FOOT & ANKLE INTERNATIONAL

A Comparison of Plates With and Without Locking Screws in a Calcaneal Fracture Model

Martinus Richter, M.D., Ph.D.; Thomas Gosling, M.D; Stefan Zech, M.D.; Mohamad Allami, M.D.; Jens Geerling, M.D.; Patricia Droste, M.D.; Christian Krettek, M.D.
Hannover, Germany

ABSTRACT

***Background*: We compared different plates in an experimental calcaneal fracture model under biocompatible loading. *Methods:* Four plates were tested: a plate without locked screws (Synthes), and three different plates with locked screws (Newdeal, Darco, Synthes). Synthetic calcanei (Sawbone) were osteotomized to create a fracture model, and the plates were fixed onto them. Seven specimens for each plate model were subjected to cyclic loading (preload 20 N, 1,000 cycles with 800 N, 0.75 mm/s), and load to failure (0.75 mm/s). Motion, forces, plastic deformation of the plate, and consequent depression of the posterior joint facet were analyzed. *Results:* During cyclic loading, all plates with locked screws showed statistically significant lower displacement in the primary loading direction than the plates without locked screws. Mean values (mm) of maximal displacements for each plate during cyclic loading were as follows: Synthes, 3.5; Darco, 4.5; Newdeal, 5.0; Synthes without locked screws, 7.5; ($p < 0.001$). No statistically significant differences between the plates were found in relation to loads to failure and corresponding displacement. *Conclusion:* This is the first biomechanical study to assess the stability of different plates currently in use in our practice for the fixation of calcaneal fractures. Our results showed that plates with locked screws provided greater stability during cyclic loading than the plate without locked screws.**

Hannover Medical School, Trauma Department, Hannover, Germany

Corresponding Author:
Martinus Richter, M.D., Ph.D.
Trauma Department
Hannover Medical School
Carl-Neuberg-Str. 1
Hannover, 30625
Germany
E-mail: martinusrichter@onlinehome.de
Homepage: http://www.martinusrichter.de
The calcaneal plates were manufactured and donated by Synthes Osteosynthese Inc., Bochum, Germany, by Newdeal Inc., Vienne, France, and by Darco Inc., Diessen, Germany.
For information on prices and availability of reprints, call 410-494-4994 X226

Key Words: Calcaneal Fracture; Experimental Testing; Fracture Model; Locked Screw; Plate Fixation

INTRODUCTION

The treatment of calcaneal fractures has been controversial and challenging even to the most experienced orthopaedic trauma surgeons.[10,17] To improve overall stability of fracture fixation, plates with locked screws were introduced. Increased stability allows for more aggressive postoperative treatment including early unprotected weightbearing, and less loss of reduction, which may improve the clinical course and outcome in patients with calcaneal fractures. Stability of plate fixation with and without screws has not been investigated under physiological conditions. In this experimental study, the stability of plates with locking screws and a conventional plate without locking screws were compared in a calcaneal fracture model, with testing done under near physiological loading. Both forces and motions were analyzed.

MATERIALS AND METHODS

Specimens

Sawbone™ specimens of left-sided calcanei models (Model Calcaneus Foam Cortical Shell; Sawbone; Pacific Research Laboratories, Vashon, WA, USA) were used (Figure 1 and 2). A fracture model according to Lin et al.[7] was created using a standard oscillating saw (model Powerdrive with oscillating saw and standard sawblade; Synthes Osteosynthese, Bochum, Germany). The fracture patterns were fashioned to simulate a type IIB fracture according to the Sanders classification.[13] An additional fracture-cut at the level of the anterior process in the parasagittal plane was made. This simulated a four-part, two-joint fracture pattern according to the Zwipp classification system.[17]

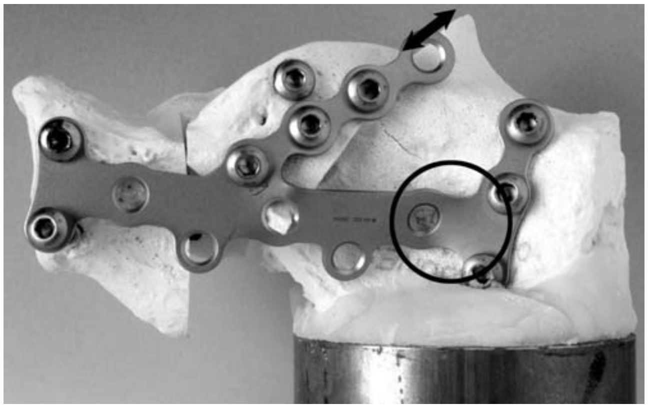

Fig. 1: Bone-plate specimen after testing sequence with typical failure pattern. Arrow: remaining joint depression, i.e. joint depression of the lateral posterior facet fragment in relation to the posterior process fragment (extent shown in Table 1 indicated). Circle: plastic deformation of the plate (extent shown in Table 1).

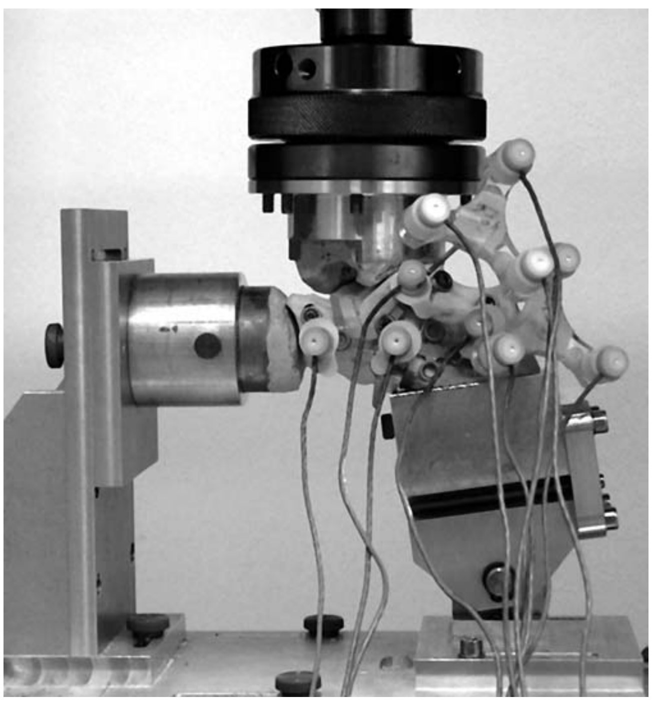

Fig. 2: Hydraulic testing and measuring machine (model Zwick 1445, test-expert Software, Zwick GmbH & Co KG, Ulm, Germany). The construct consisted of a plate fixed to an artificial calcaneal bone model. The transducers of the motion analysis system were attached to the construct. The specimens were embedded with their posterior process fixed to bone cement. The construct was held in a comparable physiological position through an anteriorly supporting arm. The interface between the anterior process of the specimen and the supporting arm consisted of a durable artificial cuboid. The load was transmitted axially onto the anterior and posterior joint facets of the talocalcaneal joint through a durable artificial talus. The pillar of the testing machine included a creation of ball and socket articulation to minimize shearing forces.

Implants

Four different plates were used: (1) plate without locked screws (Model Titanium Calcaneus Plate; Synthes Osteosynthese Inc., Bochum, Germany); (2) plate with one anterior and two posterior locked screws and standard nonlocked screws for the remaining parts (model Newdeal Calcaneus Plate; Newdeal Inc., Vienne, France); (3) plate with all locked screws (model Darco Calcaneus Plate; Darco Inc., Diessen, Germany); and (4) plate with all locked screws (Synthes new model Titanium Calcaneus Locking Plate; Synthes Osteosynthese Inc., Bochum, Germany). All plates and screws were titanium and all screws were self-tapping. The manufacturer's standard screws and instruments were used.

The implants were positioned and fixed in a standard manner as described by Zwipp and Sanders.[13,17] This involved, in the first step, the reduction and stabilization of the posterior facet fragments using one standard 3.5-mm titanium cortical lag screw (model 3.5-mm Titanium Cortical Screw; Synthes Osteosynthese Inc., Bochum, Germany). This screw was directed from the lateral side beneath the posterior facet into the sustentaculum tali. The anterior and posterior processes then were reduced, and the plates were applied and securely fixed using three screws beneath the posterior facet, three screws in the tuberosity fragment, and two screws in the anterior process. All screws were inserted in a bicortical manner.

Seven bony specimens were configured for each plate. Additionally, seven uncut specimens (control group) without implants were tested.

Mechanical Testing Machine

A hydraulic testing and measuring machine (model Zwick 1445; Zwick Inc., Ulm, Germany) was used for loading, force, and motion analysis (Figure 2). The specimens were embedded with their posterior process fixed to standard veterinary bone cement (model Demotec 95, Demotec Inc., Nidderau, Germany, Figure 1). This cement has the same ingredients and properties as that used for humans (model Palacos; Biomet Merck Inc., Berlin, Germany); however, it is of low cost. The calcaneal inclination angle of 20 degrees and a neutral hindfoot were used, simulating the normal angles and position in physiological status. The load was applied and transmitted through an artificial talus that was incorporated into the testing machine. Physiological alignment between the talus and the calcaneus was ensured. The testing machine was controlled by a standard IBM compatible personal computer with control software installed (model test-expert-Software; Zwick Inc., Ulm, Germany). The measured data were directly transferred to the same computer. All data were exported and stored in ASCII files for further statistical analysis.

Motion Analysis System

The spatial orientation of the specimen and the plate was recorded through an ultrasound measurement system (model CMS HS; Zebris Inc., Tuebingen, Germany). The sound transducers were included in the measurement system (cylindrical shape, height 10 mm, diameter 5 mm, weight 1 g). Two different measurements were taken:

1) The plate (center, anterior, and posterior portions) and the posterior facet (on the lag screw) were equipped with single transducers (uniaxial) and stickers (model Beidseitiges Klebeband; Zebris Inc., Tuebingen, Germany) (Figure 2).
2) The posterior facet and the posterior process were equipped with triaxial transducers. The transducers were situated at the edges of an equilateral star-shaped adapter (model Plexiglasstern; Workshop, Hannover Medical School, Hannover, Germany, made of Plexiglas™, Rohm and Haas, Philadelphia, PA, USA) with a side length of 50 mm. The adaptors were fixed with Kirschner wires (model 2.0-mm Titan-K-Draht, Synthes Osteosynthese Inc., Bochum, Germany) to the bone.

The motion analysis system failed after eight testing sequences and was not repairable. However, after this failure there were no alterations to the constructs for the remaining specimens.

Testing Sequences

After the specimens' construction, the mechanical testing machine and the motion analysis device were started, and the following testing sequences were performed: 1) 1,000 cycles (0.75 mm/s) of 20 N preload and 800 N cyclic load were applied; 2) load to failure at 0.75 mm/s followed.

The motion analysis system recorded the readings of the first, tenth, every hundredth and thousandth cycles, and the load to failure. Failure (endpoint) was defined as a rapid unstable increase in deformation, resulting in the specimen being unable to take anymore load or a displacement of more than 3 cm in the primary loading direction.

After the entire testing sequence, the specimen plate constructs including the transducers were removed from the testing machine. The constructs were examined independently by two senior orthopaedic trauma surgeons (M.R. and T. G.), and remarks concerning implants or fixation failures were recorded. Specimens of different evaluation ($n = 2$) were discussed for an agreement that was reached in all cases.

Statistical Analysis and Hypothesis Testing

One-way ANOVA was used for the measurements of force and motion analysis. When significant differences occurred during the ANOVA-test, a homoscedatic unpaired t-test was used to locate the differences between the different specimen plate constructs. Pearson test was used for correlation between measurements of the mechanical testing machine and the motion analysis device. The null hypothesis at the $p < 0.05$ level was that there is no difference between the different plates.

RESULTS

Mechanical Testing Machine

Table 1 shows the testing protocol and results from the mechanical testing machine. Table 2 shows results from the statistical comparison of the different implants. The following features that were shown to be statistically significant are presented in order of significance.

1) Cyclic loading: All plates with locked screws showed statistically significant lower displacement in the primary loading direction than the plates without locked screws (Table 2, Figure 3 and 4). Therefore, the null-hypothesis was rejected.
2) Joint depression and plate deformation: the measurements for plate b (Newdeal) were the lowest for both in comparison to the other plates.

The failure loads were within a small range (2476 ± 795 to 2630 ± 950 N) for all plates. The lowest motion amplitudes during load to failure were registered for plate c (Darco). However, these measurements failed to reach statistical significance. There was no significant correlation between the results of load to failure sequence (maximal load, motion amplitude during load to failure, plastic plate deformation, and remaining joint depression) and those obtained from the cyclic loading sequence (Pearson, $p > 0.05$).

Motion Analysis System

The readings of the motion analysis system before failure were only available for eight specimens (No. 1, 2, 8, 9, 15, 22, 23, 29). In these specimens, the measurements of the marker, which was fixed onto the lag screw beneath the posterior facet (see above), correlated with those of the mechanical testing machine (Pearson, $r < -0.85$, $p < 0.001$).

Examination of Specimen Plate Constructs

The examination of the specimen plate constructs at the end of the testing revealed that all plates tested shared similar failure patterns (Table 1). A joint

Table 1: Testing Protocol and Results of Mechanical Testing Machine

No.	Plate	Motion analysis	Time spent (min)	Load to failure (N)	Failure (Joint Depression Type Fracture due to Essex-Lopresti in all specimens)	Remaining joint depression (mm)	Plate deformation (°)	Problems
1	none	yes	240	3,809	eversion of anterior process	—	—	none
2		yes	240	3,454	no rotation	—	—	none
3		no	52	3,961	no rotation	—	—	none
4		no	52	4,253	complete displacement cc joint	—	—	none
5		no	45	4,734	no rotation	—	—	maximal load of mechanical testing machine exceeded
6		no	54	4,357	eversion of anterior process	—	—	none
7		no	47	4,435	complete displacement cc joint	—	—	none
8	a	yes	180	1,516	eversion of anterior process, plate deformation posterior	12	10	none
9		yes	165	2,345	eversion of anterior process, plate deformation posterior	7	10	none
10		no	88	3,995	eversion of anterior process, plate deformation posterior	12	12	none
11		no	126	1,880	no rotation, plate deformation posterior	7	7	artificial talus reached artificial cuboid
12		no	112	2,231	no rotation, plate deformation posterior	1.5	7	none
13		no	118	2,844	no rotation, no plate deformation	12	13	artificial talus reached artificial cuboid
14		no	72	2,522	no rotation, no plate deformation	5	13	artificial talus reached artificial cuboid
15	b	yes	240	1,014	eversion of anterior process, no plate deformation	7.5	5	artificial talus reached artificial cuboid
16		no	69	3,640	no rotation, no plate deformation	6	2	none

(*Continued*)

Table 1: *(Continued)*

No.	Plate	Motion analysis	Time spent (min)	Load to failure (N)	Failure (Joint Depression Type Fracture due to Essex-Lopresti in all specimens)	Remaining joint depression (mm)	Plate deformation (°)	Problems
17		no	80	3,674	no rotation, no plate deformation	5	3	artificial talus reached artificial cuboid
18		no	72	3,035	no rotation, no plate deformation	4.5	0	artificial talus reached artificial cuboid, complete lateral displacement
19		no	78	2,717	no rotation, no plate deformation	5.5	5	none
20		no	77	2,390	abduction of anterior process, no plate deformation	5.5	3	none
21		no	65	1,940	no rotation, no plate deformation	0	6	artificial talus reached artificial cuboid, complete lateral displacement
22	c	yes	120	2,000	no rotation, plate deformation posterior	10	8	none
23		yes	80	2,014	no rotation, plate deformation posterior	12.5	12	lateral displacement at 2,000 N, maximal load 3,800 N
24		no	59	2,382	no rotation, no plate deformation	5.5	5	none
25		no	58	3,175	no rotation, plate deformation posterior	9.5	15	none
26		no	68	2,918	no rotation, plate deformation posterior	12	9	none
27		no	768	3,122	no rotation, plate deformation posterior	13	7	none
28		no	75	2,129	no rotation, plate deformation posterior	6.5	5	artificial talus reached artificial cuboid

(Continued)

Table 1: (*Continued*)

No.	Plate	Motion analysis	Time spent (min)	Load to failure (N)	Failure (Joint Depression Type Fracture due to Essex-Lopresti in all specimens)	Remaining joint depression (mm)	Plate deformation (°)	Problems
29	d	yes	125	2,886	no rotation, no plate deformation	8	5	stop at 1,500 N, restart of system
30		no	120	1,683	inversion anterior process, no plate deformation	5	7	none
31		no	81	2,912	no rotation, plate deformation posterior	9	15	none
32		no	83	3,296	no rotation, no plate deformation	4	3	artificial talus reached artificial cuboid
33		no	72	2,807	no rotation, no plate deformation	4	2	artificial talus reached artificial cuboid
34		no	70	2,806	no rotation, no plate deformation	0	7	none
35		no	65	1,929	abduction of anterior process, no plate deformation	6	4	none

Plates: a, Titanium Calcaneus Plate (Synthes Osteosynthese Inc., Bochum, Germany); b, Newdeal Calcaneus Plate (Newdeal Inc., Vienne, France); c, Darco Calcaneus Plate (Darco Inc., Diessen, Germany); d, Titanium Calcaneus Locking Plate (Synthes Osteosynthese Inc., Bochum, Germany). Motion analysis: use of motion analysis system remaining joint depression: joint depression of the posterolateral facet fragment in relation to the posterior process fragment (Figure 2). Plate deformation: remaining plastic plate deformation after load to failure (Fig. 2)

Table 2: Comparison of Mechanical Properties of Different Calcaneal Plates

	Plate					Oneway ANOVA (p)		Paired t-test homoscedatic
Parameter	**none**	**a**	**b**	**c**	**d**	**all specimens**	**only plates**	**Significance $p < 0.05$**
Displacement load cycles 1-1,000 (mm)		7.50 ± 5.26	5.02 ± 3.79	4.48 ± 3.17	3.46 ± 1.25		<0.001	all versus all
Displacement unload cycles 1-1,000 (mm)		4.91 ± 4.41	3.02 ± 2.45	3.08 ± 2.86	1.71 ± 0.79		<0.001	all versus all
Amplitude displacement load/unload cycles 1-1,000 (mm)		2.60 ± 0.95	2.00 ± 1.40	1.39 ± 0.36	1.75 ± 0.58		<0.001	all versus all
Displacement load cycles 1-1,000 (mm)		7.50 ± 5.26	5.02 ± 3.79	4.48 ± 3.17	3.46 ± 1.25		<0.001	all versus all
Displacement load cycles 1–5 (mm)	1.51 ± 0.59	3.70 ± 0.76	3.95 ± 3.27	3.23 ± 1.41	2.73 ± 0.65	0.08	0.62	—
Displacement unload cycles 1–5 (mm)	0.72 ± 0.63	1.39 ± 0.49	1.69 ± 1.56	1.67 ± 1.14	0.95 ± 0.37	0.26	0.50	—
Amplitude displacement load/unload cycles 1–5 (mm)	0.77 ± 0.18	2.31 ± 0.37	2.26 ± 1.75	1.56 ± 0.32	1.78 ± 0.38	0.01	0.37	none versus all a versus c, d
Displacement load cycles 996-1,000 (mm)	1.86 ± 0.80	7.92 ± 5.89	5.31 ± 4.17	4.74 ± 3.75	3.61 ± 1.73	0.06	0.28	—

(Continued)

Table 2: *(Continued)*

Parameter	Plate					Oneway ANOVA (p)		Paired t-test homoscedatic
	none	a	b	c	d	all specimens	only plates	Significance $p < 0.05$
Displacement unload cycles 996-1,000 (mm)	1.24 ± 0.86	5.39 ± 5.10	3.41 ± 2.89	3.39 ± 3.44	1.80 ± 1.19	0.14	0.31	—
Amplitude displacement load/unload cycles 996-1,000 (mm)	0.62 ± 0.09	2.53 ± 0.86	1.90 ± 1.32	1.34 ± 0.34	1.80 ± 0.65	0.001	0.11	none versus all a versus c
Difference displacement load cycles 1–5 and 996-1,000 (mm)	0.34 ± 0.25	4.22 ± 5.40	1.36 ± 1.04	1.51 ± 2.39	0.88 ± 1.25	0.11	0.19	—
Difference displacement unload cycles 1–5 and 996-1,000 (mm)	0.49 ± 0.29	4.00 ± 4.74	1.73 ± 1.41	1.73 ± 2.33	0.85 ± 0.92	0.10	0.20	—
Load to failure (N)	4143 ± 430	2476 ± 795	2630 ± 950	2535 ± 524	2617 ± 583	<0.001	0.98	none versus all
Displacement load to failure (mm)	6.70 ± 0.31	15.80 ± 7.39	12.73 ± 5.61	10.70 ± 4.03	13.12 ± 8.25	0.074	0.55	—
Remaining joint depression (mm)	—	8.07 ± 4.11	4.86 ± 2.34	9.86 ± 2.94	5.14 ± 2.97	—	0.02	b versus c, d
Plastic plate deformation (°)	—	10.29 ± 2.56	3.43 ± 2.07	8.71 ± 3.68	6.14 ± 4.33	—	0.004	a versus b, d b versus c

Plates: similar to table 1. Mean values and standard deviations of the displacements in the primary loading direction are indicated.

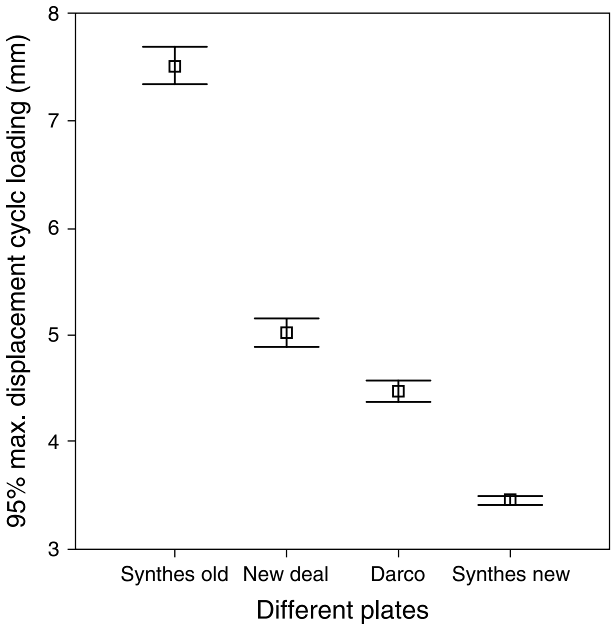

Fig. 3: Ninety-five percent maximal displacement of the plates in mm's under cyclic loading.

depression fracture type according to the Essex-Lopresti classification was the universal failure pattern in all specimens (Figure 1).[3] A rotation or translation of the anterior process occurred in seven of 21 specimens (No. 8–10, 15, 20, 30, 35). This feature was observed in all plates except for plate c (Darco).

DISCUSSION

This study introduced an experimental setting for testing calcaneal plates in a fracture model. The aim of this study was to test the relative strength of different calcaneal plates currently in use in our practice beyond the manufacturer's mechanical testing. The fracture model and the load were designed to mimic the forces transmitted through the calcaneus during standing. However, this design had several shortcomings: artificial bones were used, and these generally are of questionable biocompatibility because they cannot consider the internal architecture and resultant directional mechanical properties of a real calcaneus.[5] However, they were of identical size and accurate morphology and had a very low variability of strength.[8,16] These features can be advantageous over cadaver bone, because cadaver bones have high variability in size, quality, and strength.[7] Moreover, the biocompatibility of cadaver bones also is debatable because most of these specimens are harvested from

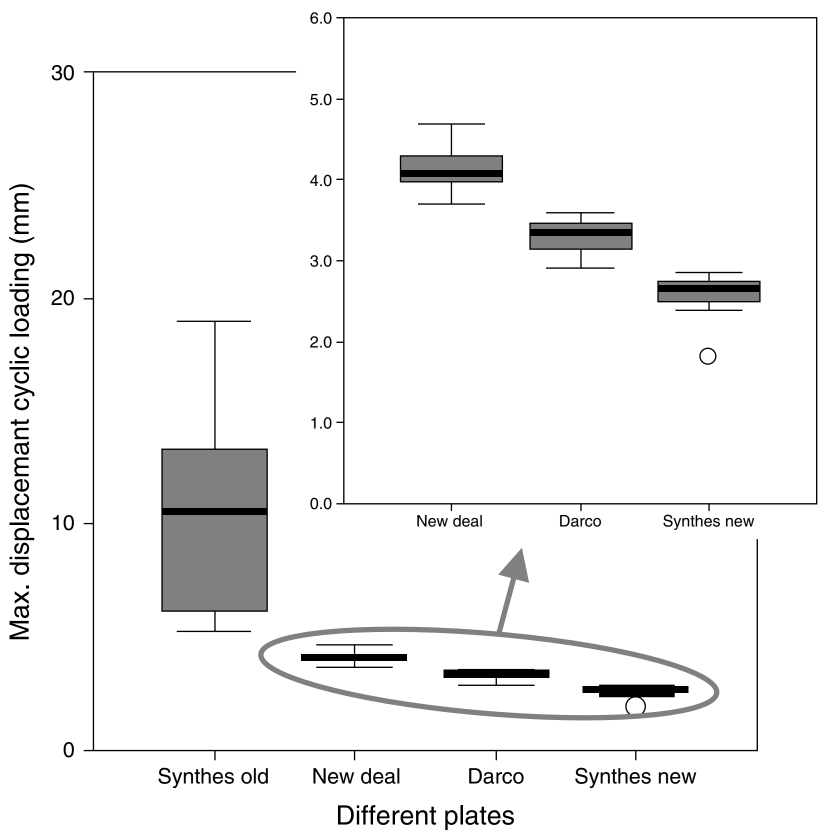

Fig. 4: Boxplots of the different constructs during cyclic loadings. Maximal displacement of the plates in mm's under cyclic loading.

individuals with a mean age of 80 years, while the mean ages of patients with a calcaneal fracture is 35 years.[11,17]

We did not measure the torsional forces that may be produced in vivo by muscular contraction and ligamentotaxis, which are of importance during standing, walking, and climbing stairs. The tested calcanei were positioned in a similar fashion to those in living individuals during standing position.[17] These constructs lack the normal force effects of the tendons and ligaments. The effect of these soft tissues has been suggested to influence the fracture patterns as described for the Achilles tendon in tongue-type fractures.[3] However, there is no evidence to support these effects.

The results of the motion analysis were difficult to interpret. Furthermore, the entire system failed during the study. However, measurements obtained from the primary loading axis also were registered by the mechanical testing machine. The readings of both systems were analyzed and found to be equivalent. Therefore, data extracted from the mechanical testing machine were sufficient for the analysis of the final results. We report these findings because we believe that our experience with the motion analysis system will be helpful for other expert groups that perform or want to perform an experimental testing comparable to the introduced testing. The most important finding is that the motion measurements of the mechanical testing machine are equivalent to those of the motion analysis system. For the future, in our or other institutions, the use of an additional motion analysis system for that kind of experimental testing does not have to be considered based on our findings.

Despite these shortcomings, our setting appears to be more appropriate than those previously described.[2,7] Lin et al. introduced fracture models similar to the ones used in our study. However, they measured only single load to failure as opposed to cyclic loading.[7] Furthermore, cadaver specimens were used in their study which have potential disadvantages described above.[7] Carr et al. showed comparable shortcomings although fresh-frozen cadaver specimens were used.[2] In their study, different fracture configurations were created through direct impact to the specimens and not through precisely defined osteotomies.[2] Despite the use of cyclic loading, the data recorded from their study were of questionable values since the loading was only 100 N.[2]

Cyclic loading appeared to be more appropriate than single load to failure, since the differences in the biomechanical behavior of the various implants were only detected by analyzing the measurements of the cyclic loading. The results of load to failure sequence (maximal load, plastic deformation of the plate, remaining joint depression) did not correlate with those from the cyclic loading sequence.

In this study, a reproducible fracture pattern was achieved with standardized osteotomies, which differed from clinical situations in certain aspects.[7] In the fracture model, the posterior facet was cleaved with only one osteotomy plane. In a clinical setting, the location of the primary fracture line varies, and the posterior facet sometimes is comminuted.[1,4,9,12,15] Comminution was simulated only in the cancellous bone beneath the posterior facet. In real fractures, comminution may occur in other areas, and this would be expected to decrease the overall stability of the construct.[7] In this model the most unstable fragment was the central articular fragment. This part would be expected to displace vertically under axial loads in line with the tibia, the case during physiological weightbearing. No failure was detected from the loss of fixation of the anterior or posterior process in any of the implants. Thus, most of the efforts were directed toward measuring vertical displacement of the central fragment under load. The displacement in the primary loading direction was found to be the best method for measurement.

The results of this study suggest that for the fixation of calcaneal fractures a lateral plate with locked screws provides higher stability than a standard plate without locked screws, especially under high cyclic loading simulating full weightbearing in vivo. The relevance of the locked screws for the entire specimen plate construct was highlighted by the magnitude of the differences between the Darco and the old Synthes plates because they had almost identical plate constructs except the one modification: locked screws in the Darco plate. The differences in the stability of different plates with locked screws were less impressive. The new Synthes plate showed lowest displacement during cyclic loading. The Darco plate showed lowest joint depression during load to failure. The Newdeal plate provided highest failure loads, lowest degree of plastic plate deformation, and lowest remaining joint depression of the posterior facet fragment after load to failure. Despite its rigid construct, the plate produced high motion amplitudes that were probably caused by the lack of locked screws beneath the posterior facet. Some constructs that were tested were able to withstand loads several times of that adult body weight.

The success or potential complications when using calcaneal fixation with locked screws has not been reported so far. The angle between the plate and locked screw (90 ± 10 degrees for most implants) may complicate the correct placement of plate screws.[3,4] Another problem may be caused by the locking process itself that prevents the technique of pulling the plate to the bone by tightening a plate screw.[6,14] Fixation of calcaneal fractures with plates without locked screws is characterized by compression of the plate to the lateral wall of the calcaneus which might be difficult to accomplish with a plate with locked screws.[1,4,9,12,15] In our experimental setting, the limited screw angle and the locking of the screw, which does not allow compression of the plate on the bone specimen, did not cause any significant problem with the screw or plate placement. However, in clinical use the compression of the plate to the bone with an unlocked screw that could be changed to a locked screw later might be a strategy for improved plate placement.

To the best of our knowledge, this is the first biomechanical study to assess the mechanical properties of different plates for the fixation of calcaneal fractures. Our results showed that plates with locked screws provide higher stability during cyclic loading than the plate without locked screws. If implants are chosen for internal fixation of calcaneal fractures, we recommend based on our results plates with locked screws. Clinical studies must show if the greater implant stability leads to a better clinical outcomes.

REFERENCES

1. **Buckley, R; Tough, S; McCormack, R; Pate, G; Leighton, R; Petrie, D; Galpin, R:** Operative compared with nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled multicenter trial. J Bone Joint Surg Am **84-A**:1733–1744, 2002.
2. **Carr, JB; Tigges, RG; Wayne, JS; Earll, M:** Internal fixation of experimental intraarticular calcaneal fractures: a biomechanical analysis of two fixation methods. J Orthop Trauma **11**:425–428, 1997.
3. **Essex-Lopresti, P:** The mechanism, reduction technique, and results in fractures of the os calcis, 1951–52. Clin Orthop **290**:3–16, 1993.
4. **Gavlik, JM; Rammelt, S; Zwipp, H:** The use of subtalar arthroscopy in open reduction and internal fixation of intra-articular calcaneal fractures. Injury **33**:63–71, 2002.
5. **Gefen, A; Seliktar, R:** Comparison of the trabecular architecture and the isostatic stress flow in the human calcaneus. Med Eng Phys **26**:119–129, 2004.
6. **Lill, H; Hepp, P; Korner, J; Kassi, JP; Verheyden, AP; Josten, C; Duda, GN:** Proximal humeral fractures: how stiff should an implant be? A comparative mechanical study with new implants in human specimens. Arch Orthop Trauma Surg **123**:74–81, 2003.
7. **Lin, PP; Roe, S; Kay, M; Abrams, CF; Jones, A:** Placement of screws in the sustentaculum tali. A calcaneal fracture model. Clin Orthop **352**:194–201, 1998.
8. **Nasson, S; Shuff, C; Palmer, D; Owen, J; Wayne, J; Carr, J; Adelaar, R; May, D:** Biomechanical comparison of ankle arthrodesis techniques: crossed screws vs. blade plate. Foot Ankle Int **22**:575–580, 2001.
9. **Rammelt, S; Gavlik, JM; Zwipp, H:** Historical and current treatment of calcaneal fractures. J Bone Joint Surg Am **83-A**:1438–1440, 2001.
10. **Richter, M; Thermann, H:** Traumatologie des Rück- und Mittelfußes. Med Orth Tech **122**:2–16, 2002.
11. **Richter, M; Wippermann, B; Thermann, H; Schroeder, G; Otte, D; Troeger, HD; Krettek, C:** Plantar impact causing midfoot fractures result in higher forces in Chopart's joint than in the ankle joint. J Orthop Res **20**:222–232, 2002.
12. **Sanders, R:** Displaced intra-articular fractures of the calcaneus. J Bone Joint Surg Am **82**:225–250, 2000.
13. **Sanders, R; Gregory, P:** Operative treatment of intra-articular fractures of the calcaneus. Orthop Clin North Am **26**:203–214, 1995.
14. **Schandelmaier, P; Partenheimer, A; Koenemann, B; Grun, OA; Krettek, C:** Distal femoral fractures and LISS stabilization. Injury **32 Suppl 3**:SC55–63, 2001.
15. **Thordarson, DB; Krieger, LE:** Operative vs. nonoperative treatment of intra-articular fractures of the calcaneus: a prospective randomized trial. Foot Ankle Int **17**:2–9, 1996.
16. **Yian, EH; Banerji, I; Matthews, LS:** Optimal side plate fixation for unstable intertrochanteric hip fractures. J Orthop Trauma **11**:254–259, 1997.
17. **Zwipp, H:** Chirurgie des Fusses, Springer Berlin Heidelberg New York, 1994.