Acta Orthop. Belg., 2016, **82**, 586-592

ORIGINAL STUDY

Comparison of interfragmentary compression in conventional and locked plating of proximal unicondylar tibia fractures : A biomechanical cadaver study

Stefan Rahm, Lukas Ebneter, Birte Schultz, Christian Spross, Fabrice Kulling, Johannes B. Erhardt

From the Universitätsklinik Balgrist Zürich, Swiss

The extent of interfragmentary compression in intra-articular fractures treated with various fixation methods have not yet been reported. Lateral split fractures were created in six pairs of cadaver tibiae treated using buttress plating with lag screws (group C) or locked buttress plating after clamp compression (group L). Interfragmentary compression and fracture displacement were continuously measured using pressure sensors and a stereoscopic 3-D image correlation system. Significantly larger interfragmentary compression was found initially after clamping the fragment ($p < 0.05$) in group C (median ± SD ; 45.1 ± 5.0 N/mm²) compared with group L (33.6 ± 3.4 N/mm²), and a statistical trend towards larger compression was also found after cyclic loading ($p = 0.05$) in group C (45.3 ± 8.6 N/mm²) compared with group L (28.7 ± 5.8 N/mm²). These data indicate that conventional plating with lag screws achieves higher interfragmentary compression in this model compared with external clamp compression and locked plating.

Keywords : interfragmentary compression ; tibia plateau fracture ; conventional plating ; locked plating.

INTRODUCTION

The biomechanics of fracture treatment and healing is of ongoing interest to researchers, surgeons, and patients. A variety of different techniques for fracture treatment can all lead to bone healing. Currently, the two major operative fracture treatments are based on relative and absolute stability, concepts that were introduced by the Swiss study group Arbeitsgemeinschaft für Osteosynthesefragen, now known as the AO Foundation (*11*). When treating an intra-articular fracture, the concept of absolute stability indicates that the fractured fragments should be anatomically reduced and stabilized to be as rigid as possible. To achieve this, locking plates seem to be advantageous, particularly for use in osteoporotic bone. For simple shaft fractures with good bone quality, however, no advantage in the use of locking plating has been found in biomechanical testing or clinical outcome measures (*2,3,6,13*). The key for treating osteoporotic intra-articular fractures is to fix the fragments that recreate the articular surface anatomically, and two basic principles are mainly

■ Stefan Rahm.
■ Lukas Ebneter.
■ Birte Ellenrieder.
■ Christian Spross.
■ Fabrice Kulling.
■ Johannes B. Erhardt.
Dept. Orthopädie, Universitätsklinik Balgrist Zürich, Swiss.
Correspondence : Stefan Rahm, Universitätsklinik Balgrist, Forchstr. 340, 8008 Zürich.
E-mail : orthopaedie@balgrist.ch www.balgrist. ch

No benefits or funds were received in support of this study.
The authors report no conflict of interests.

used to achieve this. The first is the use of lag screws to achieve maximum interfragmentary compression in combination with a conventional plate, and the second, especially in combination with anatomically pre-shaped locking plates, is the use of a clamp to achieve interfragmentary compression before fixing the fragments to the plate with locking screws.

The effect of interfragmentary compression on fracture displacement, as well as the relative amount of interfragmentary forces, has not yet been reported. Furthermore, there is no data available in the literature showing the differences during cyclic loading in interfragmentary compression in various fixation methods. Schatzker I and AO type B1.1 lateral tibia plateau fractures are common and, if displaced more than 2 mm, are usually treated operatively (*8,10,12*). Although these types of fracture can be treated with a conventional buttress plate, anatomically shaped locking plates have recently become more popular because of their availability, promised increased stability and ease of use (*7*).

Using simple lateral tibia plateau fractures as a clinically relevant test model, the aim of this study was to determine whether there are biomechanical differences in interfragmentary compression and fracture micromotion between traditional buttress plating and the use of a locking plates. The present biomechanical study was designed to show whether there is a difference in the magnitude of interfragmentary compression at different stages of fixation and after cyclic loading between those two fixation techniques. The hypotheses of this study were

1) the use of lag screws in combination with a buttress plate achieves larger magnitudes of interfragmentary compression than clamp fixation and locked buttress plating and
2) the interfragmentary compression will remain higher over time with less interfragmentary micromotion after locked plating compared with the conventional fixation technique.

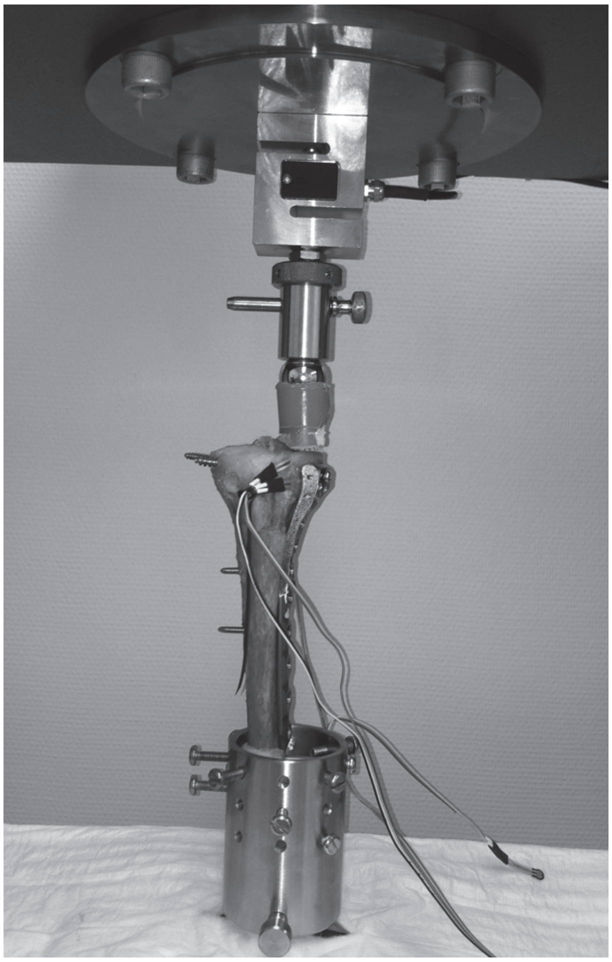

Fig. 1. — Example of a fixed tibia with a lateral NCB plate showing the four screws and the pressure sensors.

MATERIAL AND METHODS

Six matched pairs (6 right and 6 left) of fresh frozen cadaver tibiae were used in this study. The cadaver tibiae were obtained from the anatomical institute of the University of Geneva, where they were managed strictly in line with all regulations as required by law. The local IRB approved this study. At the time of testing, the cadaver tissues were at room temperature. The tibiae were numbered from 1 to 6 with R indicating the right and L indicating the left of the matched pair. The locking group L included the tibia L-1R, L-2L, L-3R, L-4L, L-5R and L-6L and the other 6 tibiae (C-1L, C-2R, C-3L, C-4R, C-5L and C-6R) were assigned to the conventional group C. This design produced two groups with matched pairs that were numbered alternatingly and prepared to avoid the effects of potential variations in the bone mineral density of the tibiae. The tissue setup is shown in Figure 1.

Implant

The implant was a polyaxial nine-hole locking plate for the proximal tibia with three proximal holes (Non-Contact Bridging Plate, NCB ; Zimmer, Warsaw, IN, USA) in all tests. This device was chosen because of the option to use it in either locking or conventional mode. The locking option is activated secondarily with a locking cap.

Testing setup

Each tibia was distally fixed into the loading device. The NCB plate was secured on the lateral tibia at the desired position for optimal testing.

Group conventional (C)

Two standard 3.3-mm holes were drilled using a uniaxial drill sleeve, and bicortical 4-mm conventional cortical screws were inserted into the two distal holes (4 and 6) of the plate. Next, the lag screw holes were drilled in two of the three proximal holes, predrilling 5 mm into the lateral fragment and 2.5 mm into the medial fragment, and the depths were verified to be bicortical. Then, the distal screws were loosened and the plate was lifted away approximately 1-2 cm. At this point, the osteotomy was performed using an oscillating saw to simulate a standardized lateral tibial plateau split fracture (Schatzker I), with the goal of passing through 50% of the lateral tibial plateau. The osteotomy gap was opened and three pressure sensors were placed precisely and in the same way in all of the specimens. The fracture was then preliminarily held with a K-wire. Two markers were placed on the medial and two more on the lateral fragments to measure the relative movements of the bone fragments. The distally loosened screws were retightened, but only enough to hold the plate in the desired position. The two measurement systems were calibrated, and then the testing phase was started (Time 0).

Group locking plate (L)

Standard 3.3-mm holes were drilled using the uniaxial drill sleeve into the two distal spaces (holes 4 and 6 as in group C), and into two of the three proximal holes using the polyaxial drill sleeve. The depths of the holes were measured. At this stage, the osteotomy was performed just as described above for group C, with the osteotomy exactly perpendicular to the drill holes. The three pressure sensors were inserted in the same way as in group C, and the fragments were held together with a K-wire. Next, two markers, as in group C, were placed onto each of the fragments. The two distal screws were tightened enough so that the K-wire could be removed without the fragments coming apart. Then, the calibration was performed and the testing phase was started (Time 0).

Testing Phase

The first procedure in both groups was to test the buttress effect, and the distal two screws were tightened after removing the K-wire. The next step was to create interfragmentary compression, which was done in group C by tightening the predrilled lag screws and in group L by closing a large reduction clamp. The results of recorded interfragmentary compression and relative fragment micromotions are listed in Table I.

Cyclic loading

Each specimen was secured in a Zwick universal testing machine (Zwick/Roell, Ulm, Germany). To avoid friction, the load was applied by a ball-and-socket-joint directly perpendicular to the lateral fragment as shown in Figure 1. Each specimen was axially preloaded with 30 N. Then, 1000 cycles of 200 N were applied, similar to the testing protocol used by Blakey *et al* (*1*).

Compression and Micromotion

To measure the interfragmentary compression, three pressure sensors (sensing area : 10 mm^2, SENSOR-TECHNICS, GmbH, Puchheim, Germany) were positioned in each osteotomy gap as described above. One sensor was positioned posterior, one anterior, and one in the middle. The readings from the three pressure sensors were summed and the mean is reported. The resulting voltage values were converted to compressive stress (N/mm^2) after calibration.

The movement between the bone fragments (the main tibia fragment and the lateral tibia plateau fragment) was measured in 3 dimensions using a stereoscopic, non-contact, full-field digital image correlation system during dynamic loading (Vic-3D System, LIMESS, Correlated Solutions, Columbia, SC, USA). The marker was tracked using pattern recognition performed for the marker placed on each bone fragment. The field of view was 100 × 130 mm with an accuracy of ~1 μm in the x- and y-planes and ~2 μm in the z-plane. The sampling

Table I. — The times are listed from 1 to 4 indicating when the readings for the interfragmentary compression were taken for every tibia tested

Measuring the interfragmentary compression :		
	Group C	*Group L*
Time 1 :	After tightening the two distal bicortical screws	After tightening the two distal bicortical screws
Time 2 :	After tightening the two proximal bicortical lag screws	After closing the interfragmentary clamp with reasonable power
Time 2a	–	After tightening the two proximal bicortical position screws
Time 2b	–	After removing the interfragmentary clamp
Time 3 :	After leaving the system rest for 60 minutes	After leaving the system rest for 60 minutes
Time 4 :	After cyclic loading	After cyclic loading

frequency was 10 Hz (4). The 3-dimensional distance and displacment in μm between the two markers was measured during the entire test setup. The displacement between the lateral fragment and the medial main tibia fragment was measured and is given as "E" in units of µm.

Statistics

A 2-tailed non-parametric Mann-Whitney U-test and a 2-tailed Pearson Correlation were used to compare the micromotions and compression values between the groups. P-values less than 0.05 were considered statistically significant.

RESULTS

The results from the first three tibiae (C-4R, L-5R and L-6R) had to be discarded because of a technical error caused by interface failure between the compression measurement, digital image correlation and material testing machine setup. In group C there was a statistical trend towards higher interfragmentary compression compared to group L at all times except at times 1 and 2a, which were immediately after tightening the two proximal bicortical position screws in group L. After removing the interfragmentary clamp from group L, the compression dropped back to levels that were significantly lower than those in group C. Taking the maximum achieved interfragmentary compression to be 100%, the compression after cyclic loading in group L was 15% lower, reaching 85%, but only 3% lower in group C, reaching 97%. The buttress effect alone provided 12% compression in group L and 67% in group C. All of the results are listed in Table II and depicted visually in Figure 2.

Micromotion

The amount of translational movement of the lateral fragment in group C was not significatnly different compared to group L (refer to Table III).

Correlations

The 3-dimensional displacements in µm and the mean interfragmentary compression were significantly correlated with a good to very good correlation in group C ($p < 0.001$, $r = 0.686$) and a fair to good correlation in group L ($p < 0.001$, $r = 0.433$).

DISCUSSION

The main finding in this study was that both systems assessed resulted in similar maximum interfragmentary compression magnitudes. However, after relieving the clamp in the locking plate group L, the compression was significantly decreased. Therefore, our first hypothesis was confirmed. The lag screw group C was able to maintain the interfragmentary compression at a higher level over time. Even after cyclic loading, it dropped only 3% of the maximum achieved interfragmentary com-

Table II. — The numerical values of the interfragmentary compression are reported in N/mm² for each tibia and the statistical significance calculated using a Mann-Whitney U rank test are shown

Summary of interfragmentary compression :						
(N/mm²)	Time 1	Time 2	Time 2a	Time 2b	Time 3	Time 4
Group L						
L-2L	0.6	30.5	36.3	31.8	23.3	20.5
L-1R	13.7	32.4	37.0	34.7	31.5	30.9
L-4L	1.0	39.6	47.5	38.9	34.2	26.6
L-3L	8.3	34.8	39.9	39.0	38.7	36.4
Median	4.6	33.6	38.5	36.8	32.9	28.7
Max	13.7	39.6	47.5	39.0	38.7	36.4
Min	0.6	30.5	36.3	31.8	23.3	20.5
SD	5.8	3.4	4.4	3.0	5.6	5.8
Group C						
C-2R	0.5	52.4	53.1	53.3	52.8	53.0
C-1L	36.2	46.6	46.7	46.7	49.0	50.8
C-5L	6.2	36.9	37.5	37.2	38.8	34.1
C-3R	44.9	44.0	45.9	44.2	36.9	31.9
C-6L	31.1	45.1	46.7	47.4	44.9	45.3
Median	31.1	45.1	46.7	46.7	44.9	45.3
Max	44.9	52.4	53.1	53.3	52.8	53.0
Min	0.5	36.9	37.5	37.2	36.9	31.9
SD	17.3	5.0	5.0	5.2	6.0	8.6
*p =	0.327	0.027	0.221	0.050	0.027	0.050

* Mann Whitney-U Test.

pression compared with a loss of 15% in group L. Thus, our second hypothesis was rejected.

The absolute magnitudes of the interfragmentary compression after the buttress effect at time 1 were to our surprise different between the two groups, but this difference was not statistically significant (Fig. 3). It may be explained by the differences between the anatomic shape of the tibiae and the precontoured NCB plate, which was not placed exactly at the same level on each tibia even though that was our aim. Another point was the relative increase when tightening the locking screw in group L at time 2a, which may be explained by the lag screw effect even though the holes were correctly drilled. Obviously, after the clamp was removed this effect lasted no longer and the compression decreased almost 50% from time 2 to 2a. To our knowledge this is the first study to investigate the magnitude and

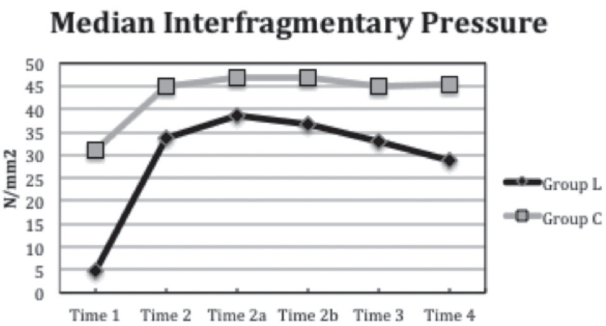

Fig. 2. — Summary of the interfragmentary compression magnitudes at different times. The x-axis shows the different times when a reading was taken. The times from 1 to 4 are explained in Table I. The y-axis shows the median interfragmentary compression in N/mm² for each group. The numbers are reported in Table II as the median, Max/Min and SD.

Table III. — The numerical values of the displacement of the lateral fragment are reported in µm for each tibia and the statistical significance calculated using a Mann-Whitney U rank test are shown, but no significant differences between the groups were found at any time

Summary of displacement of the lateral fragment						
E (µm)	Time 1	Time 2	Time 2a	Time 2b	Time 3	Time 4
Group L						
L-2L	0	42.2	-1.5	0.2	8.8	7.3
L-1R	0	-42.4	-42.4	-53.0	-52.7	-39.3
L-4L	0	-33.2	-57.7	-52.4	-52.0	-62.5
L-3L	0	-28.0	-50.4	-48.6	-44.0	-85.2
Median	0	-30.6	-46.4	-50.5	-48.0	-50.9
Max	0	42.2	-1.5	0.2	8.8	7.3
Min	0	-42.4	-57.7	-53.0	-52.7	-85.2
SD	0	38.8	25.1	25.8	29.4	39.5
Group C						
C-2R	0	-54.1	-54.0	-49.5	-50.1	-50.9
C-1L	0	-22.6	-22.3	-22.6	-23.0	-29.1
C-5L	0	-29.3	-29.2	-29.3	-29.9	-24.5
C-3R	0	0.0	1.7	2.0	-19.0	-38.1
C-6L	0	-16.1	-19.9	-19.8	-20.6	-20.8
Median	0	-22.6	-22.3	-22.6	-23.0	-29.1
Max	0	0.0	1.7	2.0	-19.0	-20.8
Min	0	-54.1	-54.0	-49.5	-50.1	-50.9
SD	0	19.8	20.0	18.5	12.8	12.1
p* =	-	n.s.	n.s.	n.s.	n.s.	n.s.

* Mann-Whitney-U Test.

mode of interfragmentary compression in a simple fracture model using cadaveric tibiae under cyclic loading.

There are a number of limitations to this study, including the small sample size. Despite the limited power, we were able to find statistically significant results. Because no comparable data were available, we did not calculate the power. In addition, we did not measure the bone mineral density of the samples. To minimize variation caused by bone mineral density, we used a matched sample design, including one tibia from each cadaver in each of the two groups. This reduces the influence of varying bone mineral density. Besides the initial failures (exclusion of the first 3 samples), the setup was standardized and not prone to failures, indicating the testing conditions should be reproducible for further studies.

In a biomechanical study by Kojima *et al*. using synthetic bone models in a simple tibia split fracture in osteoporotic bone, the authors showed a significantly higher interfragmentary compression force in fragments fixed with two 6.5-mm lag screws than in those fixed with four 3.5-mm lag screws, whereas fixation with a clamp following a locking plate and screws was no different from the screw results (*5*). The results of the present study agree with those reported by Kojima *et al*, except that we additionally showed a significant decrease in compression in the locking plate group after cyclic loading.

In other biomechanical studies (*7,9*), several fixation methods (three cancellous lag screws alone, two cancellous lag screws with an additional antiglide screw, or a buttress plate for fixation) were compared in a simple tibia split fracture, but no significant differences were found between them. However, the authors did not measure the interfragmentary compression.

Although we were able to show that the buttress effect itself is already significant, the mode of fixation via lag or locking has an additional effect. In addition, we showed that the interfragmentary compression correlated with the micromotion between fragments during cyclic loading, which supports the validity of our test setup. The lag screw group was able to maintain the interfragmentary compression at a higher level over time and during cyclic loading compared with that achieved by the locking group. These results may be of clinical importance when choosing the type of implant and mode of fixation for specific fractures. These biomechanical data support the philosophy of the AO Foundation, especially with respect to the fixation of intra-articular fractures.

To compare a next group with a combined lag screw and locking screw fixation with the already two fixation techniques described would be of great interest and should be performed in a following study with maybe even a greater number of species. The use of the combined technique could be of advantage when treating comminuted fractures in middle aged patients. This is the first study in the literature that investigated the interfragmentary compression in a biomechanical test setup in human cadavers. We believe this study provides relevant information for surgeons treating articular fractures using these two techniques.

CONCLUSIONS

Conventional plating with lag screws achieves higher interfragmentary compression in simple lateral tibial plateau split fractures than external clamp compression and locked plating.

REFERENCES

1. **Blakey CM, Rennison M, Guy SP *et al.*** A biomechanical study comparing two fixation methods in depression fractures of the lateral tibial plateau in porcine bone. *BMC Sports Science, Medicine, and Rehabilitation* 2013 ; 5 : 15.
2. **Florin M, Arzdorf M, Linke B *et al.*** Assessment of stiffness and strength of 4 different implants available for equine fracture treatment : a study on a 20 degrees oblique long-bone fracture model using a bone substitute. *Vet Surg* 2005 ;34 :231-238. doi :10.1111/j.1532.950X.2005.00035.x
3. **Gardner MJ, Brophy RH, Campbell D *et al.*** The mechanical behavior of locking compression plates compared with dynamic compression plates in a cadaver radius model. *J Orthop Trauma* 2005 ; 19 : 597-603.
4. **Giesinger K, Ebneter L, Day RE *et al.*** Can Plate Osteosynthesis of Periprosthethic Femoral Fractures Cause Cement Mantle Failure Around a Stable Hip Stem ? A Biomechanical Analysis. *The Journal of Arthroplasty* 2014 ; 29 : 1308-1312. doi :10.1016/j.arth.2013.12.015
5. **Kojima K, Gueorguiev B, Seva G *et al.*** Biomechanical Evaluation of Interfragmentary Compression At Tibia Plateau Fractures In Vitro Using Different Fixation Techniques. *Medicine* 2015 ; 94 : e 282. doi :10.1097/MD.0000000000000282
6. **Korner J, Lill H, Müller LP *et al.*** The LCP-concept in the operative treatment of distal humerus fractures - biological, biomechanical and surgical aspects. *Injury* 2003 ; 34 : 20-30. doi :10.1016/j.injury.2003.09.022
7. **Koval KJ, Polatsch D, Kummer FJ *et al.*** Split fractures of the lateral tibial plateau : evaluation of three fixation methods. *J Orthop Trauma* 1995 ; 10 : 304-308.
8. **Moore TM, Patzakis MJ, Harvey JP.** Tibial plateau fractures : definition, demographics, treatment rationale, and long-term results of closed traction management or operative reduction. *J Orthop Trauma* 1987 ; 1 : 97-119.
9. **Parker PJ, Tepper KB, Brumback RJ *et al.*** Biomechanical comparison of fixation of type-I fractures of the lateral tibial plateau. Is the antiglide screw effective ? *J Bone Joint Surg Br* 1999 ; 81 : 478-480.
10. **Rasmussen PS.** Tibial condylar fractures. Impairment of knee joint stability as an indication for surgical treatment. *J Bone Joint Surg Am* 1973 ; 55 : 1331-1350.
11. **Rüedi TP, Murphy WM.** 2000 ; *AO Principles of Fracture Management*. George Thieme Verlag.
12. **Schatzker J, McBroom R, Bruce D.** The tibial plateau fracture. The Toronto experience 1968-1975. *Clin Orthop Relat Res* 1979 ; 94-104.
13. **Wenzl ME, Porté T, Fuchs S *et al.*** Delayed and non-union of the humeral diaphysis – compression plate or internal plate fixator ? *Injury* 2004 ; 35 : 55-60.