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Locking-plate osteosynthesis versus intramedullary nailing for fixation of olecranon fractures: a biomechanical study

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Abstract

Purpose Intramedullary nailing and locked plating for fixation of olecranon fractures has recently gained popularity. However, these two new technologies have not been compared for their biomechanical efficacy. The aim of this study was to evaluate the biomechanical stability of two newly designed fracture fixation devices for treating olecranon fractures during dynamic continuous loading: the ION intramedullary locking nail and the LCP precontoured locking compression plate.

Methods Simulated oblique olecranon fractures were created in eight pairs of fresh-frozen cadaver ulnae and stabilised using either the LCP or ION. Specimens were then subjected to continuous dynamic loading (from 25 to 200 N), with a continuous angle alteration between 0° and 90° of flexion, to perform a matched-pairs comparison. Significant differences in the distance between markers surrounding the fracture gap was determined using the Wilcoxon test after four and 300 loading cycles.

Results The ION resulted in significantly less displacement in the fracture gap at 0° extension (*P*=0.036), 45° flexion (*P*=0.035) and 90° flexion (*P*=0.017) after 300 cycles of continuous loading. The measured displacements were small and were probably not of clinical significance. No mechanical failure or hardware migration was seen with either fixation technique.

Conclusion This study shows significantly less micromotion for the ION than for the LCP in treating oblique olecranon fractures after 300 cycles of dynamic loading. Both implant types could be appropriate surgical techniques for fixation of selected olecranon fractures and osteotomies.

Introduction

Olecranon fractures are relatively common adult injuries [1]. Open reduction and internal fixation are the accepted methods of treatment for displaced intra-articular olecranon fractures. Several different methods of internal fixation have been described. Tension band wiring, the standard fixation method, has been complicated by a high incidence of fixation failure and hardware migration [2–4]. Intramedullary nailing [5] and locked plating [6–8] recently gained popularity. Many biomechanical studies suggest that plate fixation of displaced olecranon fractures yields improved results [4, 9, 10]; other biomechanical evaluations demonstrate the increased stability of intramedullary nailing [11, 12]. The aim of this study was to compare biomechanical stability of an anatomic precontoured locking compression plate (LCP) (Synthes, Bettlach, Switzerland) with a newly designed intramedullary olecranon nail (ION) (Synthes) in cyclic continuous loading. We hypothesised that the biomechanical stability of an ION during cyclic loading would compare equal or even favorably compared with LCP.

Materials and methods

Eight pairs of fresh cadaver upper extremities (two male, six female, mean age 74 years, age range 68–82 years) were obtained from the Anatomical Institute of the University of

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Mainz, Germany. The use of human cadaveric specimens was approved by the local ethics committee of the University of Mainz, Germany, on 28 March 2007. Computed-tomography-assisted densitometry (Somatom Sensation 16, Siemens, Erlangen, Germany) of ulnae was performed to evaluate bone mineral density (BMD) (Table 1). Nine axial planes 3-mm thick were measured, starting at the tip of the olecranon and extending distally. All specimens were denuded of soft tissue, except the triceps tendon, which was cut to 4 cm in length. Ulnae were transected at the mid-diaphysis to a total length of 12 cm. Specimens were sealed in plastic bags and stored at −18 °C to −25 °C. A 60° oblique olecranon fracture beginning at the midpoint of the semilunar notch and running distally was simulated by means of an oblique osteotomy (Schatzker type C). The fracture was then reduced and held with a pointed reduction forceps. No additional compression device was used. The paired ulnae were subjected to osteosynthesis according to a randomizing protocol using the two methods. Group 1: LCP (Fig. 1) precontoured anatomical olecranon plate with a maximum of 12 locking combi-holes with 3.5-mm self-tapping locking screws. To achieve stability comparable with that of the tested intramedullary nail, three locking screws were used in the proximal fragment, and two locking screws with one additional bicortical nonlocking screw were used in the distal fracture. Following this protocol, both fracture fixation devices have the same amount of locking options in each fragment. The plate actually has more locking options, which could have provided more stability if they all were used. Group 2: ION (Fig. 2) 5.5-mm diameter nail 95-mm long, locked with 2.7-mm cortex screws (Prototype of Synthes, Bettlach, Switzerland). The ION has a 6° convex bend toward the radial side. The proximal locking screw is directed toward the tip of the olecranon and fixed at 60° by an end-cap locking mechanism. A second transverse hole in a plane perpendicular to the proximal one allows additional fixation of the proximal fragment. One hole at the level of the processus coronoideus and three more distal holes perpendicular to another allow for multiplanar locking in the distal fragment.
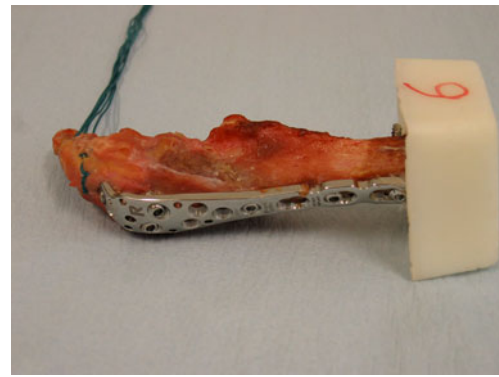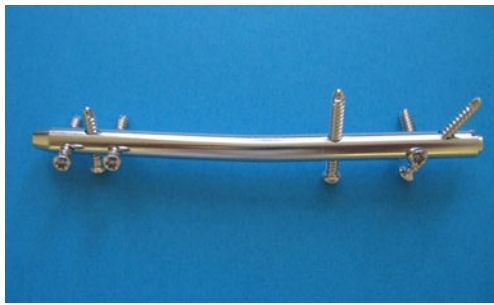

Fig. 1 Precontoured locking compression plate (LCP): Distally, the ulna is potted in polymethylmethacrylate (PMMA). The triceps tendon is lengthened with nylon sutures for fixation to the cable wire applying the pull force

Radiographs taken after implantation confirmed correct implant positioning. For fixation on the test platform, ulnae were distally potted in a polymethylmethacrylate (PMMA) cube, and the triceps tendons were lengthened with three polyester sutures. The servo-pneumatically operated test stand (SincoTec, Clausthal-Zellerfeld, Germany) was used with a maximum applicable force of 200 N and a frequency of 0.1 Hz. The rotary pneumatic engine was used for angle control of the elbow motion, and a linear pneumatic engine was used for force-control of the triceps muscle. Using a lever with two bearing pulleys, the pull direction of the triceps muscle was changed to match the motion axis of the olecranon rather than the testing axis of the linear engine. The triceps–muscle–tendon sutures were fastened with a 1.2-mm cable wire fastened to the testing system (Fig. 3). Both pneumatically operated engines (rotation and axial force) worked synchronously, with cyclic loading. At the beginning of the testing procedure, specimens were fixed in 90° elbow flexion with a pull force of 120 N. During the test at 0.1 Hz, the elbow motion changed from 90° (flexion of the elbow joint) to 0° (full extension), and the pull force of the triceps tendon changed from 25 N to 200 N with phase shift (Fig. 4). A maximum force of 200 N was applied in 50° of flexion after 2.5 seconds, and a minimum force of 25 N

Fracture fixation method	Mean BMD mgCaHA/ml (SD)	Force direction	Number	Distance (mean value) between markers after 4 cycles (mm)	Distance (mean value) between markers after 300 cycles (mm)
LCP	282 (91)	0° extension	8	0.18	0.37
		45° flexion		0.19	0.39
		90° flexion		0.10	0.21
ION	267 (96)	0° extension	8	0.16	0.29
		45° flexion		0.15	0.27
		90° flexion		0.09	0.15

Table 1 Bone mineral density (BMD) values for both osteosyntheses groups are displayed with standard deviation (SD). Distance between markers after four and 300 cycles are shown as mean value for both osteosyntheses at 0°, 45° and 90°
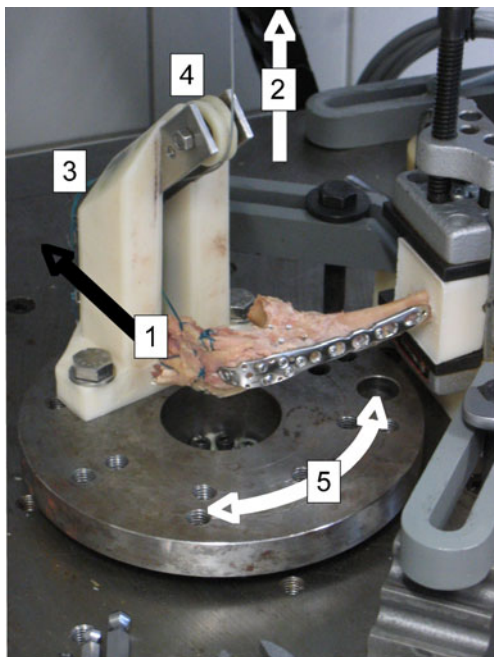
LCP locking compression plate, *ION* intramedullary olecranon nail, *CaHa* calcium hydroxyapatite
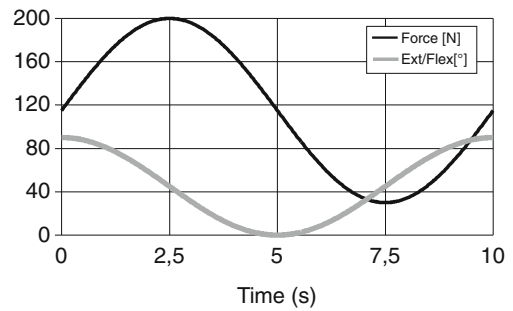
Fig. 2 Intermedullary olecranon nail (ION): The proximal screw is fixed through an end-cap locking mechanism. Three locking holes in the proximal part and three holes in the distal part perpendicular to each other allow multiplanar locking

was applied in flexion of 50° after 7.5 seconds. The applied forces imitate physiological loading of the elbow joint [13].

For video-motion analysis, two markers were placed at the proximal end and two at the distal olecranon fragment (Fig. 5). A video camera tracked motion between fracture fragments in the osteotomy gap. The optical definition of the motion analysis system was 540×540 pixels, sited on 3 cm^2 at a frequency of 8 Hz. The accuracy of the measurement method was 2/100 mm. The distance between the two pairs of markers was measured at 0°, 45° and 90° elbow flexion. Alteration of the distance between the two ventral and two caudal-sited markers was documented as mean value
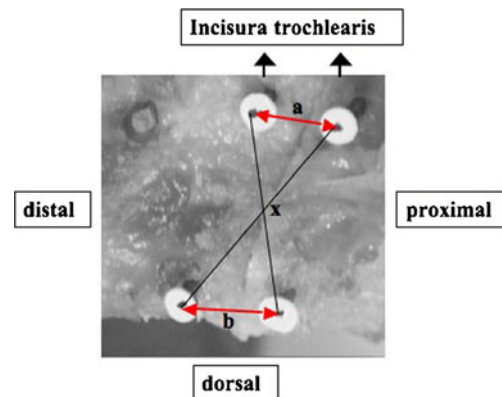

Fig. 4 During a cycle of the test procedure, elbow motion changed from 0° (extension) to 90° (flexion), and the pull force of the triceps tendon changed from 25 N to 200 N (synchronised and with phase displacement). A maximum force of 200 N is applied in 50° of flexion after 2.5 seconds, and a minimum force of 25 N in flexion of 50° is applied after 7.5 seconds

(Fig. 5). As baseline parameters, the first four cycles of elbow movement were tracked and measured, and they were then compared with the last four cycles recorded after 300 cycles of continuous loading. The distance between markers after 300 cycles was compared with the distance at baseline evaluation (Table 1). Statistical analysis was determined using the Wilcoxon signed-rank test (Table 2). Significant differences between both osteosyntheses were established at a value of $P<0.05$. No load-to-failure testing was performed at the end of the cyclic loading evaluation.

Results

Results after four cycles of continuous loading

After the initial four cycles, the LCP was associated with an average distance between the optical markers of 0.18 mm in 0° extension, 0.19 mm in 45° flexion and 0.10 mm in 90°

Fig. 3 Test setup showing the polymethylmethacrylate (PMMA) potted olecranon with a locking compression plate (LCP) implanted and markers on the lateral side of the osteotomy. The triceps tendon (*1*) is fixed with nylon sutures to a 1.2-mm wired steel cable, and the dynamically applied pull force (*2*) works over two bearing pulleys (*3*, *4*). The rotating platform (*5*) imitates flexion and extension during the test procedure

Fig. 5 Intermedullary olecranon nail (ION) in flexion with a pair of markers on distal and proximal fragments. The range (*a* and *b*) between the two pairs of markers is measured as a mean value [x = (a + b)/2] to demonstrate the extent of motion right in the middle (*x*) between the two fragments

Table 2 For statistical analysis of the distance between the markers after four and 300 cycles, the Wilcoxon signed-rank test was performed. Significant differences are established at a value of $P<0.05$

Wilcoxon test		Significance (p value)		
		0° extension	45° flexion	90° flexion
Distance between markers after 4 cycles	LCP – ION	0.182	0.32	0.752
Distance between markers after 300 cycles	LCP – ION	0.036	0.035	0.017

LCP locking compression plate, *ION* intermedullary olecranon nail

flexion. The ION showed an average distance between markers of 0.16 mm in 0° extension, 0.15 mm in 45° flexion and 0.09 mm in 90° flexion (Table 1). None of the results achieved significance on the Wilcoxon test (Table 2).

Results after 300 cycles of continuous loading

The average distance between markers of the LCP after 300 cycles was 0.37 mm in 0° extension, 0.39 mm in 45° flexion and 0.21 mm in 90° flexion. The ION displayed an advantage (0.29 mm in 0° extension, 0.27 mm in 45° flexion and 0.15 mm in 90° flexion) on the Wilcoxon test (Table 2). No implant failure was detected.

Discussion

Study results confirmed our initial hypothesis concerning the biomechanical stability of a novel intramedullary locking nail, which performed significantly better than an anatomic precontoured LCP in cyclic loading. The use of the LCP compared with the ION resulted in higher micromotion in the fracture gap after 300 cycles. These tendencies might be due to the intramedullary position of the ION compared with the extramedullary dorsal position of the LCP. The intramedullary force carrier distributed the forces more uniformly across the fracture gap. The eccentrically applied force of the LCP might yield a higher grade of displacement in the fracture gap. All measured displacements were small and were probably not of clinical significance. In a previous study, tension-band wiring and the new ION were compared using the identical test setup as our study, with equal loading parameters. If we compare results of both studies, the LCP shows much less fragment displacement than tension-band wiring [14]. If a different configuration of the proximal screws of the precontoured plate would have been used, e.g., a long intramedullary proximal screw, a higher stability could have been achieved and the differences between nail and plate probably would not have been significant. A recent study comparing five different

olecranon plates in an in vitro setup showed that the tested plates adequately stabilised osteoporotic fractures for early motion [15].

Mechanical testing of fracture fixation devices plays an important role in the evaluation of any new implant technology. Paired cadaveric testing under simulated loading conditions is an accepted standard for biomechanical analysis of fracture fixation devices [16, 17]. In our study, we closely replicated the methods published previously [11]. To simulate more physiologic forces on the triceps tendon, we increased the maximum load to 200 N. A level of loading of the triceps tendon that would be in the range anticipated for early active motion during rehabilitation was selected [13]. The use of elderly cadaveric specimens with moderate bone quality suggests that the clinical application of these techniques in younger patients might reveal an even higher stability in nonosteoporotic bone.

A biomechanical study comparing intramedullary osteosynthesis constructs with plate osteosynthesis for treating olecranon fractures was performed by Fyfe et al. A steady, slow distraction force was used to generate force-displacement data testing using 6-mm cancellous screws with and without a tension band, in comparison with semitubular plate osteosynthesis. Screw-only constructs were associated with erratic results, and the use of a tension band in conjunction with a screw did not increase stability [9]. In a recent study, Sadri et al. evaluated tension banding with K wires and an eyelet and tension banding with staples in comparison to simple K wires in a transverse fracture model in static mechanical testing with loads of 500 to 700 N. The staples showed significant less osteotomy displacement at the posterior ulna. The authors reported considerable posterior fracture-site displacement of about 0.6 mm for both K-wire techniques after the first cycle of loading [18]. Compared with our results, none of the fracture fixation devices used in their study showed a comparable displacement of the fracture site. Both the intramedullary nail and the precontoured locking plate provide a stability that could withstand dynamic cyclic loading without apparent displacement.

A limitation of our study is that all soft tissues were removed, except for the triceps tendon. Therefore, any other soft tissues near the elbow joint that may contribute to stability were not present. Other factors vital to fracture healing include preservation of the blood supply and the entire area of cancellous bone contact, which were not addressed in our study. We omitted load-to-failure testing because our focus was on cyclic loading to mimic early motion.

Conclusion

In summary, this study shows significantly less micromotion for the ION than with the LCP in treating oblique olecranon

fractures after 300 cycles of dynamic loading. Both implants could be appropriate surgical techniques for fixation of selected olecranon fractures and osteotomies. Clinical trials are needed to compare the clinical performance of these two methods.

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