after 100 cycles between tension wiring vs fixed-angle plate (P<.01).
<sup>e</sup>Significant differences after 100 cycles between screws + tension wiring vs fixed-angle plate (P<.05).
<sup>f</sup>No testing for significant differences of failure loads possible due to uneven sample sizes.

### Discussion

The surgical goals in the treatment of displaced patella fractures are analogous to other intra-articular fractures: accurate (step- and gapless) reduction with stable fixation of the articular surface, allowing for early postoperative motion. In the current study, the fixed-angle plate was the only device to completely and permanently retain an anatomic fracture reduction throughout cyclic testing at nondestructive loads, affirming the hypothesis stated at the outset. Fixation with the other compared techniques resulted in an average fracture dehiscence of 2.0±1.3 mm for modified tension wiring or 1.9±1.6 mm for cannulated lag screws with anterior tension wiring. Such a displacement after 100 cycles of isometric motion of the flexed knee against gravity has to be regarded as unsatisfactory, given that a fracture gap of more than 2.0 mm is commonly regarded as an indication for operative treatment of the patella. However, these findings may explain the relatively high number of unsatisfactory clinical results, which may be representative of the common adverse effects of tension band wiring, such as failure of fixation, wire migration, and persisting postoperative pain resulting in revision surgery with hardware removal in up to 65% of patients.

Given the fairly poor outcome of tension band wiring, other authors have investigated methods to improve fixation of patella fractures. The combination of cannulated lag screws with anterior tension wiring became an increasingly popular alternative after proving higher load-bearing capacity in biomechanical studies. However, currently, all biomechanical studies were conducted using a relatively stable transverse 2-part fracture (AO/OTA 34-C1), which admittedly is the most common fracture type. On the other hand, it only contributes to one-third of all fractures of the patella. In transverse fractures, the most common fixation techniques—modified anterior tension wiring and cannulated lag screws with anterior tension wiring—provide...
sufficient stability in different in vitro investigations. The comparatively unsatisfying clinical results with failure of fixation of these osteosyntheses might be attributed to less stable multifragmentary fracture situations occurring in vivo. Therefore, a multifragmentary articular fracture pattern (AO/OTA 34-C2.2) was created to evaluate the behavior of the current standard techniques in an increasingly unstable situation compared with the new bilateral fixed-angle plate that already displayed superior mechanical characteristics in a simple transverse 2-part fracture (AO/OTA 34-C1.1).

Although the insufficient fracture retention of the tension wire group during cyclic testing at subultimate loads might be explained by the initial tightening of the wire formation with consecutive fracture dehiscence, it might appear surprising that the combination of cannulated lag screws and tension wiring has likewise underperformed. Conceivably, the cannulated lag screws may have forfeited some of their compression force because, in the reduced bone quality of the aged cadaver specimens, the screw threads could not be anchored as firmly. Consequently, the lag screws may have acted more like a tension band construct. However, this problem is not owed solely to this in vitro test setup with aged and embalmed cadaver specimens. In a clinical setting (ie, when operating on live human specimens), it is arguable whether the initial compression of the lag screws can be maintained throughout the process of fracture consolidation. Micromotion at the screw-bone-interface during the postoperative rehabilitation phase might promote loosening of the screw threads in the predominantly cancellous bone structure of the patella. Another possible explanation may be the relatively small size of the distal fragments in this fracture model. This would confirm literature recommendations for the use of cannulated lag screws with tension wiring only in centered transverse patellar fractures.

In contrast, the entirely undisplaced fracture gap of 0.0 mm throughout all test cycles displayed by the fixed-angle plate system underlines that the angle-stable interface of threaded screw heads and plate holes prevents loosening of the osteosynthesis with consecutive fracture displacement at nondestructive loads.

A limitation of the current study, as found in all biomechanical studies, is the restricted reproduction of the complex procedures occurring in vivo. The current study setup aimed to reproduce the complex loading pattern at the patella by simulating quasi-active knee range of motion, allowing for not only mere tensile forces through the quadriceps and patellar tendon, but also compressive forces along the posterior facet of the patella. Contrary to comparable biomechanical studies where a predefined load was applied to simulate knee motion from 90° flexion to full extension, in the current study a test procedure was performed that assured full range of motion for each specimen to better reflect the individual anatomic con-
ditions and physiologic circumstances. Mean loads applied for cyclic tensile testing in the current study all ranged around 250 N (Table 2), which is only slightly inferior to comparable experiments with predefined loads of mostly 300 N. The number of loading cycles in such a setup simulating repetitive motion of the knee joint against gravity may be a subject of discussion. Obviously, in the first 8 to 12 weeks of postoperative rehabilitation until fracture consolidation, an average patient would have to perform approximately 100,000 cycles of flexion and extension, which is impossible to reproducibly simulate in such a cadaver setup.

In the current study, 100 cycles from 90° flexion to full extension were executed, not in an attempt to simulate fatigue testing, but rather to register early fracture dehiscence at loads below 300 N as a sign of failure of fixation. Loads of approximately 300 N can be considered physiological in the context of early postoperative rehabilitation because forces acting on the patella during active extension of the knee against gravity match this value. The results of previous testing on synthetic patellae over 10,000 cycles depicted the most significant fracture dislocation to occur during the initial 100 cycles, after which a steady state was reached without further notable alterations. Working with human cadaveric specimens naturally means working with aged specimens, such as those with a mean age of 74.6±6.4 years in the current study. It can be argued that patella fractures in vivo peak between 20 to 50 years.

To reduce potential bias of embalmed specimens of older donors, emphasis was placed on forming groups of specimens with homogeneous ages, sexes, and bone mineral densities by selecting from an exceptionally large pool of cadaver specimens (76 in total) and by way of pqCT screening (Table 1). Thus, the adverse effect of working with formalin-embalmed specimens might have been diminished or compensated. Furthermore, some data indicate that differences in the mechanical properties of frozen and embalmed bone are nonsignificant, suggesting either use in biomechanical studies. Concerning the simulated fracture pattern, the authors were aware of the fact that most multifragmentary fractures occurring in vivo involve extensive comminution of the patella. Creating a reproducible and comparable comminuted fracture pattern in vitro appeared to be hardly possible. Therefore, it was decided to create a transverse articular component together with a vertical split of the inferior pole resulting in a T-shaped fracture situation (AO/OTA 34-C2.2). Even if this exact fracture type is not the most common type, in the authors’ experience and according to literature, the above mentioned fracture components (transverse and inferior pole) are those occurring most frequently in vivo. A completely extra-articular distal pole fracture was not simulated because small distal fragments cannot be addressed by modified tension wiring, cannulated lag screws, or fixed-angle plates.

In the current study, destructive tensile loading occurred for those specimens that did not fail during cyclic testing. All 6 specimens of the fixed-angle plate group went on to failure loading, where they exhibited the highest mean (1214.7±616.2 N) and absolute (maximum, 1909 N) load values, whereas half of the specimens in each of the other 2 groups had to be excluded before testing for failure loading. Therefore, evaluating the results comparatively or using significance testing was inapplicable, particularly given the widespread load-to-failure values throughout the groups (Table 2). However, even supposing the minimum failure value of the fixed-angle plate (623 N) underlines its capacity to resist distinctively higher tensile loads than the 300 N required for extension of the lower leg against gravity.

Although not investigated in the current study, an important clinical aspect in the fixation of patellar fractures, apart from fixation stability, is its influence on patellar blood supply. Arterial blood supply of the patella comprises an extraosseous anastomotic ring running along the lateral margins of the patella, which might be jeopardized by circumferential application of fixation devices. Arguably, the fixed-angle plate might pose a risk to patellar perfusion due to its application at the medial and lateral margin of the patella. Otherwise, due to its internal fixator principle, only punctual contact is made between the plate and bone, so the periosseal blood supply might be mostly spared. In addition, the equally important intraosseous arterial pattern, which enters the patella on its anterior surface and at the distal pole, is not affected by placement of the fixed-angle plate compared with anterior tension wiring, which requires direct and firm bony contact independent of the use of cannulated screws or K-wires. However, future clinical studies are necessary to investigate the outcome of fixed-angle plate osteosynthesis in patella fractures, including its potential influence on blood supply.

**CONCLUSION**

In a bone density–matched human cadaveric model imitating a multifragmentary distal patella fracture (AO/OTA 34-C2.2), the fixed-angle plate was the only device to sustainably retain anatomic fracture reduction under cyclic loading at nondestructive loads. Both techniques of modified anterior tension wiring and cannulated lag screws with anterior tension wiring displayed significantly more fracture dehiscence in this multifragmentary fracture pattern.

**REFERENCES**