TRAUMA SURGERY

Biomechanical analysis of recently released cephalomedullary nails for trochanteric femoral fracture fixation in a human cadaveric model

Torsten Pastor[1,2] · Ivan Zderic[1] · Dominic Gehweiler[1] · Michael J. Gardner[3] · Karl Stoffel[4] · Geoff Richards[1] ·
Matthias Knobe[2] · Boyko Gueorguiev[1]

Abstract

Background Recently, two novel concepts for intramedullary nailing of trochanteric fractures using a helical blade or interlocking dual screws have demonstrated advantages as compared to standard single-screw systems. However, these two concepts have not been subjected to a direct biomechanical comparison so far. The aims of this study were to investigate in a human cadaveric model with low bone quality (1) the biomechanical competence of nailing with the use of a helical blade versus interlocking screws, and (2) the effect of cement augmentation on the fixation strength of the helical blade.

Methods Twelve osteoporotic and osteopenic human cadaveric femoral pairs were assigned for pairwise implantation using either a short TFN-ADVANCED Proximal Femoral Nailing System (TFNA) with a helical blade head element or a short TRIGEN INTERTAN Intertrochanteric Antegrade Nail (InterTAN) with interlocking screws. Six osteoporotic femora, implanted with TFNA, were augmented with bone cement. Four groups were created: group 1 (TFNA) paired with group 2 (InterTAN), both consisting of osteopenic specimens, and group 3 (TFNA augmented) paired with group 4 (InterTAN), both consisting of osteoporotic specimens. An unstable trochanteric AO/OTA 31-A2.2 fracture was simulated and all specimens were tested until failure under progressively increasing cyclic loading.

Results Stiffness in group 3 was significantly higher versus group 4, $p = 0.03$. Varus (°) and femoral head rotation around the femoral neck axis (°) after 10,000 cycles were $1.9 \pm 1.0/0.3 \pm 0.2$ in group 1, $2.2 \pm 0.7/0.7 \pm 0.4$ in group 2, $1.5 \pm 1.3/0.3 \pm 0.2$ in group 3 and $3.5 \pm 2.8/0.9 \pm 0.6$ in group 4, being significantly different between groups 3 and 4, $p = 0.04$. Cycles to failure and failure load (N) at 5° varus or 10° femoral head rotation around the neck axis in groups 1–4 were $21,428 \pm 6020/1571.4 \pm 301.0$, $20,611 \pm 7453/1530.6 \pm 372.7$, $21,739 \pm 4248/1587.0 \pm 212.4$ and $18,622 \pm 6733/1431.1 \pm 336.7$, being significantly different between groups 3 and 4, $p = 0.04$.

Conclusions Nailing of trochanteric femoral fractures with use of helical blades is comparable to interlocking dual screws fixation in femoral head fragments with low bone quality. Bone cement augmentation of helical blades provides significantly greater fixation strength compared to interlocking screws constructs.

Keywords Helical blade · Bone cement augmentation · Interlocking lag screws · Trochanteric fracture · Proximal femur · Cephalomedullary nailing · Biomechanical study

---

Torsten Pastor, Ivan Zderic, Matthias Knobe, and Boyko Gueorguiev contributed equally to this study.

✉ Torsten Pastor
  Torsten.pastor@luks.ch

[1] AO Research Institute Davos, Davos, Switzerland

[2] Department of Orthopaedic and Trauma Surgery, Lucerne Cantonal Hospital, Lucerne, Switzerland

[3] Department of Orthopaedic Surgery, Stanford Hospitals and Clinics, Stanford, CA, USA

[4] University Hospital Basel, Basel, Switzerland

Introduction

Osteoporotic trochanteric fractures are an increasingly common challenge for patients and incur significant socioeconomic costs. Despite numerous advances in implant design, complication rates and mortality remain high. Technical aspects of the implant placement, and the individual surgeons preferences play an important role in successful fixation, however, the ideal solution has yet to be developed [23]. Since its introduction, cephalomedullary nailing is a widely accepted treatment option for this type of fractures [14, 21, 23]. Initially,

these implants implemented single-screw systems to bridge the fracture line, which achieved reasonable radiological and clinical outcomes. However, mechanical complication rates of up to 16% have been reported in unstable fractures, being mostly related to varus collapse, rotation and cut-out of the femoral head fragment [1, 11, 26, 28, 35]. Higher complication rates were observed with increasing fracture complexity and decreasing patient bone quality [45]. Revision rates of up to 6.3% were reported, accompanied by poorer prognosis, an increase of mortality and fewer patients returning to their original residence [33]. Because of this, novel concepts for intramedullary nailing of trochanteric fractures have been developed. One newer implant is a helical blade instead of a lag screw as the head element, which compacts the cancellous bone in the femoral head during insertion [8]. This theoretically provides better fixation strength in low bone quality by preventing bone loss because pre-drilling of the entire head-element length—as required for use of lag screws—is not always necessary. On the other hand, lower pull-out forces and an increase of the rare complication related to medial cut-through of the head element along its axis have been observed using helical blade fixation [4]. Recently, the option for bone cement augmentation of helical blades has been introduced, potentially providing better fixation strength in the femoral head in patients with poor bone quality. Although early results are promising [15, 40], the downside of this technique is possible cement leakage into the hip joint if the augmentation is not performed correctly [47]. A different approach to address the fixation problem of the femoral head fragment was the introduction of interlocking dual screws, which provides interfragmentary compression at the fracture gap during implantation using an additional compression screw [41]. Furthermore, the larger oval shaped cross section of the two screws provides an advantage against rotational moments [12, 20]. These two novel concepts for intramedullary nailing of trochanteric fractures using either a helical blade with or without bone cement augmentation, or interlocking dual screws are commonly used in the orthopaedic field today and have demonstrated advantages as compared with single-screw systems [8, 30, 42, 46]. However, they have not been subjected to a direct biomechanical comparison. Therefore, the aims of this study were to investigate in a human cadaveric model with low bone quality (1) the biomechanical competence of nailing with the use of a helical blade versus interlocking dual screws, and (2) the effect of cement augmentation on the fixation strength of the helical blade in the femoral head.

Materials and methods

Specimens and study groups

Twelve pairs of fresh-frozen (− 20 °C) human cadaveric femora from 5 female and 7 male donors aged 77.8 years on average (range 70–87 years) were used. Based on Dual-Energy X-ray Absorptiometry (DEXA) measurements [5], they included six osteoporotic and six osteopenic pairs. All specimens underwent computed tomography (CT) scanning at a slice thickness of 0.63 mm (Revolution EVO, GE Medical Systems AG, Switzerland) to calculate volumetric bone mineral density (BMD) within a cylinder of 20 mm diameter and 30 mm length, located in the center of the femoral head, using a phantom (European Forearm Phantom QRM-BDC/6, QRM GmbH, Möhrendorf, Germany).

The specimens were assigned for pairwise implantation using either a short TFN-ADVANCED Proximal Femoral Nailing System (TFNA, length 170 mm, Ø10mm, 130 deg, DePuy Synthes, Zuchwil, Switzerland) with a helical blade head element, offering the option for cement augmentation, or a short TRIGEN INTERTAN Intertrochanteric Antegrade Nail (InterTAN, length 180 mm, Ø10mm, 130 deg, Smith and Nephew, Memphis, USA) with interlocking dual screws. Next, six osteoporotic femora, assigned for implantation with TFNA, were allocated for bone cement augmentation. As a result, four study groups were created and combined in two clusters comprising specimens of the same donors each – group 1 (TFNA) paired with group 2 (InterTAN), consisting of osteopenic femora (cluster 1), and group 3 (TFNA augmented) paired with group 4 (InterTAN), consisting of osteoporotic femora (cluster 2). The sample size of six specimens per group was considered sufficient for detection of existing significances among the corresponding groups, based on previous published work with similar study design, investigating different fixation methods of trochanteric fractures [13, 25, 48]. The optimal length of the nail head elements of each donor were determined from the CT scans considering a tip-apex distance (TAD) of less than 25 mm [1].

Specimens preparation and surgical technique

Prior to surgery, soft tissues of all intact femora were removed. According to the manufacturers guidelines, their implantation was performed under fluoroscopic control, with Ø11mm intramedullary canal reaming, center–center head-element position [36] and static distal screw locking mode. The head elements of both nail designs were left free to slide through the nail slot with blocked rotation by the set-screw. Following, an oscillating saw was used to

create an unstable trochanteric fracture AO/OTA 31-A2.2 with complete removal of the lesser trochanter and the whole calcar support (Fig. 1). Symmetry in the fracture patterns was ensured using a predefined jig for creation of the osteotomies. The first osteotomy line connected the most proximal aspect of the greater trochanter with the aspect right below the lesser trochanter, while the second osteotomy line connected the middle of the first line with the aspect right above the lesser trochanter. After completion of the osteotomies' setting, interfragmentary compression was applied via the compression screw of the Inter-TAN nails. Next, the six osteoporotic specimens in group 3 were augmented with 3 ml TRAUMACEM V + bone cement (DePuy Synthes, Zuchwil, Switzerland) as recommended by the manufacturer guidelines, preheating them in a 37 °C water bath to simulate in-vivo conditions. The volume of 3 ml was injected as follows: after injection of 1 ml through the perforations of the head element into the cranial side of the femoral head, the cannula was turned 180 deg, allowing caudally directed injection of another 1 ml. Subsequently, the cannula was withdrawn over 10 mm, and the same procedure was repeated by injecting 0.5 ml twice [40]. Anteroposterior X-rays of exemplified specimens post implantation and fracturing are presented in Fig. 2. After cutting the femoral condyles at a distance
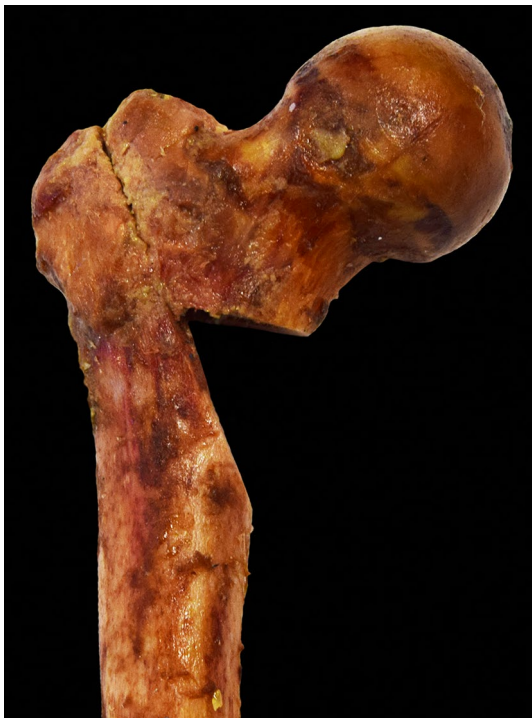

Fig. 2 Anteroposterior X-rays of specimens implanted with TFNA without (left) and with (middle) cement augmentation, and InterTAN (right). Unstable trochanteric fracture AO/OTA 31-A2.2 is created by complete removal of the lesser trochanter and the whole calcar support

Fig. 1 Anteroposterior view of a right human cadaveric femur representing a simulated unstable trochanteric fracture AO/OTA 31-A2.2 with complete removal of the lesser trochanter and the whole calcar support
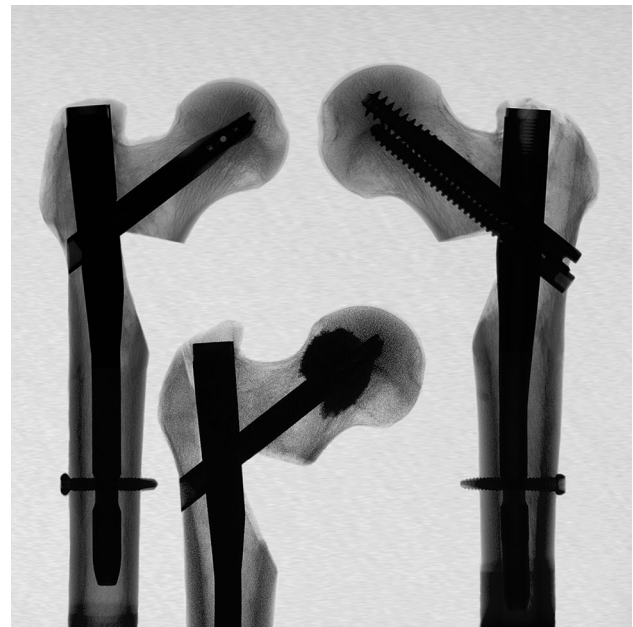
of 25 cm measured from the tip of the greater trochanter, all specimens were embedded distally in a 7 cm long cylinder filled with polymethylmethacrylate (PMMA, SCS-Beracryl D-28, Suter Kunststoffe AG, Fraubrunnen, Switzerland). Further, the femoral head of each specimen was embedded in a PMMA shell with a custom-made detector integrated in the embedding. The detector included a special electro-conducting foil, attached to the articular surface of the femoral head and used for immediate automatic detection of implant penetration. Finally, four optical marker sets were mounted to the femoral head, the specimen's shaft, the proximal tip of the nail and the lateral tip of the head element for motion tracking.

Test setup

Biomechanical testing was performed on a servo-hydraulic test system (Mini Bionix II 858, MTS Systems Corp., Eden Prairie, MN, USA) equipped with a 4 kN load cell. Test setup was adopted from previous studies [3, 10, 43, 48] (Fig. 3). All specimens were tested in 20° adduction of the femoral shaft to simulate physiological forces acting during the mid-stance phase of the human gait [2, 27]. Distally, they were attached to the machine base via a cardan joint. Proximally, the load transfer between the load cell—mounted to the machine actuator—and the femoral head was carried out via a ball-and-socked joint, whereby a steel ball pressed on
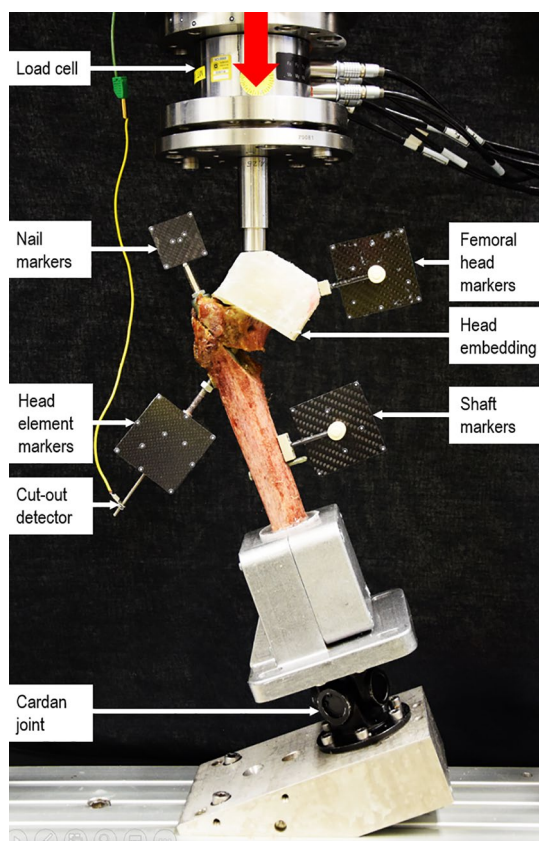
Fig. 3 Setup with a specimen mounted for biomechanical testing

the femoral head embedding at the point right above the superior aspect of the femoral head.

Loading protocol

The loading protocol comprised an initial non-destructive quasi-static axial compression ramp from 50 to 200 N at a rate of 15 N/s, followed by progressively increasing cyclic axial loading at 2 Hz with physiologic profile of each cycle [2, 43]. Whereas the valley load of the cycles was kept at 200 N, their peak load started at 500 N and then increased at a rate of 0.05 N/cycle until failure of the bone-implant construct. The application of progressively increasing cyclic loading has been demonstrated as useful in previous studies [9, 43] and allows construct failure of specimens with different bone quality to occur within a predefined number of cycles. The test stop criteria were either 40 mm displacement of the machine actuator relative to the initial position, reaching 4 kN axial load, or cut-out of the implant through the femoral head, the latter being immediately detected by the electric contact occurring between the head element of the implant and the foil of the embedded detector to prevent further implant damage.

Data acquisition and analysis

Machine data in terms of axial load and axial displacement were recorded from the machine controllers at 128 Hz. Based on this data, initial axial construct stiffness was calculated from the ascending slope of the load–displacement curve from the initial quasi-static ramp within the linear range between 100 and 200 N axial loading. Further, the coordinates of the optical markers attached to the tested constructs were continuously acquired throughout the tests at 75 Hz by means of stereographic optical measurements using contactless full-field deformation technology (Aramis SRX, GOM GmbH, Braunschweig, Germany) to assess both interfragmentary and bone-implant movements in all six degrees of freedom. Based on the motion tracking data, the following parameters were evaluated: (1) varus deformation, defined as the relative femoral head rotational movement with respect to the femoral shaft in the coronal plane; (2) femoral head rotation around the neck axis; (3) implant migration and cut-out, defined as the relative movements of the head-element tip with respect to the femoral head, directed along and perpendicular to the head-element axis, respectively. The outcome values of these parameters were analyzed after 2000, 4000, 6000, 8000 and 10,000 test cycles under valley loading to assess the degradation of construct stability over the course of cyclic testing. Furthermore, 5° varus deformation and 10° femoral head rotation around the neck axis, relative to initial position, were defined as clinically relevant failure criteria. The number of cycles until fullfilment of one of these criteria under valley loading conditions, defined as cycles to clinical failure, was calculated together with the corresponding peak load of those cycle number, the latter being defined as clinical failure load of each specimen [40].

In addition, anteroposterior radiographic images were taken at the beginning (50 N) and the end (200 N) of the quasi-static ramp and at timed intervals every 250 cycles during the cyclic test under valley loading (200 N) using a triggered C-arm (Siemens ARCADIS Varic, Siemens Medical Solutions AG, Erlangen, Germany). Together with the machine data, they were used to detect the time point of catastrophic failure of each specimen.

Statistical analysis

Statistical analysis was performed with SPSS software package (IBM SPSS Statistics, V27, IBM, Armonk, NY, USA). Shapiro–Wilk test was used to screen and prove normality of the data distribution. Significant differences between the groups and clusters with regard to T-score, BMD, initial stiffness, and cycles and load to clinical and catastrophic failure were identified with Independent-Samples t test, Paired-Samples t test and One-Way Analysis of Variance

(ANOVA). General Linear Model Repeated Measures test was applied to detect significant differences between the groups with regard to the parameters evaluated over the five time points after 2000, 4000, 6000, 8000 and 10,000 cycles. Level of significance was set to 0.05 for all statistical tests.

Results

T-scores and volumetric bone mineral density

T-score in cluster 1 (median − 2.0, range − 2.4 to − 1.3) was significantly higher compared to cluster 2 (median − 3.3, range − 5.1 to − 2.6) ($p = 0.03$), although they did not differ significantly between the paired groups within each cluster ($p \geq 0.21$). Similarly, volumetric BMD (mgHA/cm^3) in cluster 1 (median 298.6, range 228.3–362.9) was significantly higher compared to cluster 2 (median 215.9, range 123.5–338.0) ($p < 0.01$), with no significant differences between the paired groups within each cluster ($p \geq 0.11$).

Initial axial stiffness

Initial axial stiffness (N/mm) was highest in group 3 (371.5 ± 63.8, mean ± standard deviation, SD), followed by group group1 (335.7 ± 65.3), group 2 (326.9 ± 62.2) and group 4 (301.6 ± 85.9). It was significantly higher in group 3 compared with group 4 ($p = 0.03$), with no further detected significances between the groups.

Varus deformation, femoral head rotation, implant migration and implant cut-out at 2000, 4000, 6000, 8000 and 10,000 cycles

The results for these four parameters of interest are summarized in Table 1 and presented in Figs. 4 and 5. Smallest values of each parameter were observed in group 3, followed by groups 1, 2 and 4. The values of each parameter increased significantly over these numbers of cycles in each group ($p < 0.01$). Both varus deformation and femoral head rotation were significantly lower in group 3 compared with group 4 after 8000 cycles ($p = 0.04$). Implant migration was significantly lower in both groups 1 and 3 compared with group 4 after all predefined numbers of

Table 1 Parameters of interest in the four study groups after predefined number of cycles in terms of mean value and standard deviation

Parameter	Cycles	Study groups			
		Osteopenic bone (cluster 1)		Osteoporotic bone (cluster 2)	
		1 TFNA	2 InterTAN	3 TFNA augmented	4 InterTAN
Varus deformation [deg]	2000	0.585 ± 0.250	0.612 ± 0.232	0.567 ± 0.369	0.901 ± 0.779
	4000	0.951 ± 0.553	1.026 ± 0.320	0.815 ± 0.580	1.482 ± 1.174
	6000	1.240 ± 0.796	1.436 ± 0.381	1.039 ± 0.783	2.146 ± 1.558
	8000	1.618 ± 0.983	1.885 ± 0.492	1.282 ± 1.137	2.778 ± 2.022
	10,000	1.885 ± 1.008	2.238 ± 0.674	1.464 ± 1.308	3.549 ± 2.827
Femoral head rotation [deg]	2000	0.077 ± 0.037	0.200 ± 0.127	0.072 ± 0.047	0.222 ± 0.196
	4000	0.125 ± 0.052	0.325 ± 0.203	0.122 ± 0.080	0.335 ± 0.296
	6000	0.251 ± 0.105	0.446 ± 0.260	0.189 ± 0.136	0.468 ± 0.388
	8000	0.291 ± 0.140	0.554 ± 0.326	0.229 ± 0.161	0.629 ± 0.497
	10,000	0.347 ± 0.198	0.688 ± 0.403	0.326 ± 0.199	0.933 ± 0.639
Implant migration [mm]	2000	0.008 ± 0.004	0.016 ± 0.014	0.006 ± 0.004	0.041 ± 0.032
	4000	0.016 ± 0.007	0.032 ± 0.025	0.011 ± 0.009	0.070 ± 0.056
	6000	0.022 ± 0.012	0.049 ± 0.033	0.015 ± 0.012	0.112 ± 0.091
	8000	0.034 ± 0.015	0.067 ± 0.039	0.025 ± 0.021	0.130 ± 0.101
	10,000	0.045 ± 0.021	0.085 ± 0.045	0.030 ± 0.025	0.154 ± 0.104
Implant cut-out [mm]	2000	0.071 ± 0.049	0.154 ± 0.032	0.069 ± 0.039	0.262 ± 0.181
	4000	0.109 ± 0.053	0.270 ± 0.094	0.091 ± 0.055	0.447 ± 0.302
	6000	0.143 ± 0.059	0.393 ± 0.123	0.135 ± 0.089	0.656 ± 0.431
	8000	0.207 ± 0.105	0.505 ± 0.177	0.205 ± 0.116	0.935 ± 0.652
	10,000	0.296 ± 0.108	0.645 ± 0.249	0.284 ± 0.167	1.229 ± 0.821

The four groups are combined in two clusters comprising specimens of the same donors each—group 1 (TFNA) paired with group 2 (InterTAN), consisting of osteopenic femora (cluster 1), and group 3 (TFNA augmented) paired with group 4 (InterTAN), consisting of osteoporotic femora (cluster 2)
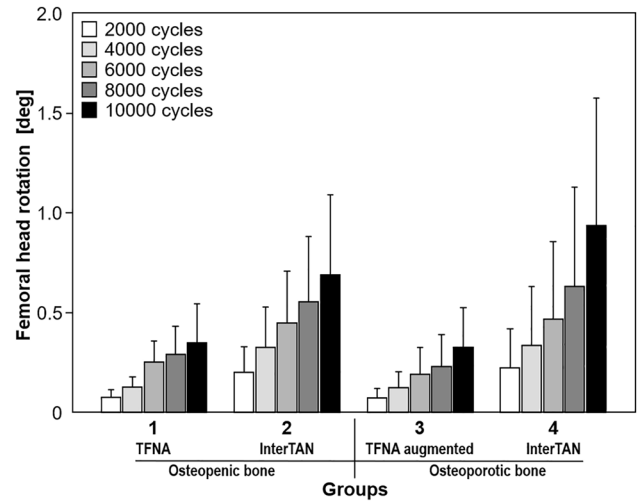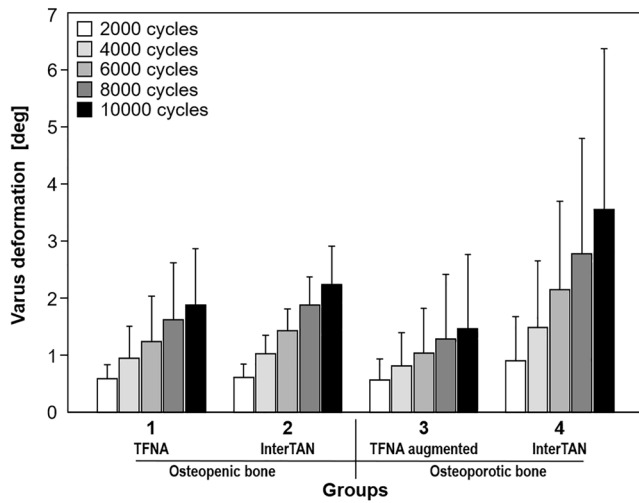
Fig. 4 Varus deformation (left) and femoral head rotation (right) in the four study groups after 2000, 4000, 6000, 8000 and 10,000 test cycles, presented in terms of mean value and standard deviation. The four groups are combined in two clusters comprising speci-mens of the same donors each – group 1 (TFNA) paired with group 2 (InterTAN), consisting of osteopenic femora (cluster 1), and group 3 (TFNA augmented) paired with group 4 (InterTAN), consisting of osteoporotic femora (cluster 2)
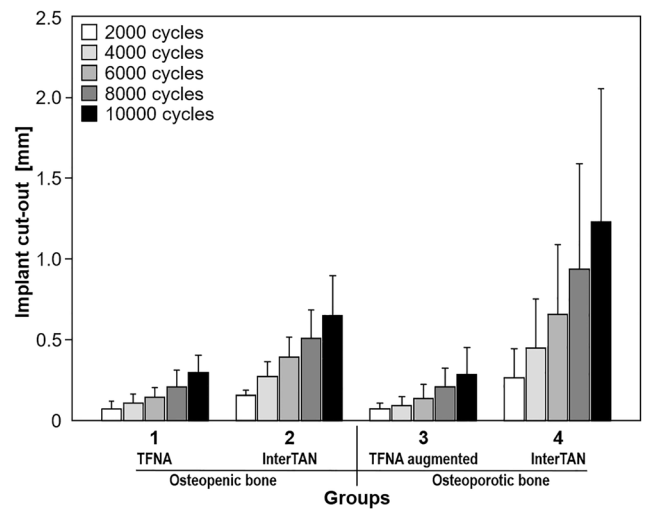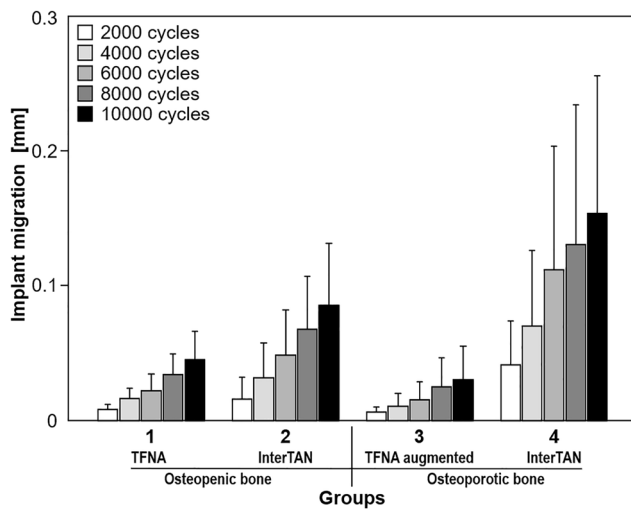

Fig. 5 Implant migration (left) and implant cut-out (right) in the four study groups after 2000, 4000, 6000, 8000 and 10,000 test cycles, presented in terms of mean value and standard deviation. The four groups are combined in two clusters comprising specimens of the same donors each—group 1 (TFNA) paired with group 2 (InterTAN), consisting of osteopenic femora (cluster 1), and group 3 (TFNA aug-mented) paired with group 4 (InterTAN), consisting of osteoporotic femora (cluster 2)

cycles, and in group 3 compared with group 2 after 8000 cycles ($p \leq 0.04$).

Implant cut-out was significantly lower in both groups 1 and 3 compared with both groups 2 and 4 after all pre-defined numbers of cycles ($p \leq 0.04$). No further signifi-cant differences were detected among the groups.

Cycles and load to clinical failure

Both cycles and load to clinical failure were highest in group 3 ($21,739 \pm 4248$ and 1587.0 ± 212.4 N) followed by group 1 ($21,428 \pm 6020$ and 1571.4 ± 301.0 N), group 2 ($20,611 \pm 7453$ and 1530.6 ± 372.7 N) and group 4

(18,622 ± 6733 and 1431.1 ± 336.7 N), respectively. They were significantly higher in group 3 compared with group 4 ($p = 0.04$), with no other detected significant differences among the groups.

Cycles and load to catastrophic failure

Both cycles and load to catastrophic failure were highest in group 3 (27,936 ± 2936 and 1896.8 ± 146.8 N) followed by group 1 (27,542 ± 6783 and 1877.1 ± 339.1 N), group 2 (23,847 ± 7574 and 1692.4 ± 378.7 N) and group 4 (22,085 ± 7875 and 1604.2 ± 393.7 N), respectively, with no significant differences among the groups.

Discussion

Trochanteric fractures represent a significant burden for health systems since most patients need to be operated and consequently hospitalized [23]. Surgeons have the choice between different implant designs for cephalomedullary nailing of these fractures [21]. In the current study we investigated the biomechanical characteristics of two different novel nail constructs, using either a helical blade or interlocking dual screws. Moreover, the effect of bone cement augmentation on the helical blade fixation strength within the femoral head was explored in osteoporotic specimens.

Comparable stability of cephalomedullary nailed trochanteric fractures with use of non-augmented helical blade or interlocking screws in the femoral head fragments with osteopenic bone quality was reported in the current study. Although the non-augmented helical blade revealed slight superiority compared with the interlocking screws in terms of initial stiffness, resistance to varus deformation and femoral head rotation, and endurance to failure, the differences between the two fixation systems were not significant so that both implants demonstrated similar biomechanical behavior. Despite the theoretically expected higher resistance to rotational moments by the larger cross-sectional area of the interlocking screws, they did not demonstrate advantageous resistance to rotational moments compared to the helical blade. One possible explanation is the bone compaction in the femoral head around the helical blade's surface during insertion, resulting in its enhanced anchorage by a previously proposed mechanism [24, 44]. The downside of the helical blade design is its rather low resistance to pull-out forces restricting intraoperative compression [31]. Some complications such as cut-through or reverse migration of the helical blade have already been reported [7]. However, none of these events occurred in the current study. Comparable low rates of femoral head rotation and head migration following implantation of helical blades or interlocking screws were observed in previous biomechanical studies [20, 22].

Considerably improved fixation strength was detected after cement augmentation of the helical blades in the current study, resulting in significant differences between the two nail systems in osteoporotic bone quality and demonstrating significantly higher initial stiffness and resistance to rotational and varus deforming forces and moments, as well as endurance until catastrophic failure of the blade when compared with the interlocking screws. No technical challenges were encountered during the augmentation procedure of the helical blades in osteoporotic femoral heads, being in agreement with previous clinical and biomechanical cadaveric studies [16, 37]. Furthermore, the cement injection succeeded without experiencing excessive reaction forces at the syringes, achieving homogeneous cement distribution. This is in line with previous reports on helical blade augmentation, demonstrating symmetric cement distribution around the cephalic implant [39]. As reported by Sermon et al. [38], cement augmentation is most efficient in osteoporotic bone quality. However, possible complications such as cement leakage into the hip joint are a major downside of this technique, therefore it should be applied only after confirmation of no guide wire penetration of the femoral head. A standard leakage test should always be performed prior to bone cement injection as previously recommended [15]. In a survey from 2013, only 7–17% of the responding surgeons fully agreed with the benefit of applying cement augmentation techniques for hip fracture implants [21]. Furthermore, in a multidirectional gait-simulation scenario, cement augmentation did not enhance implant anchorage with regard to femoral head rotation, implant migration, stiffness, femoral neck shortening or vertical displacement in femoral neck fractures [19]. However, our study not only demonstrated superior stability of augmented helical blades compared with interlocking screws in osteoporotic bone quality but also increased stability of the former compared with non-augmented helical blades and interlocking screws in osteopenic femoral heads. This stronger fixation in osteoporotic bone quality is in line with previously published work demonstrating less catastrophic failures in patients with augmented implants [16]. Moreover, a systematic review on 455 patients reported higher stability in terms of varus deformity and head-element sliding of cement-augmented versus non-augmented implants [29]. Furthermore, increased postoperative loading capability of augmented helical blades over non-cemented implants was demonstrated [18]. Recent biomechanical work reported similar stability between augmented TFNA blade and screw head elements [40]. Therefore, it could be expected that cement augmentation of TFNA screws would result in similar resistance to failure, related to implant anchorage within the femoral head, when compared with interlocking dual screws fixation. Most geriatric patients are incapable of following postoperative weight bearing restrictions [17]. Therefore, confidence in the osteosynthesis might encourage surgeons

to allow mobilization with full weight bearing of their elderly patients immediately after operation as there is increasing evidence supporting its importance after hip fractures [34]. This is likely to decrease postoperative complications due to immobility and could have a positive effect on the functional recovery of geriatric patients [32].

Limitations

This study has some limitations inherent to all human cadaveric investigations. First, a limited number of human cadaveric femora were used, resulting in restriction of the translation to generalized clinical applications. Despite this, we were able to detect several significant differences related to the two tested implant systems. An appropriate study design was set to explore both their biomechanical competence in two different categories of bone quality and the effect of cement augmentation on the fixation strength. Second, a cadaveric model is incapable to completely simulate in-vivo situations with surrounding soft tissues, swelling and biological reactions following clinical fractures in humans. Third, artificially created fractures via osteotomizing do not necessarily obey the physical laws of real fracture mechanisms, however, they were created because of standardization purposes for implant comparisons. Fourth, the applied biomechanical model did not take into account all in-vivo forces and moments acting on the femur, however, the test setup and loading protocol were defined to ensure a close simulation of dynamic physiologic loading conditions. Fifth, only short nails were investigated in the current study, despite that some clinicians use long nails as a rule of thumb for unstable trochanteric fractures. However, a recently conducted meta-analysis of 3208 patients concluded that short nails could be used for the majority of trochanteric fractures [6]. As the clinical outcome depends on several factors besides the implant design, such as quality of reduction, duration of surgery, consequences of cement augmentation, soft tissue damage, potential wound infections and other postoperative complications, further prospective randomized clinical trials need to be conducted to confirm the findings of the current study in the clinical practice.

Conclusion

Cephalomedullary nailing of trochanteric femoral fractures with use of helical blades is comparable to interlocking dual screws fixation in femoral head fragments with low bone quality. Bone cement augmentation of helical blades provides significantly greater fixation strength compared to interlocking screws constructs.

Declarations

References

1. Baumgaertner MR, Solberg BD (1997) Awareness of tip-apex distance reduces failure of fixation of trochanteric fractures of the hip. J Bone Joint Surg Br 79(6):969–971
2. Bergmann G, Deuretzbacher G, Heller M et al (2001) Hip contact forces and gait patterns from routine activities. J Biomech 34(7):859–871
3. Bonnaire F, Weber A, Bösl O, Eckhardt C, Schwieger K, Linke B (2007) "Cutting out" in pertrochanteric fractures–problem of osteoporosis? Unfallchirurg 110(5):425–432
4. Chapman T, Zmistowski B, Krieg J, Stake S, Jones CM, Levicoff E (2018) Helical blade versus screw fixation in the treatment of hip fractures with cephalomedullary devices: incidence of failure and atypical "Medial Cutout." J Orthop Trauma 32(8):397–402
5. Chun KJ (2011) Bone densitometry. Semin Nucl Med 41(3):220–228
6. Cinque ME, Goodnough LH, Md BJS et al (2021) Short versus long cephalomedullary nailing of intertrochanteric fractures: a meta-analysis of 3208 patients. Arch Orthop Trauma Surg. https://doi.org/10.1007/s00402-021-03752-z
7. Frei HC, Hotz T, Cadosch D, Rudin M, Käch K (2012) Central head perforation, or "cut through," caused by the helical blade of the proximal femoral nail antirotation. J Orthop Trauma 26(8):e102-107
8. Goffin JM, Pankaj P, Simpson AH, Seil R, Gerich TG (2013) Does bone compaction around the helical blade of a proximal femoral nail anti-rotation (PFNA) decrease the risk of cut-out?: a subject-specific computational study. Bone Joint Res 2(5):79–83
9. Gueorguiev B, Ockert B, Schwieger K et al (2011) Angular stability potentially permits fewer locking screws compared with conventional locking in intramedullary nailed distal tibia fractures: a biomechanical study. J Orthop Trauma 25(6):340–346
10. Hoffmann S, Paetzold R, Stephan D, Püschel K, Buehren V, Augat P (2013) Biomechanical evaluation of interlocking lag screw design in intramedullary nailing of unstable pertrochanteric fractures. J Orthop Trauma 27(9):483–490
11. Hsueh KK, Fang CK, Chen CM, Su YP, Wu HF, Chiu FY (2010) Risk factors in cutout of sliding hip screw in intertrochanteric fractures: an evaluation of 937 patients. Int Orthop 34(8):1273–1276
12. Huang Y, Zhang C, Luo Y (2013) A comparative biomechanical study of proximal femoral nail (InterTAN) and proximal femoral nail antirotation for intertrochanteric fractures. Int Orthop 37(12):2465–2473

13. Jiang W, Liu Y, Yang L et al (2014) Biomechanical comparative study on proximal femoral locking plate and Gamma3 for treatment of stable intertrochanteric fracture. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi 28(9):1096–1099

14. Johnson NA, Uzoigwe C, Venkatesan M et al (2017) Risk factors for intramedullary nail breakage in proximal femoral fractures: a 10-year retrospective review. Ann R Coll Surg Engl 99(2):145–150

15. Kammerlander C, Gebhard F, Meier C et al (2011) Standardised cement augmentation of the PFNA using a perforated blade: a new technique and preliminary clinical results. A prospective multicentre trial. Injury 42(12):1484–1490

16. Kammerlander C, Hem ES, Klopfer T et al (2018) Cement augmentation of the Proximal Femoral Nail Antirotation (PFNA)—a multicentre randomized controlled trial. Injury 49(8):1436–1444

17. Kammerlander C, Pfeufer D, Lisitano LA, Mehaffey S, Böcker W, Neuerburg C (2018) Inability of older adult patients with hip fracture to maintain postoperative weight-bearing restrictions. J Bone Joint Surg Am 100(11):936–941

18. Keppler AM, Pfeufer D, Kau F et al (2021) Cement augmentation of the Proximal Femur Nail Antirotation (PFNA) is associated with enhanced weight-bearing in older adults. Injury. https://doi.org/10.1016/j.injury.2021.01.037

19. Knobe M, Bettag S, Kammerlander C et al (2019) Is bone-cement augmentation of screw-anchor fixation systems superior in unstable femoral neck fractures? A biomechanical cadaveric study. Injury 50(2):292–300

20. Knobe M, Gradl G, Buecking B et al (2015) Locked minimally invasive plating versus fourth generation nailing in the treatment of AO/OTA 31A2.2 fractures: a biomechanical comparison of PCCP(®) and Intertan nail(®). Injury 46(8):1475–1482

21. Knobe M, Gradl G, Ladenburger A, Tarkin IS, Pape HC (2013) Unstable intertrochanteric femur fractures: is there a consensus on definition and treatment in Germany? Clin Orthop Relat Res 471(9):2831–2840

22 Knobe M, Nagel P, Maier KJ et al (2016) Rotationally stable screw-anchor with locked trochanteric stabilizing plate versus proximal femoral nail antirotation in the treatment of AO/OTA 31A22 fracture: a biomechanical evaluation. J Orthop Trauma 30(1):e12–e18

23. Knobe M, Siebert CH (2014) Hip fractures in the elderly: osteosynthesis versus joint replacement. Orthopade 43(4):314–324

24 Kold S, Rahbek O, Vestermark M, Overgaard S, Søballe K (2005) Bone compaction enhances fixation of weightbearing titanium implants. Clin Orthop Relat Res 431:138–144

25. Konstantinidis L, Papaioannou C, Hirschmüller A et al (2013) Intramedullary nailing of trochanteric fractures: central or caudal positioning of the load carrier? A biomechanical comparative study on cadaver bones. Injury 44(6):784–790

26. Lenich A, Vester H, Nerlich M, Mayr E, Stöckle U, Füchtmeier B (2010) Clinical comparison of the second and third generation of intramedullary devices for trochanteric fractures of the hip-blade vs screw. Injury 41(12):1292–1296

27. Lewis CL, Sahrmann SA (2015) Effect of posture on hip angles and moments during gait. Man Ther 20(1):176–182

28. Lorich DG, Geller DS, Nielson JH (2004) Osteoporotic pertrochanteric hip fractures: management and current controversies. Instr Course Lect 53:441–454

29. Namdari S, Rabinovich R, Scolaro J, Baldwin K, Bhandari M, Mehta S (2013) Absorbable and non-absorbable cement augmentation in fixation of intertrochanteric femur fractures: systematic review of the literature. Arch Orthop Trauma Surg 133(4):487–494

30. Nherera L, Trueman P, Horner A, Watson T, Johnstone AJ (2018) Comparison of a twin interlocking derotation and compression screw cephalomedullary nail (InterTAN) with a single screw derotation cephalomedullary nail (proximal femoral nail antirotation): a systematic review and meta-analysis for intertrochanteric fractures. J Orthop Surg Res 13(1):46

31. O'Neill F, Condon F, McGloughlin T, Lenehan B, Coffey JC, Walsh M (2011) Dynamic hip screw versus DHS blade: a biomechanical comparison of the fixation achieved by each implant in bone. J Bone Joint Surg Br 93(5):616–621

32. Oldmeadow LB, Edwards ER, Kimmel LA, Kipen E, Robertson VJ, Bailey MJ (2006) No rest for the wounded: early ambulation after hip surgery accelerates recovery. ANZ J Surg 76(7):607–611

33. Parker MJ, Handoll HH (2004) Gamma and other cephalocondylic intramedullary nails versus extramedullary implants for extracapsular hip fractures. Cochrane Database Syst Rev 1:Cd000093

34. Pfeufer D, Zeller A, Mehaffey S, Böcker W, Kammerlander C, Neuerburg C (2019) Weight-bearing restrictions reduce postoperative mobility in elderly hip fracture patients. Arch Orthop Trauma Surg 139(9):1253–1259

35. Rupprecht M, Grossterlinden L, Ruecker AH et al (2011) A comparative biomechanical analysis of fixation devices for unstable femoral neck fractures: the Intertan versus cannulated screws or a dynamic hip screw. J Trauma 71(3):625–634

36 Sarai H, Schmutz B, Schuetz M (2021) Potential pitfalls of lateral radiographic assessment of the nail position in the distal femur. Arch Orthop Trauma Surg. https://doi.org/10.1007/s00402-021-03851-x

37. Sermon A, Boner V, Boger A et al (2012) Potential of polymethylmethacrylate cement-augmented helical proximal femoral nail antirotation blades to improve implant stability—a biomechanical investigation in human cadaveric femoral heads. J Trauma Acute Care Surg 72(2):E54-59

38. Sermon A, Boner V, Schwieger K et al (2012) Biomechanical evaluation of bone-cement augmented Proximal Femoral Nail Antirotation blades in a polyurethane foam model with low density. Clin Biomech 27(1):71–76

39. Sermon A, Hofmann-Fliri L, Richards RG, Flamaing J, Windolf M (2014) Cement augmentation of hip implants in osteoporotic bone: how much cement is needed and where should it go? J Orthop Res 32(3):362–368

40. Sermon A, Zderic I, Khatchadourian R et al (2021) Bone cement augmentation of femoral nail head elements increases their cut-out resistance in poor bone quality—a biomechanical study. J Biomech 118:110301

41. Serrano R, Blair JA, Watson DT et al (2017) Cephalomedullary nail fixation of intertrochanteric femur fractures: are two proximal screws better than one? J Orthop Trauma 31(11):577–582

42. Simmermacher RK, Ljungqvist J, Bail H et al (2008) The new proximal femoral nail antirotation (PFNA) in daily practice: results of a multicentre clinical study. Injury 39(8):932–939

43. Windolf M, Braunstein V, Dutoit C, Schwieger K (2009) Is a helical shaped implant a superior alternative to the Dynamic Hip Screw for unstable femoral neck fractures? A biomechanical investigation. Clin Biomech 24(1):59–64

44. Windolf M, Muths R, Braunstein V, Gueorguiev B, Hänni M, Schwieger K (2009) Quantification of cancellous bone-compaction due to DHS Blade insertion and influence upon cut-out resistance. Clin Biomech 24(1):53–58

45. Wu CC, Wang CJ, Shyu YI (2011) Variations in bone mineral density of proximal femora of elderly people with hip fractures: a case-control analysis. J Trauma 71(6):1720–1725

46. Yaozeng X, Dechun G, Huilin Y, Guangming Z, Xianbin W (2010) Comparative study of trochanteric fracture treated with the proximal femoral nail anti-rotation and the third generation of gamma nail. Injury 41(12):1234–1238

47. Yee DKH, Lau W, Tiu KL et al (2020) Cementation: for better or worse? Interim results of a multi-centre cohort study using a fenestrated spiral blade cephalomedullary device for

pertrochanteric fractures in the elderly. Arch Orthop Trauma Surg 140(12):1957–1964

48. Zderic I, Oh JK, Stoffel K et al (2018) Biomechanical analysis of the proximal femoral locking compression plate: do quality of reduction and screw orientation influence construct stability? J Orthop Trauma 32(2):67–74