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Anterior variable-angle locked plating of complex patella fractures – Does the type of polar screw matter?

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A R T I C L E I N F O

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A B S T R A C T

Background: Treatment of complex patella fractures represents a challenging clinical problem. Whereas controversy exists regarding the most appropriate fixation method, anterior plating is an emerging treatment option. A novel design of anterior variable-angle locking plates features radiating legs with integrated screw holes aiming at capturing fragments of the distal comminuted zone via either a locking or a cortical polar screw.
The aim of this study was to compare the biomechanical performance of the novel anterior variable-angle locking plates used for fixation of complex patella fractures with either a locking or a cortical polar screw.
Methods: Complex five-part AO/OTA 34-C3 patella fractures mimicking comminution around the distal pole were simulated in twelve human cadaveric knees. Specimens were randomized to two groups for treatment with an anterior variable-angle locking plate fixing the patella with either one locking or one cortical caudo-cranial bicortical polar screw. Biomechanical testing was performed over 5000 cycles by pulling on the quadriceps tendon, simulating active knee extension and passive flexion within the range from 90° flexion to full extension. Interfragmentary movements were captured by motion tracking.
Findings: No significant differences between the two fixation techniques were detected in terms of longitudinal and shear articular displacements, and relative rotations around the mediolateral axis measured between the proximal and distal fragments at the central patella aspect between 1000 and 5000 cycles, $P \geq 0.116$.
Interpretation: From a biomechanical perspective, anterior locked plating of complex patella fractures provides comparable fixation stability when using either a locking or a cortical polar screw.

1. Introduction

Being surrounded by the quadriceps tendon proximally and the patella ligament distally, the patella represents the largest sesamoid bone in the human body (Carpenter et al., 1994; Huberti et al., 1984). By acting as a pulley, its main function is to increase the lever arm and hence the torsional moment in the knee joint around its main axis of rotation, induced by forces generated through contraction of the quadriceps muscle (Reilly and Martens, 1972). The patella's function is most effective at full knee extension (Kaufer, 1971). However, the torque intensifying mechanism pays tribute to the patellofemoral joint, which exerts high contact forces, overtopping 7-fold body weight in crouching position of approximately 60° knee flexion angle (Reilly and Martens, 1972). As a result, depending on the knee angle, the patella is stressed in tension or combined tension and three-point-bending, reaching a maximum magnitude of tensile forces on its anterior surface at 45° flexion (Goldstein et al., 1986).

Fractures of the patella account for 0.5–1.5 % of all fractures occurring in the human skeleton (Wendl et al., 2002), with an increase in incidence of about 40 % between the 1950s and 2011 (Court-Brown

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et al., 2014). Among different types of patella fractures, the comminuted type AO/OTA 34-C3 is most common, followed by simple transverse fractures type AO/OTA 34-C1 (Larsen et al., 2016). The injury mechanism in majority of the cases is a combination of direct trauma on the anterior surface with an indirect eccentric force exerted by contracted quadriceps muscle (Carpenter et al., 1994). Displaced simple or comminuted patella fracture fragments associated with a disrupted extensor mechanism qualify for surgical refixation (Wendl et al., 2002). Thereby, anatomic reposition with reestablishment and perseverance of a smooth articular surface is given high importance to prevent post-traumatic osteoarthritis, the latter being prone to develop due to high patellofemoral joint forces (Carpenter et al., 1997; Schnabel et al., 2009).

Surgical treatment of complex patella fractures can be performed with tension band wiring with additional circumferential cerclage wiring (Carpenter et al., 1994; Mueller, 1961). However, a lack of congruity is especially pronounced in comminuted patella fractures (Kfuri et al., 2021).

Recently, anterior variable-angle (VA) locking plates were developed for specific treatment of both simple and comminuted patella fractures, establishing an armamentarium for their plating with implementation of multiplanar fixation. The plates are made of medical grade stainless steel (316 L) or Titanium (cp-Ti) and are provided in two sizes with three different configurations each. The configurations vary the three leg branches for capturing of the distal patella pole, namely core (without legs), three-hole, and six-hole. The radially arranged six arms and the distally extending three legs are designed to be bent, allowing for best-possible patient-specific fit on the corresponding patella fragment surface. The legs allow bicortical polar (apex to base) screw placement for interfragmentary fixation. Each plate hole is characterized with VA locking technology, accepting either 2.7 mm VA locking or 2.7 mm cortex screws (*Variable Angle Locking Anterior Patella Plates 2.7 - Surgical Technique*, 2020).

The aim of this study was to compare the biomechanical performance of the novel anterior VA locking plates used for fixation of complex patella fracture with either a locking or a cortical polar screw.

2. Methods

2.1. Specimens and preparation

Twelve fresh-frozen (−20 °C) human cadaveric knees from 7 female and 5 male donors (mean age 77 years, range 67–84 years, mean height 170 cm, range 167–175 cm, mean body mass index 21.9, range 13.38–26.61) were used. All donors gave informed consent within the donation of anatomical gift statement during their lifetime. Inclusion criteria for the specimens were normal range of motion without any macroscopic bone deformities or osseous joint irregularities, as radiologically proven, and no previous surgical treatment around the joint, such as fracture fixation or joint replacement. The knees were thawed at room temperature for 24 h prior to preparation and biomechanical testing. Each femur and tibia were transected at 15 cm and 25 cm from the knee joint, respectively.

The patellae of all knees were assessed for bone mineral density (BMD) within their trabecular region via computed tomography (CT) scanning (General Electric Healthcare, Buckinghamshire, UK) with a phantom (BDC-6, QRM GmbH, Möhrendorf, Germany) and subsequent image analysis (Amira, v.6.0, Thermo Fisher Scientific, Waltham, MA).

Based on BMD, the knees were randomized to two groups with equal right and left specimens each ($n = 6$). The sample size was calculated based on a priori power analysis, assuming that after biomechanical testing the mean difference in fracture displacement of 30 % between the groups would represent a clinically meaningful difference, and that a standard deviation of 66 % (2/3) of this mean difference (effect size: 0.3; SD: 0.2) could be expected deviations. Based on these assumptions, a sample size of 6 specimens would be necessary to reach significant differences between the two groups. A five-part patella fracture type AO/OTA 34-C3 was created in all specimens as follows. A mid-axial longitudinal approach was used to expose the anterior patella surface. A horizontal cutting line was marked centrally after identification of the proximal and distal poles. To minimize variations in fracture morphology, fracture creation was performed via osteotomies using a custom cutting guide, aligned with the corresponding horizontal mark, oriented parallel to the articular surface and attached on the anterior patella surface with olive Kirschner (K-) wires. The complex fracture pattern was characterized with a smaller medial and a larger lateral proximal fragment, together with an inferomedial, an inferolateral and an inferior fragment mimicking comminution around the distal patella pole. The corresponding slots of the cutting guide were designed radially, crossing each other at one central point. All fragments were fully separated from each other during osteotomizing. The extensor retinaculum was divided in line with each transverse cut. A lateral arthrotomy was performed for anatomical fracture reduction, provisionally fixed with pointed forceps and temporary K-wires. A smooth articular surface was confirmed by palpatory inspection.

The two groups were assigned for fixation with a small size anterior VA locking three-hole plate using either locking or cortical polar screw.

The next step comprised plate positioning as needed to best fixate the fragments based on specimen’s anatomy, and its subsequent provisional attachment with olive K-wires. Care was taken for each fragment (1) to receive a screw through at least one of the plate arm screw-holes, and (2) to interact with at least two screws (Stoffel et al., 2023).

Plate arms and legs were bent individually to ensure optimal fit to the patella surface using dedicated bending instruments. Thereby, the bending of the plate legs was to the extent that each of them embraced one of the three distal fragments basket-like. Pilot holes were pre-drilled with 2.0 mm drill bits using VA drill guides, allowing to set appropriate drill hole direction with a maximum deviation from the nominal axis of the plate hole up to 15°. Following, 2.7 mm VA locking screws were placed in the pilot holes in unicortical fashion. The proximal and distal three holes of the plate arms were occupied with screws together with the two inner plate body holes. Fixation of the distal fragments was enhanced with two 2.7 mm locking rim screws through the two outer leg screw-holes. Finally, according to the group assignment, either one locking or one cortical polar screw was inserted through the central leg screw-hole, vectored caudo-cranially in frontal plane (apex to base), transfixing additionally the transverse fracture line in bicortical fashion. Whereas all locking screws were locked at 1.2 Nm, the cortical polar screws were tightened according to the operator’s tactile feedback.

All used implants were made of stainless steel and provided by the same manufacturer (JnJ MedTech, Zuchwil, Switzerland). Two experienced surgeons performed all instrumentations under fluoroscopic control (Fig. 1) ensuring consistency of the procedures. Skin and subcutaneous tissue were completely excised after instrumentation. The fibula and all surrounding muscles were removed, with the exception that the extensor mechanism, ligaments, and joint capsule of the knee were preserved. The proximal 6 cm of the femur and the distal 6 cm of the tibia were embedded in a polymethylmethacrylate (PMMA, Suter Kunststoffe AG, Fraubrunnen, Switzerland) socket. A threaded steel rod was additionally secured in the intramedullary canal during tibia embedding, allowing to attach a disc of 3.1 kg weight to it at a distance of 25 cm from the knee joint to mimic lower limb weight (Carpenter et al., 1997; Schnabel et al., 2009; Scilaris et al., 1998; Thelen et al., 2012). Retro-reflective marker sets were attached to the tibia, the proximal and the central distal patella fragments for motion tracking.

2.2. Biomechanical testing

Biomechanical testing was performed on a servo-hydraulic material testing machine (Bionix 858.20, MTS Systems Corp., Eden Prairie, MN, USA) equipped with a 5 kN load cell, adopting a test setup and a loading protocol from previous studies (Kfuri et al., 2021; Nienhaus et al., 2018)

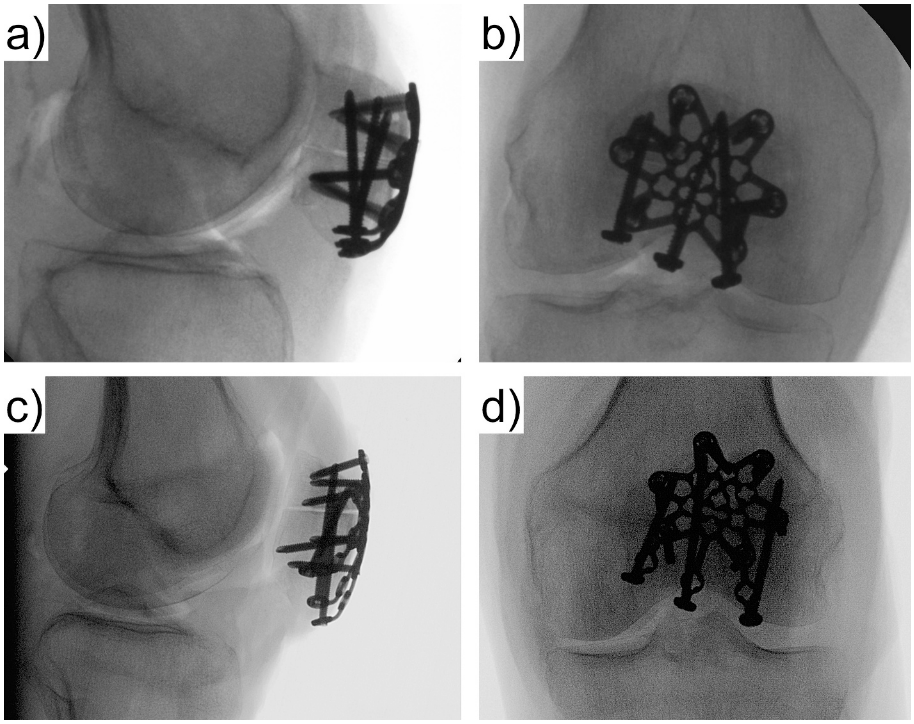

Fig. 1. Exemplified radiographs of specimens treated with anterior locked plating using a cortical (a,b) or a locking (c,d) polar screw in mediolateral (a,c) and anteroposterior (b,d) view.

(Fig. 2). The proximal part of each femur was mounted horizontally on the machine base using a custom-made fixture. Pulling force was transmitted to the quadriceps tendon via a steel cable directed via a pulley to the machine actuator. The quadriceps tendon was isolated from the muscle, inserted into a Chinese finger trap, sutured to it with a size-zero Ti-Cron thread (Medtronic plc, Dublin, Ireland) and connected to the steel cable with a spring hook.

Each specimen underwent cyclic loading at 1/6 Hz mimicking knee movements of a sitting patient between 90° 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 tensile force. The test stop criteria were defined by either failure of the fixation construct or reaching 5000 test cycles.

2.3. Data acquisition and analysis

Machine data in terms of actuator displacement and pulling force were collected from the test system controllers at 128 Hz. In addition, two optical cameras (Aramis SRX, Carl Zeiss GOM Metrology GmbH, Braunschweig, Germany) continuously recorded the marker positions for motion tracking, operating at resolution of 12 megapixel and maximum acceptance error of 0.004 mm (vdi/vde, 2002). Based on these, interfragmentary motions were evaluated in all six degrees of freedom at five time points after 1000, 2000, 3000, 4000, and 5000 loading cycles. Three metrics of fracture site motion were evaluated. The first two of them were fracture site displacement along the tibia axis—longitudinal displacement—and perpendicular to it in anteroposterior direction—shear displacement—, calculated at the most articular margin of the horizontal osteotomy plane located centrally in mediolateral direction. The third metric was interfragmentary rotation around the mediolateral axis. All metrics were derived at 90° knee flexion and calculated between the proximal medial and distal central fragment.

All cyclic tests were accompanied with mediolateral x-rays, taken at test start with knee flexed at 90°, and then every 100 cycles at full knee extension for radiological examination of any temporal degradation processes within the bone-implant interface.

Statistical analysis was performed using SPSS software package (IBM SPSS Statistics 27, IBM, Armonk, NY, USA). Normality of data distribution within each fixation technique was screened and proved with Shapiro-Wilk test, following Independent-Samples *t*-test used to check and confirm appropriate randomization of the knees based on their BMD. General Linear Model Repeated Measures test was applied to identify significant differences between the two fixation techniques. Level of significance was set to 0.05 for all statistical tests.

3. Results

BMD was 234.5 ± 44.2 (mean ± standard deviation, SD) mgHA/cm^3 for plating with polar cortical, and 260.8 ± 43.5 mgHA/cm^3 for plating with polar locking screw, demonstrating homogeneous distribution with no significant differences between the fixation techniques ($P = 0.322$).

The results for all motion tracking metrics, namely longitudinal and shear articular displacements, and interfragmentary rotation after 1000, 2000, 3000, 4000, and 5000 cycles are visualized in Fig. 3 and summarized in Table 1. Each separate fixation technique was associated with a significant increase of all outcome measures over time ($P \leq 0.036$). However, the outcome measures for all three investigated metrics demonstrated non-significant differences between the fixation techniques ($P \geq 0.116$). In addition, BMD revealed no significant influence on the results when considered as a covariate ($P \geq 0.624$). All cyclic tests were completed without catastrophic implant failure in any of the specimens (Fig. 4).

4. Discussion

Treatment of complex patella fractures represents a challenging clinical problem. This study's objectives were to compare the biomechanical performance of the novel anterior VA locking plates using either locking or cortical polar screws in a human cadaveric model. No

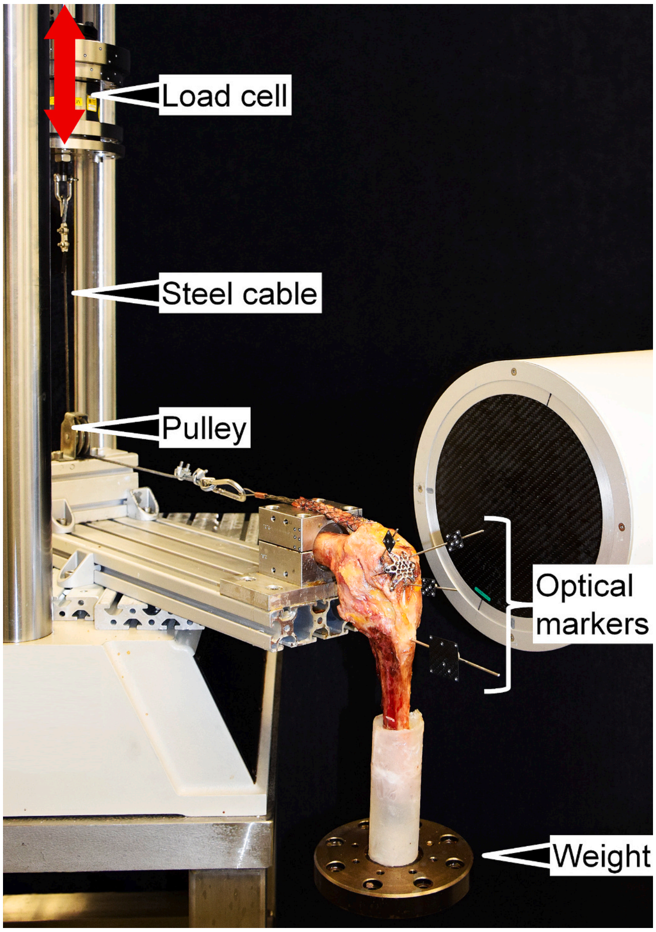

Fig. 2. Setup with a specimen implanted with a three-hole anterior variable-angle three-hole locking plate, equipped with markers for motion tracking and mounted for biomechanical testing. Vertical double-arrow indicates movement direction of the machine transducer.

significant differences between the two fixation techniques were detected. Based on these findings, use of both cortical and locking polar screw deems, from a biomechanical perspective appropriate within the cohort of specimens featuring the reported BMD.

Since patella fracture fixation relies on primary bone healing, requiring absolute interfragmentary stability, with regard to the measured marginal interfragmentary movements, good healing rates may be prognosed following both presented plate fixation. Although there was a significant increase of interfragmentary movements within the course of cyclic testing, they remained at a very low level. This was also substantiated by a visual inspection of the tested specimens post testing, revealing closed fracture gap sites to each other. Such a good stability can be explained by the rigid fixation achieved and maintained via an angular stable screw-plate construct. Thereby, the locking mechanism is predominantly stressed in cantilever bending and shearing at the screw head for the antero-posterior screws, while the polar locking or cortical screws undergo axial pullout forces combined with bending moments. However, despite the high forces exerted by the extensor mechanism, in the current testing series no breakage of plate fixation screws was observed.

Results of the current study do not allow a prognostic statement whether different performance could be expected for bone quality deviating from the investigated cohort. Generally, a polar cortical cortex screw can be used to enhance interfragmentary compression and can be dependent on surgical technique, whereas use of a polar locking screw provides more repeatable fixation and minimizes fragmentary motion comparatively.

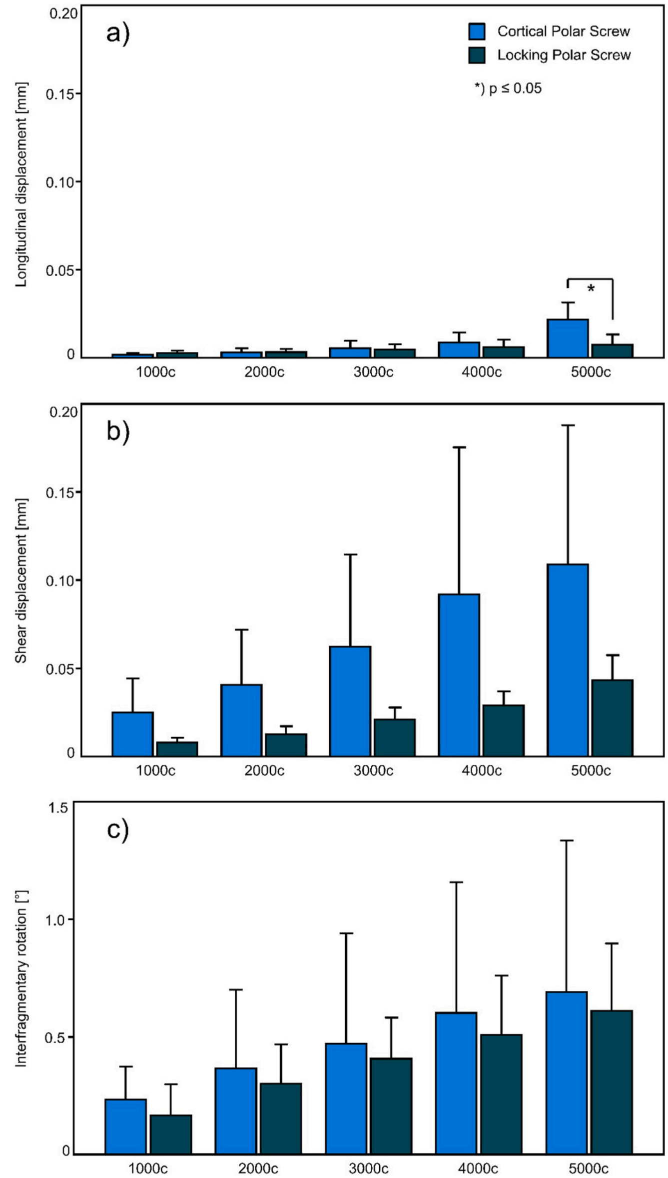

Fig. 3. Longitudinal (a) and shear (b) articular displacement at the central aspect of the patella, and interfragmentary rotation around the mediolateral axis (c) in terms of mean and standard deviation, measured between the proximal and distal patella fragments after 1000, 2000, 3000, 4000 and 5000 test cycles for the fixation techniques using either a cortical or locking polar screw.

Table 1
P-values for outcomes' progression over time (increase over cycles) for each separate fixation technique (cortical or locking polar screw), from comparisons between fixation techniques (cortical versus locking) and for BMD influence as a covariate.

Outcome	Increase over cycles		Cortical versus locking	BMD influence
	Cortical	Locking		
Longitudinal displacement	0.004	0.036	0.268	0.922
Shear displacement	0.028	0.004	0.116	0.624
Interfragmentary rotation	0.013	0.005	0.352	0.782

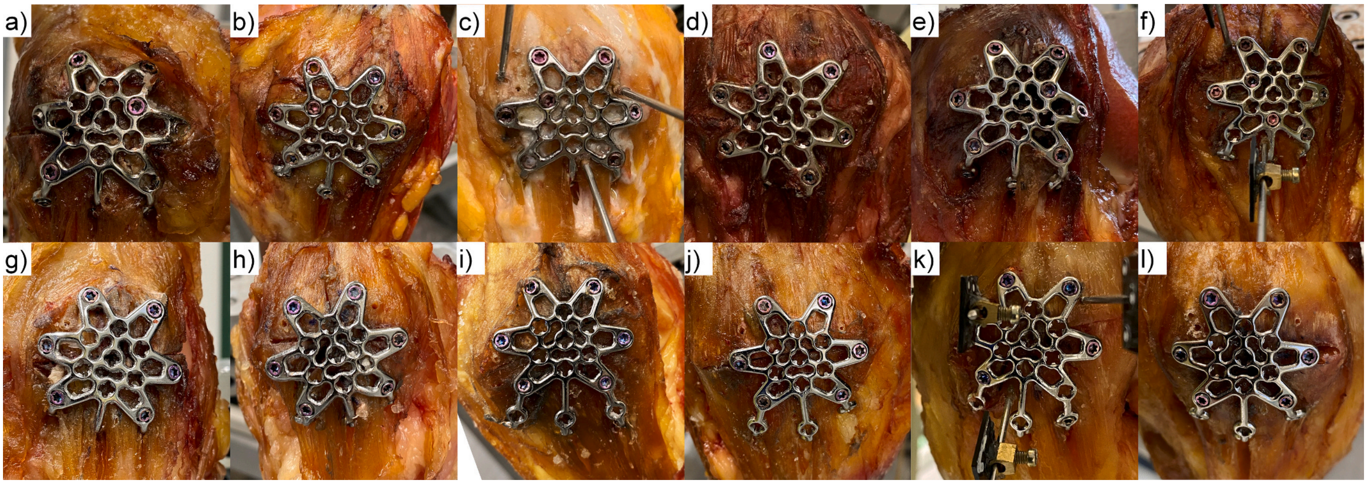

Fig. 4. Post-test photographs of specimens treated with anterior variable-angle locked plating using a cortical (a-f) or a locking (g-l) polar screw.

There is growing evidence from biomechanical in-vitro studies that anterior plating of complex patella fractures is superior compared to tension band wiring (Kfuri et al., 2021; Stoffel et al., 2023; Wagner et al., 2020). It seems that the maintenance of congruity and neutralization of tensile forces are more efficient when using low-profile locking plates (Taylor et al., 2014; Wild et al., 2016). On the other hand, clinical studies have yet to confirm these findings, despite promising results reported in several clinical trials, case reports and surgical techniques, using a variety of locked plating techniques for treatment of complex patella fractures (Kancherla and Nwachuku, 2017; Lorich et al., 2015; Lorich et al., 2017; Matthews et al., 2017; Moore et al., 2018; Muller and Frosch, 2017; Siljander et al., 2017a; Siljander et al., 2017b; Siljander et al., 2018; Volgas and Dreger, 2017; Wild et al., 2016; Wurm et al., 2018).

Generally, different plating techniques have been described, comprising anterior plating with unicortical screws (Siljander et al., 2017b) and various lateral plating techniques. The latter have been described as either using contoured plate and screws placed bicortically from lateral to medial in combination with unicortical screws from anterior to posterior (Lorich et al., 2015), semicircular and quasi-bilateral peripheral plating with screws placed sideways to the patella (Thelen et al., 2012; Warner et al., 2024), basket plating of specifically distally comminuted poles (Matejcic et al., 2006), or more recently anterior plating with branches of the plate encompassing the superior and inferior patella pole and allowing for multiplanar screw fixation (Kfuri et al., 2021). In a biomechanical study, the latter has demonstrated promising results versus both lateral plating and tension band wiring in a novel comminuted patella fracture model including coronal split of the distal pole (Kfuri et al., 2021). However, for all these plating techniques, VA mesh locking plates with a primary field of use for foot fractures were trimmed. The current study presents a novel plate design purpose-made for patella fracture fixation that does not require additional trimming.

The distally comminuted patella zone is challenging and requires manual dexterity to address each of the small fragments. This circumstance may be alleviated using the caudally emerging legs of the anterior plates that can be bent basket-like around the distal patella pole to capture all fragments in the comminuted zone. Moreover, this plate feature presents a further cornerstone for improved fixation stability by allowing insertion of polar screws from caudal to cranial in the frontal plane for fracture fixation in two orthogonal planes.

The efficacy assessment of plating of comminuted patella fractures is sparce (Kfuri et al., 2021; Krkovic et al., 2007; Wagner et al., 2020). The current study best compares to the one published by Stoffel et al. (Stoffel et al., 2023) regarding the used implants, the applied fracture model, and the conducted test protocol. In the previous study the authors investigated for the first time the biomechanical competence of the novel VA locking plate in comparison to tension band wiring in a simple and a comminuted patella fracture model. Thereby, a cortical polar screw was used. Furthermore, an identical five-part comminuted fracture was applied. Biomechanical testing was identical to the current study. The authors concluded that anterior locked plating of both simple and complex patella fractures provides considerable superior construct stability versus tension band wiring.

Another study performed by Wagner et al. (Wagner et al., 2020) used a different anterior plating design featuring 3.5 mm locking screws for fixation of a similar five-part comminuted patella fracture, and biomechanically investigated its fixation stability versus tension band wiring through cannulated screws, demonstrating unequivocal better stability for the plating technique.

Despite the scarce biomechanical data of plating of patella fractures, the last two decades have witnessed a significant increase in patella plate osteosyntheses, with most plated cases being applied to comminuted patella fractures (Rau et al., 2023). Especially the use of locking plates is expected to reduce complication and revision rates, and with it enhance long-term outcomes (Wild et al., 2016; Wurm et al., 2018). In a recent retrospective multicenter cohort study Berninger et al. (2024) found significantly lower implant-related complications following locked plate osteosynthesis compared to conventional tension band wiring techniques (Berninger et al., 2024).

The current study has some limitations inherent to all human cadaveric investigations using a limited number of specimens. Not all fragments could be monitored via motion tracking due to setup-related technical reasons. However, the most important anticipated relative movements were identified and accordingly tracked. Although all distal fragments could be addressed with the plate screws, this scenario may not hold true for other types of comminuted fractures. In this regard, an anatomical study applying different fracture models may assess the universality of the current plate design. Another limitation is given by the non-paired, BMD matched study design with limited number of specimens, rendering the study underpowered. At the time of study conduct, no paired specimens were available. Furthermore, the advanced donors' age of the used specimens may not holistically represent the population affected by comminuted patella fractures, which could partially be compensated be the relatively high donors' BMD values, allowing for enhanced fixation stability. However, a one-to-one projection of the results would require investigating the implant in a bimodally distributed cohort. On the one hand, previous retrospective clinical studies found that most surgical interventions on patella fractures are performed on patients aged 50–70 years (Larsen et al., 2016; Rau et al., 2023). On the other hand, it has been shown that the risk of sustaining multi-fragment fractures is increased by low-energy fractures associated with osteoporosis in elderly women (Sontag and Krege, 2010; Warriner et al., 2011).

Methodological strengths of this study comprise the use of an accurate motion tracking system, allowing precise investigation of interfragmentary movements. Furthermore, an established test setup and loading protocol were adopted to mimic physiologic conditions and test the bone-implant constructs, implementing a more distinguished assessment of key biomechanical parameters. In addition, implant fixation in a comminuted fracture model resembling clinically realistic situations was addressed.

Future studies shall focus on the biomechanical comparison between the different plating systems available on the market to assess their strengths and weaknesses, especially in terms of fixation efficacy of the comminuted fragments. Such comparisons serve as groundbreaking for further implant design optimizations.

5. Conclusions

From a biomechanical perspective, anterior locked plating of complex patella fractures provides equal fracture fixation stability when using either locking or cortical polar screws.

CRediT authorship contribution statement

Karl Stoffel: Writing – review & editing, Supervision, Conceptualization. **Ivan Zderic:** Writing – original draft, Formal analysis, Data curation. **Torsten Pastor:** Writing – review & editing, Methodology, Investigation. **William Woodburn:** Writing – review & editing, Resources, Funding acquisition. **Richard Castle:** Writing – review & editing, Validation, Resources, Conceptualization. **Jessica Penman:** Writing – review & editing, Funding acquisition, Conceptualization. **Eladio Saura-Sanchez:** Writing – review & editing, Validation. **Boyko Gueorguiev:** Writing – review & editing, Supervision, Software, Resources, Project administration, Formal analysis, Data curation. **Christoph Sommer:** Writing – review & editing, Supervision, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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