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ORIGINAL ARTICLE

Comminuted patellar fractures: The role of biplanar fixed angle plate constructs

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ABSTRACT

Background: Comminuted patellar fractures represent a challenging clinical problem. Treatment aims to restore the integrity of the extensor mechanism and the congruity of patellofemoral joint. Controversy exists regarding the ideal fixation method. Metallic constructs aiming to convert pulling forces on the anterior aspect of the patella into compression forces across the fracture site are the standard of care. More recently, low profile plates have been described in the management of comminuted patellar fractures. The aims of this study were to (1) develop a novel unstable patellar fracture model and (2) to compare biomechanically three different constructs for fixation comminuted patellar fractures. We hypothesized that an orthogonal biplanar disposition of the screws within an anteriorly placed locking plate provides the best biomechanical properties in the management of comminuted fractures.

Methods: Six-part complex AO 34–C3 patella fractures were simulated in 18 human cadaveric knees by means of osteotomies including comminution around the distal patellar pole. The specimens were randomly assigned to 3 fixation techniques ($n = 6$) for either anterior plating, antero-lateral plating, or tension band wiring (TBW). Biomechanical testing was performed over 5000 cycles in active extension and passive flexion, followed by ultimate destructive quasi-static testing. Interfragmentary movements were captured by means of optical motion tracking.

Results: Displacement between the proximal and distal medial patella fragments was lower after anterior plating compared to both antero-lateral plating ($P = 0.084$) and TBW ($P < 0.001$). Moreover, displacement between the proximal and distal lateral fragments was significantly lower after anterior plating compared to both other techniques ($P \leq 0.032$). In addition, it was significantly lower for antero-lateral plating versus TBW ($P < 0.001$). Rotation around the medio-lateral axis between the proximal and distal medial fragments was significantly lower after anterior plating compared to TBW ($P = 0.017$).

Conclusions: Anterior mesh plating with biplanar placement of locking screws provides superior stability for fixation of comminuted patellar fractures when compared to both antero-lateral mesh plating and TBW. The latter is associated with considerably inferior performance.

Introduction

The patella is a sesamoid bone levering the knee extension by augmenting the quadriceps torque [1]. The anatomical location of the patella and its relationship with the quadriceps muscle and the patellar tendon result in high compression forces to the patellofemoral joint and substantial tension forces through the bone. Since the patella works as a longitudinal pulley torque intensifier, the patellofemoral joint is

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subjected by high forces, stressing the patella mainly via 3-point bending and reaching maximum values of up to 3.3-fold body weight during stair-climbing and up to 7.6-fold body weight while crouching in a range of 50–70° flexion angle [2,3]. Patellar fractures result from indirect eccentric forces or a direct blow to the knee [4]. The concept of tension band wiring (TBW), consisting of a figure of eight cerclage in association with two axially placed Kirschner wires, requires an optimal circumferential bone contact at the fracture site, which is the case in simple transverse fractures [4]. Tension band constructs require contact of the opposite cortex, converting tension forces on the anterior surface of the patella into compression forces on the articular surface [5]. The challenge in cases of comminuted fractures is the lack of continuity on the articular surface of the patella. Low profile locking plates have been used to neutralize tension forces in case of comminuted patellar fractures [6,7]. However, we lack standardization with regard to the tridimensional distribution of the screws within a plate. Thelen et al. described the use of a plate placed on the peripheral aspect of the patella, with screws applied from side to side of the bone [8]. Lorich et al. propose the use of a contoured plate that would allow for screws being placed from lateral to medial and from anterior to posterior [9]. Siljander et al. described the use of an anterior plate with unicortical screws applied from anterior to posterior [10]. Translational studies involving patellar fixation with plates are in general based on simple transverse fracture models [8,10–12]. However, to the best of our knowledge, there is no currently existing experimental study based on a comminuted patellar fracture model. Therefore, the first aim of this study was to develop a novel experimental model of an unstable patellar fracture, which could be eventually used for future investigations regarding the biomechanics of patellar fixation constructs. Second aim was to compare three different bone-implant constructs aimed to stabilize a comminuted fracture pattern. Two of the constructs were previously reported in the literature, namely, the tension band wiring [4,5], and the multiplanar plate fixation construct [9]. The third construct, proposed by the first author of this manuscript, involves the use of a contoured low-profile locking plate, establishing an anterior cage, capturing the superior and inferior poles of the patella and allowing for insertion of screws in an orthogonal fashion. We hypothesized that this novel construct would have superior biomechanical performance regarding displacement and rotation among fractured fragments.

Material and methods

Creating a reproducible fracture model

Nine pairs of fresh-frozen (−20 °C) human cadaveric knees from 4 male and 5 female donors (mean age 74 years, range 61–84 years) with a normal range of motion and no macroscopic deformities or osseous joint irregularities as proved by radiographs, were used in this study. The specimens were thawed at room temperature prior to instrumentation and biomechanical testing. Each knee was dissected 15 cm proximally and 25 cm distally to the joint surface. All specimens were scanned via computed tomography (CT, General Electric Healthcare, Buckinghamshire, UK) to assess the bone mineral density (BMD) of the cancellous bone using image processing software Amira (V.6.0, Thermo Fisher Scientific, Waltham, MA).

A longitudinal incision was placed on the anterior aspect of the knee. The patella was exposed, and its anterior perimeter was identified. The most peripheral points on the superior, inferior, medial and lateral rim of the patella were landmarked with a marking pen. The midline longitudinal axis of the patella was defined by a point located in the center of the superior pole and another point located in the center of the inferior pole. The midline transverse axis of the patella was defined using the same strategy, i.e. connecting the center of the lateral rim of the patella with the center of its medial rim and being perpendicular to the longitudinal axis of the bone. The cross section of the two axes was considered the center of the anterior patellar cortex. This point was marked as a reference to place a specially designed cutting guide. The latter was produced by means of tridimensional printing technology, fitting precisely the anterior cortex of the patella. Four Kirschner wires fixed the cutting guide to this cortex. A 15-degree wedge of the anterior patellar cortex was resected with an oscillating saw, producing a transverse fracture with an anterior cortical defect (Fig. 1). The oscillating saw was then used to cut the superior pole following its longitudinal axis, as well as the inferior pole following its longitudinal and transversal axes with sagittal- and frontal-plane cuts, respectively. As a result, the superior pole was fractured into two main pieces, whereas the inferior pole was fractured into four pieces (Fig. 2). Thus, a comminuted unstable fracture pattern was generated, with lack of circumferential contact between the anterior cortical edges of the bone, and with main fracture lines oriented in the sagittal and in the coronal planes.

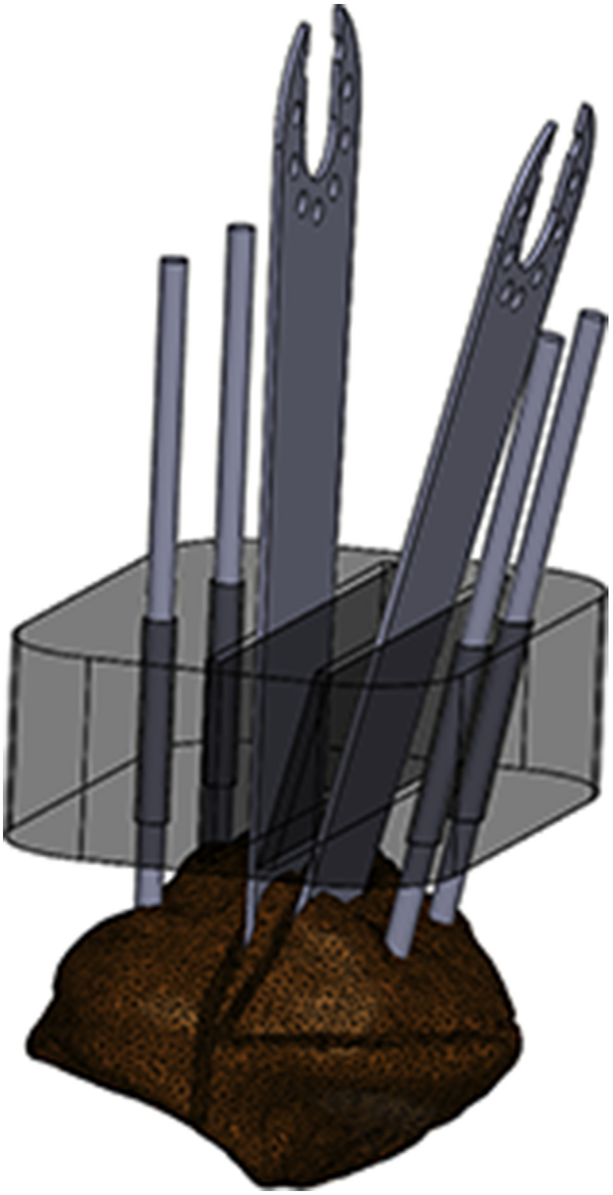

Figure 1. Cutting jig for a standardized patellar anterior wedge resection. The cutting guide was obtained by 3D printing and fits the anterior surface of the patella. It is fixed to the bone with four Kirschner wires. It has slots that allow for a reproducible 15-degree anterior wedge resection.

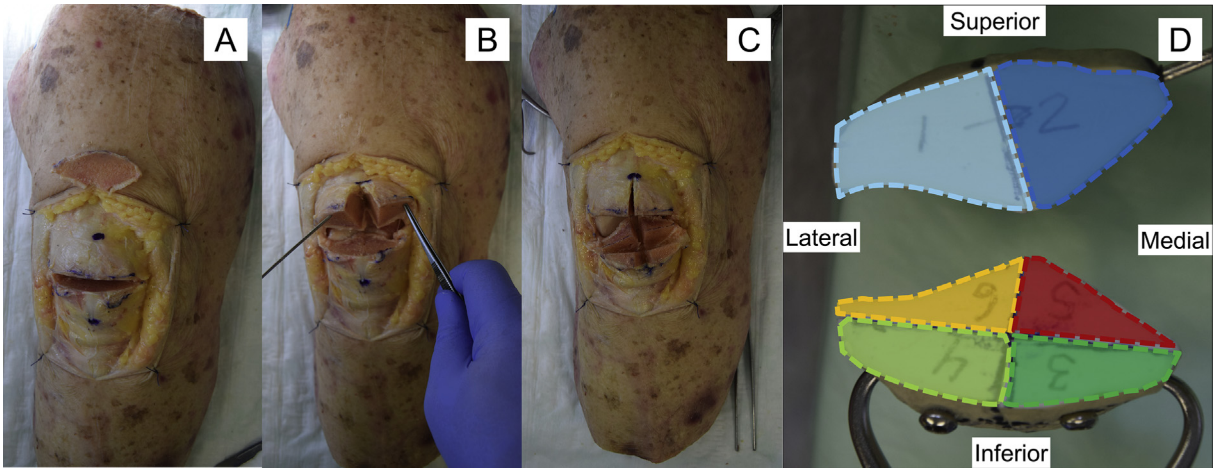

Figure 2. Development of a comminuted patellar fracture. A: Resection of the anterior wedge and creation of a transverse fracture; B: Sagittal fracture of the superior pole; C: Sagittal and coronal fractures of the inferior pole; D: Axial view of the six main patellar fragments.

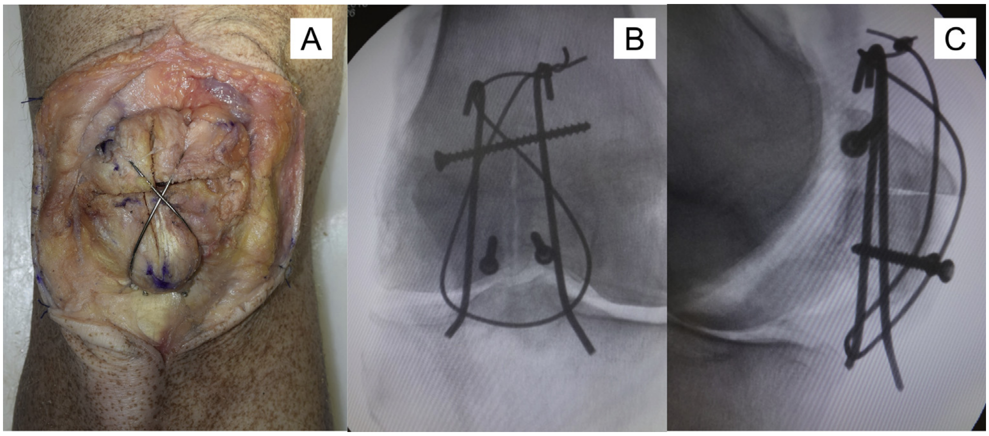

Figure 3. Visualization of tension band wiring (TBW); a) photograph of an instrumented specimen; b) anteroposterior and c) lateral radiograph projections of the instrumented specimen.

Study groups

Based on their BMD, the specimens were randomized to three study groups for fixation by means of either anterior plating, antero-lateral plating or tension band wiring [1]. Each fixation technique was performed on six specimens (n = 6) and followed a standardized protocol. Same sequence and technique were applied in all groups for provisional reduction of the fractures with point reduction clamps and Kirschner (K-) wires. The superior patellar pole was reduced and fixed with a transverse 2.7 mm stainless lag screw (Depuy Synthes, Zuchwil, Switzerland) placed perpendicular to its longitudinal axis. The inferior pole was reduced with multiple 1.25 mm K-wires. The superior and inferior poles were then provisionally fixed to each other with K-wires. The goal was the best possible reduction of the articular surface, leaving an anterior cortical defect generated by the resected bone wedge. Fluoroscopy was used to control the accuracy of reduction and proper placement of the provisional hardware.

Control group (tension band wiring)

This group combined 2.7 mm lag screws and a tension band construct. In addition to the lag screw inserted in the superior pole, two additional 2.7 mm screws were inserted monocortically from anterior to posterior in the inferior pole, fixing the coronally oriented fracture at this site and preserving the articular surface of the patella. After placement of the three screws, the preliminary K- wires were removed, and a tension band wiring construct was assembled following the AO Foundation guidelines [5]. Two 2.0 mm K-wires were placed parallel to the longitudinal axis of the patella, fixing the superior to the inferior pole. Next, a 1.6 mm cerclage wire was applied in a figure-of-eight tightened with cerclage wrench until reaching a torque of 0.5Nm [13]. The cerclage knot was bent anteriorly to avoid loss of initial cerclage tension [14]. Finally, the distal ends of the K-wires were bent at 180° and progressed proximally into the patellar bone by means of slight and controlled hammer blows, while their proximal ends were trimmed and bent medially and laterally (Fig. 3). Fluoroscopy was used during the procedure to confirm proper reduction and hardware placement.

Antero-lateral locking plate

A low-profile stainless locking plate (Variable Angle LCP Forefoot/Midfoot System 2.4/2.7, DePuy Synthes, Zuchwil, Switzerland) was used for the definitive fixation of the fracture. The application of the plate followed the technique described by Lörich et al. [9] A vertical patellar length of 50 mm was set as a threshold value to cut the plate into either a large (>50 mm) or a small (<50 mm) box-like part covering the anterior aspect. The plate was then applied to the lateral aspect of the patella and bent until it anatomically matched to the peripheral contour of the bone. Its inferior long arm was passed posteriorly to the patella tendon, establishing contact with the inferior pole. The implant was slightly rotated such that the complete distal pole was covered by the plate and kept in place with two olive threaded wires. Four 2.4-mm and four

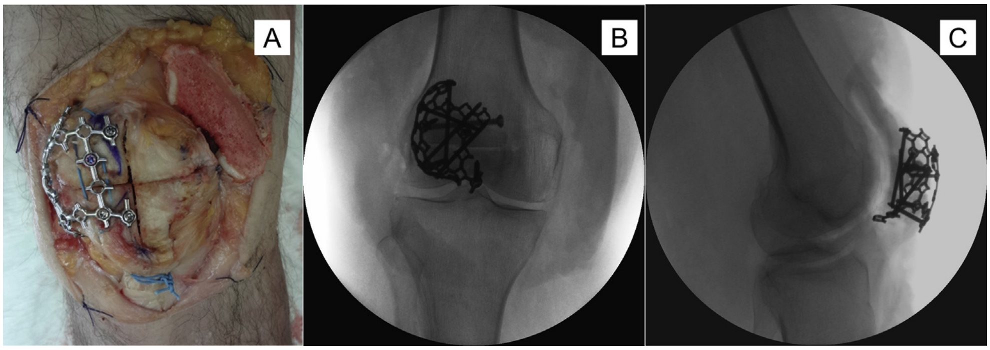

Figure 4. Visualization of anterolateral plating; a) photograph of an instrumented specimen; b) anteroposterior and c) lateral radiograph projections of the instrumented specimen.

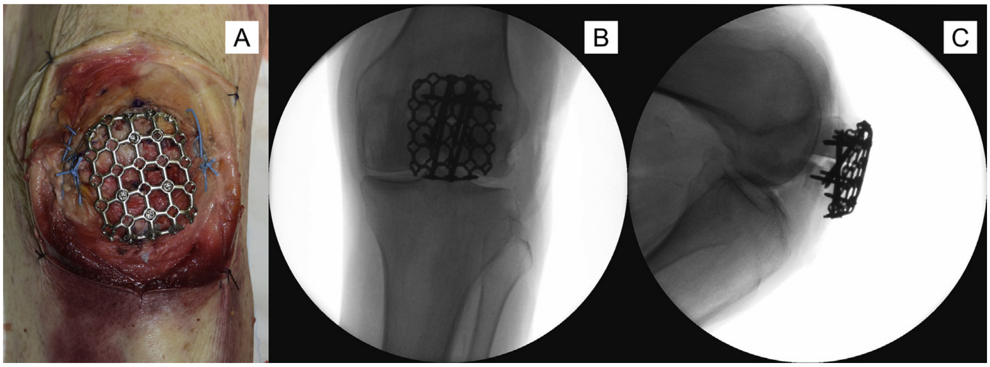

Figure 5. Visualization of the anterior plating; a) photograph of an instrumented specimen; b) anteroposterior and c) lateral radiograph projections of the instrumented specimen.

2.7-mm locking screws were used for plate fixation. Torque limiter screw drivers with a threshold of 1.2 Nm were used for proper application of the screws. Two 2.7-mm screws were placed in coronal plane, directed slightly oblique from the proximal to the distal pole. The other two 2.7-mm screws were inserted in the lateral aspect of the plate and crossed the longitudinal axis of the patella with divergent paths. Finally, the four 2.4-mm screws were placed in the box-like part of the plate, directed from the anterior cortex towards the articular cartilage, not violating the articular surface (Fig. 4).

Anterior locking plate (cage construct)

Following fracture reduction, a piece of paper was applied to determine the exact dimensions of the patella. A low-profile locking plate (Variable Angle LCP Forefoot/Midfoot System 2.4/2.7, DePuy Synthes, Zuchwil, Switzerland) was then taken and trimmed to the size of the patella anteriorly. Plate corners were cut in a way to avoid sharp edges. The plate was then contoured to fit the anterior aspect of the patella but also bent almost 90° on its superior and inferior ends to capture the poles of the bone. Once the contouring of the plate was accepted, it was fixed to the anterior aspect of the bone with olive threaded wires. Fluoroscopy was used to confirm the proper placement of the plate in relationship to the length of the patella. A total of 8 variable-angle (VA) locking screws were used with each plate. Torque limiter screw drivers with a threshold of 1.2 Nm were used for proper application of the screws. Four 2.7 mm screws were inserted in the coronal plane, fixing the superior to the inferior pole. Four unicortical 2.4 mm screws were inserted in the sagittal plane, fixing the bone from anterior to posterior. Fluoroscopy was used during the procedure certifying the surgeon that no hardware was protruding into the joint (Fig. 5).

At the end of fixation, each knee underwent a radiographic examination. Anteroposterior, lateral and oblique views of the knee were obtained for each specimen of each group. The proximal 6 cm of the femur and the distal 6 cm of the tibia were embedded in a polymethylmethacrylate (PMMA) socket (Suter Kunststoffe AG, Fraubrunnen, Switzerland). A steel rod was secured intramedullary in the tibia canal during embedding. A 3.1-kg disc was attached to the rod at a distance 25 cm from the knee joint to simulate lower limb weight [8,13,15,16]. Finally, seven retroreflective marker sets of four markers each were attached to the six fracture fragments and to the tibia tuberosity for optical motion tracking.

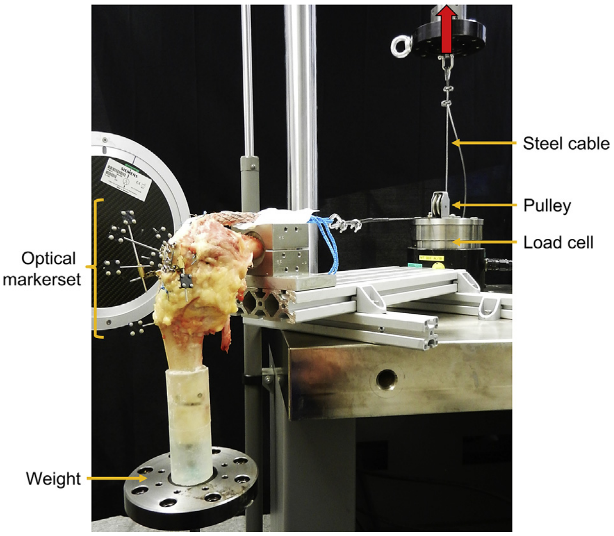

Figure 6. Specimen preparation and set up for biomechanical testing.

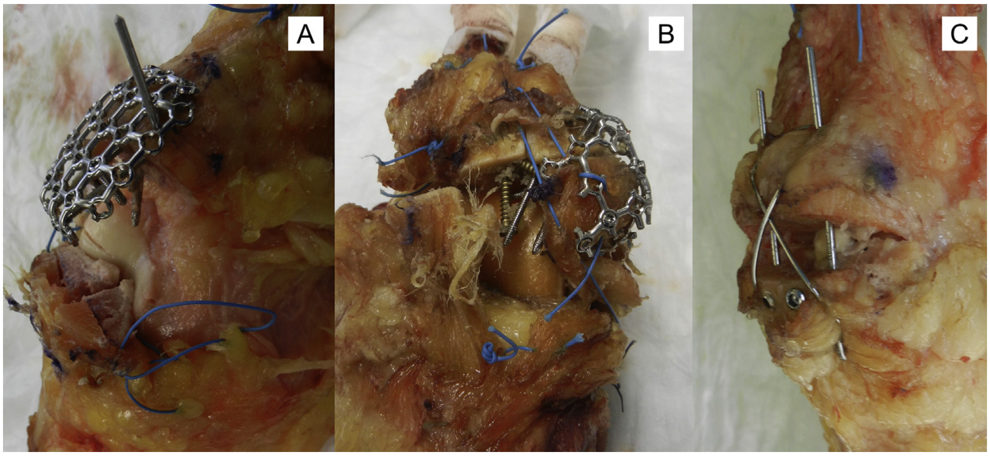

Figure 7. Modes of catastrophic failure after cyclic testing for the three fixation constructs a) anterior plating and b) anterolateral plating, and c) TBW.

Biomechanical testing

Biomechanical testing was performed on a servo hydraulic material testing apparatus (Bionix 858.20; MTS Systems Corp., MN) equipped with a 25-kN load cell. Previous set up and protocol, presented by Schnabel et al. [13], were adopted (Fig. 6). The proximal part of the femur was mounted horizontally on the machine base using a custom-made fixation. Pulling force was transmitted to the quadriceps tendon via a steel cable directed via a pulley to the machine actuator. The quadriceps tendon was approached and isolated from the muscle by dividing into two equal parts and allowing each of them to be inserted into Chinese finger traps at their site of minimal cross-sectional area. The tendon parts were sutured to the finger traps with a Ti-Cron number 5 thread (Covidien, Dublin, Ireland). These were connected to the steel cable with a cord in a 2-point load-distributing anchor, to ensure equally distributed pulling forces over the two tendon parts.

Each specimen underwent cyclic loading at a 1/6 Hz test frequency in load control mimicking knee extension-flexion movements of a sitting patient between 90° of flexion and full knee extension. Starting from a preload of 20 N with the knee flexed at 90°, the quadriceps tendon was pulled during each cycle until full knee extension and then returned to 90° flexion, applying a bell-shaped loading profile with 300 N peak force. The test stop criteria were defined by either reaching 5000 test cycles or failure of the fixation construct. If no failure was detected after completion of the cyclic test, a quasi-static load-to-failure test was performed, exposing the specimens to a continuously increasing pulling force at 20 N/s under 45° constrained flexion with 200 N initial traction.

Data acquisition

A three-dimensional optical motion tracking system with 5 infrared cameras (ProReflex MCU 120, Qualisys AB, Gothenburg, Sweden) was used to capture movements of the seven marker sets at 50 Hz throughout the cyclic tests. Based on these, interfragmentary motions were evaluated at seven time points after 50, 500, 1000, 2000, 3000, 4000 and 5000 loading cycles. Fracture site displacement in the direction of the tibial axis and interfragmentary rotation around the mediolateral axis of the patella, both at full knee extension, were considered relevant metrics for evaluation. They were evaluated separately between the superior-medial and anterior-inferior-medial fragments (defined as displacement medial and rotation medial, respectively), as well as between the superior-lateral and anterior-inferior-lateral fragments (defined as displacement lateral and rotation lateral, respectively). In addition, fracture site displacement between the superior-medial and superior-lateral fragments (defined as displacement superior), as well as between the anterior-inferior-medial and anterior-inferior-lateral fragments (defined as displacement inferior) was evaluated.

Failure criterion of the osteosynthesis was defined as 2-mm displacement at the articular margin at the fracture site. The number of cycles until fulfillment of this criterium was calculated and defined as cycles to failure.

All cyclic tests were accompanied by mediolateral x-rays, taken at test begin with the knee flexed at 90°, and then every 100 cycles at full knee extension.

During the quasi-static load-to-failure tests machine data in terms of axial load (N) and axial displacement (mm) were considered to calculate the maximum load at the time point when catastrophic failure settled in by loss of fixation due to collapse of the respective fixation construct. Every specimen reaching the 2-mm failure criterion during the cyclic test was excluded from this evaluation.

Statistical evaluation over the parameters of interest was performed with SPSS (IBM SPSS Statistics 23.0, IBM, Armonk, NY). Normality of data distribution was screened and proved by Shapiro–Wilk test for each separate fixation technique. Interfragmentary motions at the 7 different time points were screened for differences between the fixation techniques by applying General Linear Model Repeated Measures test. Independent-Samples t-test was applied to identify differences between the fixation techniques regarding cycles to failure and load at failure. The level of significance was set to 0.05 for all statistical tests, considering multiple comparisons tests where necessary.

Results

BMD was 259.5 ± 94.9 (mean ± standard deviation, SD) mg hydroxyapatite (HA)/cm^3 for anterior plating, 246.1 ± 26.1 mgHA/cm3 for antero-lateral plating, and 240.1 ± 35.5 mgHA/cm3 for TBW, with no significant differences between the fixation techniques ($P = 0.868$).

Two specimens with TBW and one specimen with antero-lateral plating failed catastrophically during cyclic testing, as indicated by their excessive uniform displacement between the superior and inferior fragments in the transverse fracture plane. This displacement was more asymmetrical after antero-lateral plating, emphasizing substantial displacement particularly on the medial aspect of the patella (Fig. 7). All other specimens completed 5000 cycles without catastrophic failure.

In addition, all specimens with anterior plating completed 5000 cycles without reaching the 2-mm failure criterion for both medial and lateral patella fragments. For antero-lateral plating, this failure criterium was reached considering the lateral patella fragments in one specimen, and the medial patella fragments in three specimens. All specimens with TBW reached the failure criterium considering their both lateral and medial fragments before 5000 cycles of testing. Consequently, none of them qualified for the load-to-failure test.

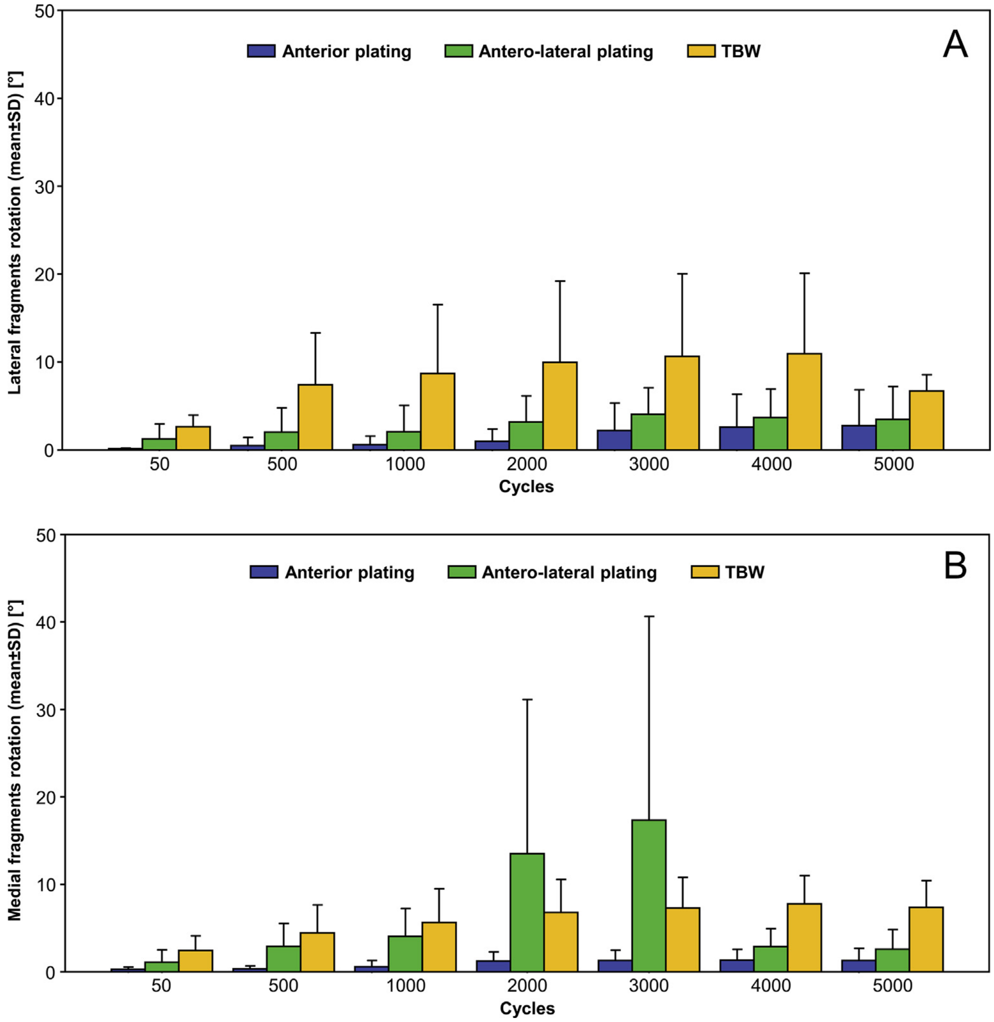

Figure 8. Interfragmentary rotation around the medio–lateral axis between the superior and inferior a) lateral and b) medial fragments in terms of mean and SD over the seven investigated time points for each fixation technique separately.

The outcomes of the parameters of interest evaluated over the seven time points – displacement and rotation, both medial and lateral – increased significantly in the course of time (rotation lateral: $P = 0.028$, rotation medial: $P < 0.001$, displacement lateral: $P < 0.001$, displacement medial: $P < 0.001$). However, lateral fragment rotation resulted in no significant differences among the three fixation techniques, $P = 0.111$ (Fig. 8a). On the other hand, medial fragment rotation was significantly lower for anterior plating compared to TBW ($P = 0.017$), with no further identified significant differences among the fixation techniques (TBW versus anterolateral plating: $P = 0.099$ anterolateral versus anterior plating: $P > 0.999$) (Fig. 8b). Further, lateral displacement was significantly lower for anterior plating compared to both antero-lateral plating ($P \leq 0.032$) and TBW ($P \leq 0.001$), and in addition significantly lower for antero-lateral plating compared to TBW ($P < 0.001$) (Fig. 9a). Medial fragment displacement was lowest for anterior plating, showing a trend to significance versus antero-lateral plating ($P = 0.084$), and being significantly lower compared to TBW ($P < 0.001$). In addition, medial fragment displacement was significantly lower for antero-lateral plating compared to TBW ($P < 0.001$) (Fig. 9b). Superior and inferior fragment displacements, evaluated over the seven time points, were below 0.35 mm and did not reveal any significant differences among the fixation techniques ($p \geq 0.212$).

Cycles to failure (defined as the number of cycles until 2-mm displacement at the articular margin at the fracture site, considered as failure of the osteosynthesis) were 5000 ± 0 for anterior plating, 3736 ± 1968 for antero-lateral plating, and 268 ± 251 for TBW. They were significantly higher for anterior and antero-lateral plating compared to TBW ($P \leq 0.002$), with no other detected significances ($P \geq 0.180$).

Finally, the load at catastrophic failure during the ultimate destructive quasi-static testing was significantly higher for anterior plating (1637.9 ± 397.8 N) compared to antero-lateral plating (1035.9 ± 219.4 N) ($P = 0.048$).

Discussion

Previous studies have reported superior biomechanical performance of locking plating versus tension band wiring of simple transverse fracture types [8,12,17]. Nevertheless, to the best of our knowledge, this is the first biomechanical study that compares these constructs for fixation of comminuted and unstable patellar fractures.

Tension band wiring revealed poor performance confirming that circumferential contact at the fracture site is a very important requisite for the success of this technique [5].

Locking plates may have distinct functions according to the way they are applied to the bone [18]. The use of locking plates on the anterior aspect of the patella allows not only for the fixation of multiple fragments but also for the conversion of tensile forces into compression forces across the fracture site along the range of motion of the knee [7,9].

The multiplanar orientation of the screws with locking plates allowed for better control of the fragments if compared with TBW. When

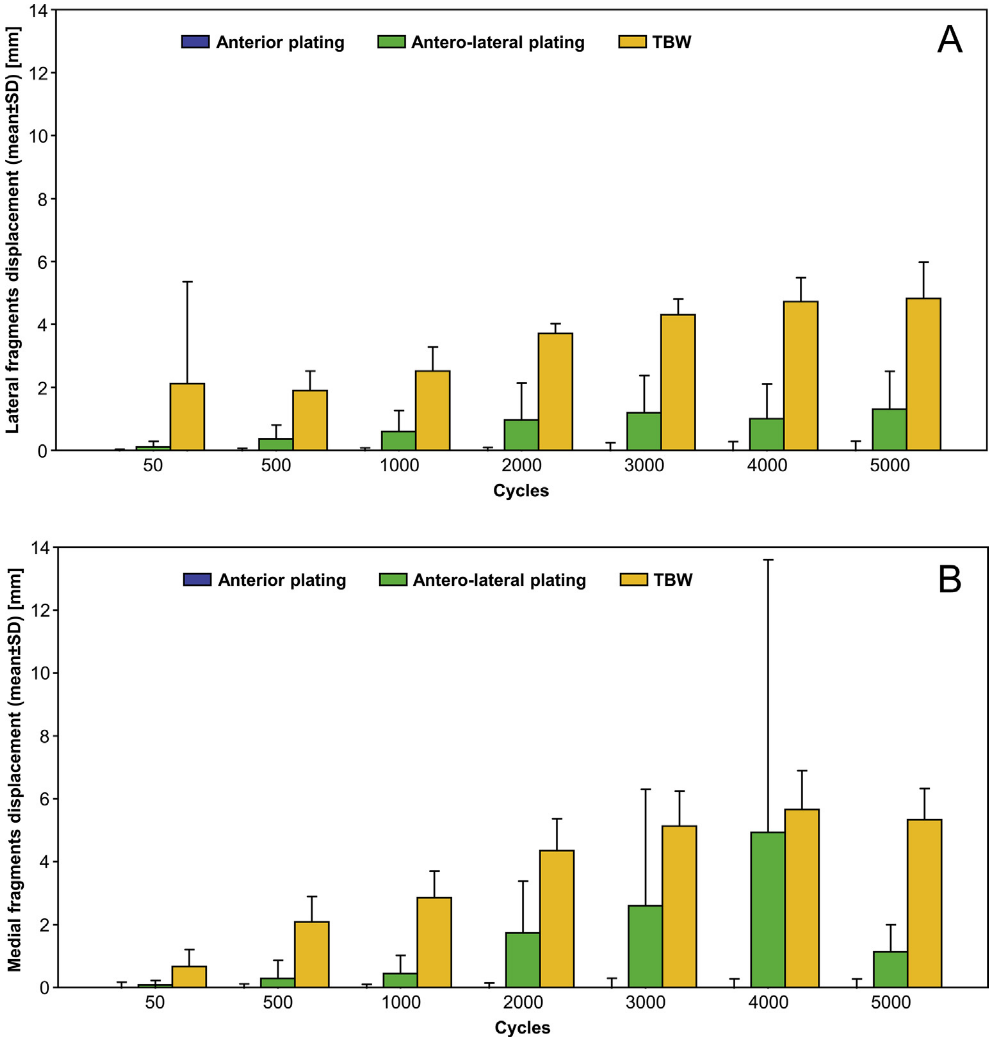

Figure 9. Interfragmentary longitudinal displacement between the superior and inferior a) lateral and b) medial fragments in terms of mean and SD over the seven investigated time points for each fixation technique separately.

comparing the two plate constructs, the anterior plate revealed biomechanical superiority in terms of displacement and rotation between the proximal and distal fragments on both medial and lateral aspects of the patella, number of cycles to failure, and load at catastrophic failure. Despite the fact that both plates have used the same number of screws, the tridimensional orientation of the screws was quite different between these two groups. While the antero-lateral plate had its 2.7 mm screws inserted from side to side mediolaterally, the anterior “cage” construct had the 2.7 mm screws inserted from superior to inferior and in the other way around. The biomechanical superiority of the anterior plate may be eventually explained by the fact that the larger screws are applied to lock the superior and inferior poles, withstanding the shearing forces on the anterior aspect of the patella during the flexion and extension of the joint. The anterior plating technique revealed better stability compared to the antero-lateral one, which can be attributed to higher degree of plate coverage with the former in contrast to the highly asymmetrical plate location after antero-lateral plate positioning. The latter provides less anchorage possibilities in the medial implant area due to its design leading to a higher degree of dislocation at the medial than the lateral patella aspect. The remarkably good performance of the anterior plating was manifested by the fact that during cyclic testing its specimens kept the interfragmentary displacement below 2 mm – defined as a failure criterion – which was additionally confirmed by the significantly higher load at catastrophic failure for anterior versus antero-lateral plating during the final destructive quasi-static test.

In the group of TBW the outcomes could have been potentially enhanced in case of use of cannulated screws instead of smooth Kirschner wires. The use of cannulated screws in association with a figure of eight cerclage demonstrated superior biomechanical properties if compared to the standard TBW construct used in this study [15]. Moreover, the orientation of compression screws commonly used in modified TBW techniques, corresponding approximately to the orientation of the screws placed in the coronal plane in both anterior and antero-lateral plate systems, may have contributed to additional stabilization of the patellar fragments.

This study has limitations inherent to all cadaveric studies using a limited number of specimens. In addition, the fracture model comprised 6 fragments, however, only the 4 anteriorly located ones were captured with motion tracking due to technical reasons – the tracking of the hidden posterior patella fragments was not reliable. Nevertheless, precise motion tracking of the remaining four fragments was performed which is a strength of the study. Furthermore, due to the nature of the experimental loading mechanism, main relative movements were observed between the superior and inferior patella fragments, whereas those between the medial and lateral ones were practically negligible. This means that even for fixation of a complex fracture situation the main attention should be paid to stabilize the fragments separated by the transversally oriented fracture line. This insight further explains the mechanical superiority of the anterior plating technique over the tension band technique concerning axial displacement of the main fragments. Another limitation concerns the procedural use of the tension band wires. As seen on the postinterventional x-rays, the applied cerclage wires did not fully attach to the osseous surface of the patellae due to soft tissue interference. The fact that the cerclage instrumentations do not directly reach the poles of the patellae represents the clinical reality. The absence of direct contact between the implant and the bone further diminishes the stability of tension band wiring constructs in supero-inferior direction. Therefore, this procedural issue represents a clear disadvantage of the tension band wiring technique in comparison to the anterior plating technique.

A strength of the study was its elaborated test setup for cyclic loading, including simulation of the knee extensors with a wide range of 90° motion to mimic physiological conditions.

This study allows for reflection about possible implications in the clinical management of comminuted fractures with locking plates. The plates used in this study had a low profile and were perfectly contoured to the surface of the patella. However, as it applies to all other metallic constructs placed under the superficialis fascia of the knee, a second procedure for hardware removal should be taken into consideration. The contouring of the plate is critical especially with regard to the attachment of the quadriceps and patellar tendons. The patellar tendon covers the inferior pole of the patella. Therefore, the plate should be trimmed in a way that some of its holes may be bent and placed onto the inferior pole, by splitting longitudinally the fibers of the patellar tendon. Locking plates should only be applied to the patella after complete reduction of the fracture, as the plate in the way it has been described in this manuscript does not promote fracture reduction.

Conclusion

From a biomechanical point of view, anterior mesh locked plating of complex patella fractures provides superior stability compared to both antero-lateral mesh locked plating and tension band wiring. It can be considered as valuable treatment option providing an encompassing and multiplanar stability to the fractured fragments. The locked mesh plate offers the advantage of versatile applicability in terms of pre-contouring and screw positioning. On the other hand, tension band wiring is associated with considerably inferior performance as evidenced by the highest interfragmentary movements. Clinical studies should evaluate the feasibility and outcomes of the anterior locking plate with orthogonally placed screws for comminuted patellar fractures.

Conflict of interest

The authors have no conflicts of interest to disclose in relation to this article.

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