Paper:

The stabilising effect by a novel cable cerclage configuration in long cephalomedullary nailing of subtrochanteric fractures with a posteromedial wedge

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Manuscript word count 3818

Abstract word count 249

25 **Abstract**

26 **Background:** Clinical studies suggest that an adjunctive cerclage in intramedullary nailing of
27 subtrochanteric fractures improves the outcome. Despite this, to what extent various cerclage
28 configurations influences the fixation strength, remains undocumented. We tested the
29 hypothesis that the stability of subtrochanteric fractures with a posteromedial wedge treated
30 with long cephalomedullary nail varies with cerclage configuration.

31 **Methods:** 40 composite femurs with a subtrochanteric osteotomy including a posteromedial-
32 wedge were locked by cephalomedullary nailing (T2 recon, Stryker) and divided into 4 groups.
33 In Group-A no cerclage was applied. The Group-B received a lateral tension-band (cerclage
34 cable with crimp, Depuy-Synthes). Without any fixation, the wedge-component was removed
35 in these groups. The Group-C was fixed with a cerclage encircling the wedge-component,
36 while in the Group-D a novel figure-of-8 cerclage stabilised the wedge-component. Each
37 femur was tested quasi-static in a material-testing-machine for stiffness calculation, first
38 horizontally to simulate seated-position and then vertically to simulate standing-position.
39 Finally, cyclic testing was performed in the upright-posture to measure deformation over time.

40 **Findings:** In Group-D the mean stiffness in the sitting-position was 6.4, 5.8 and 3.1 times
41 higher than the Groups-A, B and C, respectively, and correspondingly 2.0, 2.1 and 1.7 times
42 higher in the standing-position ($p < 0.05$). Over time, Group-D demonstrated less mean
43 deformation than tension-band ($p = 0.05$), while the deformation was not significantly different
44 from the other groups.

45 **Interpretation:** Additional use of cerclage enhances the stability of intramedullary nailed
46 subtrochanteric fractures, and use of the figure-of-8 cerclage configuration, compressing the
47 entire posteromedial-buttress, is the superior technique.

48

49 **Key words:** Subtrochanteric fracture; Posteromedial buttress; Intramedullary nail; Cerclage
50 cable; Biomechanics; Composite bone

51

Main text

1. Introduction:

The subtrochanteric fractures, as with proximal femur fractures in general, exhibit an increased burden coinciding with the aging population. Even with a decline in incidence, due to increase in the elderly population, the number of subtrochanteric fracture will increase globally in the coming decades (Stoen et al., 2012). Generally, these fractures occur in the elderly after a low-energy fall and thereafter significantly reduce the quality of life (Ekstrom et al., 2009).

Subtrochanteric fractures are best treated operatively with long cephalomedullary nailing. This method is shown to reduce fracture healing complications and reoperation rates compared to plate-osteosynthesis (Matre et al., 2013; Parker and Handoll, 2008). In spite of using the latest generation of nails and plates, the risk of complications remains high with non-unions, mal-unions, screw cut-outs, implant-breakages etc. (Craig et al., 2001; de Vries et al., 2006; Sims, 2002).

The explanation of non-union rates up to 20% includes mechanical and biological factors, as this region experiences the highest mechanical stress in humans and has a high bone density with an increased ratio of cortical-bone relative to cancellous-bone leading to a relative decrease in blood supply (Barquet et al., 2004; Bedi and Toan, 2004; Haidukewych and Berry, 2004; Lundy, 2007; Melis et al., 1979; Maquet and Pelzer-Bawin, 1980; Tencer et al., 1984). The posteromedial proximal femur is compressed, whilst the tensile-forces work anterolaterally. The muscular actions by the psoas, abductors, adductors, hamstrings and the gluteal muscles distract the fracture and prevents its optimal reduction (Lundy, 2007). Malreduction contributes to a too lateral entry-point of the intramedullary nail (Bedi and Toan, 2004; Lundy, 2007) which introduces varus deformity of the fracture. Likewise,

78 comminution of the posteromedial-buttress results in a varus deformity (Fielding et al., 1974;
79 Kyle et al., 1995; Lee et al., 2006; Malkawi, 1982), an important predictor of complications
80 (Barquet et al., 2004; Haidukewych and Berry, 2004; Giannoudis et al. 2013; Shukla et al.,
81 2007). To avoid a varus deformity postoperatively, which has an incidence as high as 20%,
82 the reduction of the posteromedial-buttress has been a well-established recommendation (Park
83 and Kim, 2013; Schatzker and Waddell, 1980).

84 Amongst various reduction tools, clamps and cerclage are frequently used to obtain
85 and maintain reduction (Codesido et al., 2017; Kim et al., 2014; Hoskins et al., 2015; Ruecker
86 and Rueger, 2014). For the transverse and short oblique fractures, no further intervention than
87 the clamp is typically needed (Afsari et al., 2009). For transverse and comminuted fractures a
88 cerclage is not implantable (Cebesoy et al., 2011). Occasionally, long fractures with spiral,
89 oblique or wedge may re-displace after clamp release and cerclage might come in handy
90 (Afsari et al., 2009).

91 Insight and innovations have turned around the cerclage technology's decades of
92 disrepute. The use of minimally invasive cerclage technique is reported in 2-20% of patients
93 (Afsari et al., 2009, Robinson et al., 2005). It is applied through the same proximal incision or
94 its prolongation and minimises the soft tissue injury and vascular disruption (Apivatthakakul
95 et al., 2012, Ban et al., 2012). Many authors report the advantages of cerclage wiring of
96 subtrochanteric fractures prior to intramedullary nailing (Afsari et al., 2009; Apivatthakakul
97 and Phornphutkul, 2012; Kennedy et al., 2011; Tomas et al., 2013). It improves fracture
98 reduction and fixation strength, reduces time to union and decreases complication and
99 reoperation rates (Ban et al., 2012; Codesido et al., 2017; Finsen, 1995; Hoskins et al., 2015;
100 Trikha et al., 2018). Biomechanical advantages of open reduction and cerclage are claimed to
101 outweigh the concerns of violating the principles of biologic internal fixation and the
102 consequences of malreduction.

The debate is still on considering the optimal device or configuration for the cerclage technique. Biomechanically, when a crimp is used, the multifilament cable made of titanium or steel, is stronger and maintains the applied tension better, as compared to monofilament, solid steel wire, where the handling of the twist regularly decreases tension (Wähnert et al., 2011). Regarding configurations, double looping is reported comparable with two single items (Lenz et al., 2013). Remarkably, no scientific reports of other configurations are available to our knowledge. To what extent various cerclage configurations influence the strength of the osteosynthesis remains insufficiently evaluated biomechanically in this setting. The only former biomechanical study found in the literature changed failure mode by an adjunctive circumferential wire cerclage applied on short, oblique fractures reduced and stabilised by a short intramedullary nail (Müller et al., 2011).

The aim of the present study was to test the novel figure-of-8 cable cerclage that we use clinically. In the current biomechanical experiment cerclage was tested as an adjunct to long cephalomedullary nailing of unstable subtrochanteric fractures with or without reduction of the postero-medial hinge.

2. Method

2.1. Model preparation

Forty synthetic femurs (model # 3406, Left, Large, Fourth Generation Composite Bone, Sawbones® Pacific Research Laboratories, Vashon, WA, USA) were osteotomised using a hacksaw with a 0.7 mm blade. The osteotomies corresponded with the 32-B2.1 AO/OTA classification of subtrochanteric fractures (Marsh et al., 2007), with a standardized, oblique cut 50° to the longitudinal axis of the diaphysis, 25 mm below the border of the lesser

trochanter in the intramedullary centre. A posteromedial-wedge was carved off the posterior half of the proximal fragment extending proximally from the same level, from 60 mm medially to 10 mm laterally, including the lesser trochanter. This defined the posteromedial buttress (Fig. 1).

For all specimens, the fixation method applied was a long cephalomedullary nail, 11 mm in diameter and 420 mm in length with two titanium lag screws in the femoral head and two locking screws distally in static mode, as well as an end-cap (T2 recon, Stryker, MI, USA). Both the trochanteric entry point of the nail and all screw holes were predrilled with a jig before osteotomy, ensuring a standardised, anatomically reduced fracture in all specimens before testing. The femurs were operated according to the surgical technique advised by the manufacturer and controlled by fluoroscopy.

The test specimens were divided into 4 groups and differed regarding the presence of any adjunctive fixation (N=10/group). The Group-A got no cerclage and without fixation the posteromedial wedge-component was removed. The Group-B received a lateral tension-band cerclage without any stabilisation of the wedge-component, which was detached. The Group-C was fixed with a circular cerclage around the wedge-component. In the Group-D, a figure-of-8 cerclage was introduced around the posteromedial wedge-component. The cerclage formed a figure-of-8 being introduced distally from lateral, crossing itself on the wedge component posteromedially and closed proximally anchored to the proximal lag screw. By being threaded perpendicularly across the fracture gap distally and proximally, the cable facilitated compression along all fracture lines, both in the proximal, distal and anteroposterior direction (Fig. 2). The applied stainless-steel cerclage cables with crimp and diameter 1.7 mm (Depuy-Synthes, Oberdorf, Switzerland) were inserted and tensioned until 500 N (maximum value advised by the manufacturer) by a cable tensioner provided by the company. The applied tension on the cerclage was the same for the Groups B, C and D. A

standardised 2.0 mm hole was drilled through the distal femoral fragment laterally in anteroposterior direction at the distal level of the fracture. This was done as the surface of the artificial bone was too smooth for the cerclage to remain in the desired position. This solution, acting as an anchoring-point for the cerclage, has already been accepted with the tension-band cerclage technique (Volpon et al. 2008).

2.2. Test procedure

The fixed composite femurs were mounted in a test-jig by press-fit insertion at the diaphysis, 10 mm distal to the end of the osteotomy into a channeled steel tube, accepting movements of the proximal 150 mm of the femur while the distal part of the femur was fixed. During testing micro-movement by the nail intramedullary was allowed in its whole length due to this set-up. Movement of the femoral head would hence correspond with movements of the proximal femur as varus deformity in upright position and with movements in the fracture zone in any direction. The jig was mounted in a testing machine (MiniBionix 858 MTS Systems, Eden Prairie, MN, USA) equipped with a load cell having axial characteristics calibrated by the manufacturer (capacity 10 kN; resolution 1 N; accuracy 0.5%).

For the initial quasi-static stiffness test, each femur was compressed 3 times within the instrument testing machine with a linear motion pattern using load control (ramp, 10N/s; maximum load stiffness test, 100 N). Both sitting and standing positions were tested to simulate different directions of hip joint reaction force, as recommended for other proximal femur fractures (Basso et al., 2012). Proximally, the machine's actuator transferred compression on the femoral head through a piston. During the sitting part of the non-destructive stiffness test specimens were oriented horizontally with compression on the anterior aspect of the femoral head, to simulate the direction of the hip contact force vector

when sitting down (Bergmann et al., 2001). In upright posture, the stiffness test was conducted with 7 degrees adduction, corresponding with the direction of the hip contact force vector during one leg stand phase (Bergmann et al., 2001) and compression on the cranial part of the femoral head. In both orientations the displacement of the femoral head by axial compression was measured by the load cell and data recorded by a computer.

With the same set-up as the upright stiffness test, cyclic loading followed by an applied load of 1000 N with 10.000 cycles. The vertical compression was applied at the femoral head dynamically with a sinusoidal motion pattern using load control (rate, 1 Hz; maximum load standing test, 1000 N; preload 10 N). The applied load approximated in vivo results from measurements of postoperative joint reaction force in partial weight-bearing by use of walker, crutches or a cane during rehabilitation (Davy et al. 1988). The physiological subject-specific axial load of approximately one body weight during cyclic testing corresponded with a 92 kg caucasian male, the model behind the applied large composite femoral bones (Basso et al., 2014b). The number of cycles recommended intend to simulate the amount of gait cycles during the first 4-6 weeks postoperatively, a crucial time interval for bone healing complications (Aminian et al. 2007).

The best line fit of the slope of the compression load-deformation curve's linear elastic portion defined stiffness of the fixated femur. The three non-destructive compressions in each of the quasi-static tests both in seated and upright posture were used to obtain an average value for initial stiffness of the fixation, an accepted way of defining stiffness (Zdero et al., 2010). Axial displacement of the proximal femur fragment from pretest to after unloading the last cycle, was chosen as outcome in the dynamic test. The measured deformation should reflect the varus deformity and the impaction both at the fracture zone and at the bone-implant interface after the cyclic test. During the test the fracture zone was

inspected visually for movements, and during dismantling after the test the bone-implant construct was examined for signs of failure.

2.3. Statistical analysis

Data were processed with IBM SPSS Statistics (version 25 for Windows; SPSS Inc., Chicago, IL, USA). Average values were expressed as arithmetic means, and dispersion as standard deviations and confidence intervals. For comparisons of continuous parameters, one-way analyses of variance (ANOVA) were conducted. Level of significance was set to $p < 0.05$. Post hoc multiple comparisons were made with Bonferroni correction.

2. Results

Initial stiffness and final deformation with standard deviations (SD) are presented in Table 1 for all configurations along with their comparisons.

During the initial test in the seated-position the mean fixation stiffness of the four groups varied from 7.4 N/mm (95% CI; 5.6-9.1) in Group-A to 47.1 N/mm (95% CI; 35.4-58.9) in Group-D. The absence or presence of any adjunctive fixation to intramedullary nails in our model affected the initial fixation stiffness in the seated-position ($p < 0.001$). In subgroup analyses, this corresponded with the mean initial fixation stiffness in Group-D which increased by a factor of 3.1 to Group-C, 5.8 to Group-B and 6.4 to Group-A, when the respective groups were compared while seated ($p < 0.05$).

In the subsequent stiffness test in the standing-position the mean fixation stiffness of the four groups varied from 298.3 N/mm (95% CI; 195.4-401.3) in Group-B to 631.2 N/mm (95% CI; 597.1-665.2) in Group-D. Moreover, the concept of adjunctive fixation to

intramedullary nails influenced the initial fixation stiffness with the current set-up ($p < 0.001$). The mean stiffness provided by Group-D increased by a factor of 1.7, 2.1 and 2.0 when compared to the other groups C, B and A, respectively ($p < 0.05$). Only the Group-D had statistically significant higher stiffness as compared to the other groups, in both sitting and standing position.

The mean deformation after cyclic testing varied from 0.9 mm (95% CI; 0.7-1.1) in Group-D to 1.6 mm (95% CI; 1.2-2.1) in Group-B, revealing the only statistical difference in this setting ($p = 0.05$).

No other statistically significant findings were detected. A trend towards less deformation with the figure-of-8 cerclage was noticed compared to both fixation with circular cerclage (D vs C) and no adjunctive cerclage in cyclic testing (D vs A), but only the difference between Group-D and Group-B was significant. A trend towards increased stiffness in both sitting and standing orientations by any cerclage was identified compared to no cerclage (A vs B, C and D). Likewise, a trend towards increased stiffness by fixation of the posteromedial-buttress was detected (A and B vs C and D). The only deviation from this observation was the absence of any effect of the tension-band cerclage in standing-position when the wedge-component was removed.

By visible inspection of the fracture gap during both the non-destructive and dynamic testing, no certain movements were spotted within the Group-D, contrasted by the fixation methods by the other groups. Neither formation of new fracture lines nor signs of hardware impairment were discovered during disassembling. By visual inspection, displacement of the cerclage's position was not found between pre- and post-test. Hence, no detectable macroscopic signs of decreased tensioning with movements of the cable cerclage at the crimp-bone contact area was discovered.

3. Discussion

In our experiment we wanted to analyse the stabilising effect in terms of stiffness and capability to resist a varus deformity by different cerclage configurations. We found a stabilising effect on fixation stiffness by the concept of cable cerclage in long cephalomedullary nailing of unstable subtrochanteric fractures. The fixation by the adjunctive figure-of-8 cerclage rigidly fixing the posteromedial-buttress increased initial fixation stiffness in both the simulated sitting and standing positions. In addition, the figure-of-8 group documented the lowest deformation after simulated walking when compared to the group fixed by the tension-band cerclage. Additionally, the figure-of-8 group also trended towards less deformation compared to the groups with a circular cerclage, or without any cerclage.

A physical explanation of the findings involves interpreting the fracture pattern and configurations by groups. Without a cerclage (A) the fracture is either treated without addressing the posteromedial-buttress at all or, if the wedge-component is comminuted a cerclage is not implanted as it is not indicated. The lateral tension-band cerclage (B) enables lateral tension and hence offloads the hinge posteromedially in correspondence with the trend to have an effect on stiffness compared to the group without any cerclage. Similarly, the circular cerclage (C) trended towards both having an effect of improved configuration of cable cerclage (B vs C) and an effect of reducing the wedge (A vs C). These findings correspond with the circular cerclage fixating the posteromedial-wedge to the proximal segment, converting the fracture to a simple, oblique type, allowing increased posteromedial compression to some extent. The figure-of-8 is an innovative cerclage configuration in this location, as it stabilises the posteromedial-wedge to both the proximal and distal fragment simultaneously, enclosing the fracture gap. Hence, a better and more balanced distribution of tensile and compression forces in the proximal femur occurs, preventing varus deformity by regaining fracture stability. Correspondingly, we argue that the figure-of-8 group performed

superiorly because the cerclage secured the reduced posteromedial-buttress better, resulting in improved load transfer. The biomechanical advantage of this configuration is its ability to compress the whole fracture system when fixating the posteromedial-buttress in cross combined with cephalomedullary nailing (Figures 2 and 3), the femur regaining stability. Similar with other fracture patterns a cerclage ensuring compression along the entire fracture zone should increase stability, just as documented by Müller et al. (2011) in simple subtrochanteric fractures.

The only previous biomechanical study on this topic evaluated short, oblique subtrochanteric fractures in human femurs fixated with short intramedullary nails with an optional circular cerclage wire before testing by incrementally increasing the load until failure (Müller et al., 2011). No preliminary differences were detected until radiological examination revealed differing failure modes. The presented failure mode with fragmentation of the circular cerclage fixed posteromedial-buttress is logical. The maintained reduction by the cerclage enable posteromedial compression until fragmentation. Despite reporting this not commonly observed failure mechanism, the authors were in favour of the cerclage as the osteosynthesis was intact, contrasting the varus deformity occurring in the group without any cerclage (Müller et al., 2011).

Our study aimed at a clinically more relevant set-up. A fracture pattern likely to benefit from cerclage was chosen (Afsari et al., 2009), and the most commonly used fixation method by a long cephalomedullary nail and cerclage cables that should perform better was applied (Wähnert et al., 2011). A more systematic investigation with two relevant load directions and both initial quasi-static and cyclic loading with an appropriate load was performed, as recommended in simulation of rehabilitation after another type of hip fractures (Basso et al., 2012). Our findings in favour of cerclage are in accordance with the results of the only preceding biomechanical study (Müller et al., 2011). We argue a more noticeable

effect detected solely in our study, by the increased mean stiffness with the figure-of-8 cerclage configuration. This was found both in the seated and standing-position initially and was combined with a reduced deformation after cyclic loading. This suggests a separate and distinguished mechanical property of the figure-of-8 configuration involving rigid fixation of the posteromedial-buttress compared to the other conventional configurations. This stabilising effect with possible clinical implications needs further investigation.

Several limitations to our findings are noted.

Concerning the bone models, a standardised low-friction osteotomy was chosen to focus on fixation rather than a fracture pattern with a more realistic rough fracture surface. Impaction happened in all constructs, the nail preventing further shortening. This might be explained by the composite femur revealing very stable bone-implant constructs (Basso et al., 2014b). Simultaneously, using composite bones eased multiple comparisons for the detection of a possible step-wise effect of cerclage configuration and reduction of the posteromedial buttress. A trend was detected towards an effect of cerclage configuration itself and towards fixation of the posteromedial-buttress.

The applied cerclage-cables are supposed to maintain tension better than cerclage-wires (Wähnert et al., 2011). Due to the smooth surface in composite bones a hole for anchorage to prevent sliding was necessary. In-vivo we have not seen sliding movement of the cerclage which has been tensioned and thereafter stabilised by crimp. We argue that the less prominent effect of the optimum cerclage technique in cyclic testing was not due to loss of tension, but rather the fractures regaining their stability through impaction.

In our test set-up, we used a titanium cephalomedullary nail and stainless-steel cerclage. There are concerns about corrosion in-vivo. The tests were conducted on artificial bones, hence there were no direct clinical implications. Nevertheless, we advise surgeons to follow the current literature and evidence when treating a patient. There is available literature

where authors have studied clinical effects of mixing titanium and stainless-steel implants in-vivo and have found no adverse effects (El-Zayat et al, 2013; Serhan et al, 2004; Koh et al, 2015; Høl et al, 2008.).

Regarding the tests chosen, we intended to test the potential to prevent varus deformation, a fundamental cause and major problem among subtrochanteric fracture healing complications (Barquet et al., 2004; Haidukewych and Berry 2004; Giannoudis et al., 2013; Shukla et al., 2007). Provoking failure modes represents an advantage in biomechanical testing, but provoking clinically relevant failure scenarios like varus deformation is not an easy task. Instead of a load-to-failure test, postoperative fixation stability with application of loading and load directions relevant to rehabilitation was tested. The load applied in cyclic testing reflected joint reaction force in postoperative weight-bearing (Davy et al., 1988). Initially, we tested the load directions of hip flexion and extension. The gait cycle could be interpreted as a varying proportion of these two load directions. Despite the fact that quasi-static testing may not imitate real clinical conditions, these tests represent an established standard in comparative studies, potentially revealing circumstances disturbing fracture healing. This is in accordance with the theory of strain, explaining the maximum instability tolerated and the minimal motion between the fragments required for induction of callus formation (Perren, 2002). Micro-motions were practically invisible with the novel cerclage in all test scenarios. As suggested by other authors (Basso et al., 2014a), micro-motions in the fracture zone should have been measured, making a conclusion on a preferable situation for fracture healing possible. However, there is no available documentation within biomechanical studies on clinical relevance with local measurements better predicting fracture healing complications than measurements of deformation of the whole bone-implant construct.

Regarding generalisation of our findings, the impact of the cerclage configuration on fixation stiffness was detected in two relevant test situations, documenting its biomechanical

superiority in a more pervasive investigation (Basso et al., 2012). The additional finding of an effect of cerclage-configuration in cyclic testing supports a biomechanical effect not restricted to the initial postoperative fixation stability. Contrarily, the less striking impact in cyclic testing might reflect the clinical setting, explaining initial stiffness having minor clinical relevance, as differences less than 5 mm shortening of the proximal femur after hip fractures are not associated with any functional difference (Zlowodzki et al., 2008). To conclude on optimal circumstances for undisturbed fracture healing clinical studies are needed, which emphasize the most obvious shortcoming of experimental ex-vivo studies. Considering mobilisation and rehabilitation, all fixations provided sufficient stability to perform normal rehabilitation, as no failure happened during simulated partial weight-bearing.

Finally, it has to be acknowledged that the figure-of-8 cerclage being a new technique, takes practice to get used to. It might as well be argued that the technique of using the figure-of-8 cerclage per se is of technical difficulty. We recommend its use by a percutaneous cerclage passer, as advocated by others (Apivatthakakul and Phornphutkul, 2012).

Conclusion

The novel figure-of-8 cable cerclage enhanced fixation stability and reduced re-displacement of the posteromedial-buttress in cephalomedullary nailing of subtrochanteric fractures when compared to more traditional cerclage configurations or no cerclage. The change in initial stiffness was more pronounced than deformation after cyclic loading. Clinically, the question remains if additional cerclage cabling promotes fracture healing and facilitates early rehabilitation in subtrochanteric fractures treated with long cephalomedullary nails. A randomised controlled study is already planned to examine these queries.

Acknowledgments

We value the illustrations by Photographer Øystein Horgmo at the University of Oslo.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not for profit sector.

Conflict of Interest Statement

All authors declare no conflict of interest.

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Legends to Figures

Fig. 1. The osteotomy of the composite left femur seen from behind.

The fourth generation of large composite femur from Sawbones® osteotomized corresponding with the 32-B2.1 AO/OTA classification of subtrochanteric fractures. The osteotomy involved a standardized, oblique cut 50° to the diaphysis, 2.5 cm below the border of the lesser trochanter in the center intramedullary. To the right the carved medial bending wedge of the posterior half with a trapezoid shape extending proximally from the osteotomy level, with a 6 cm medial and 2 cm lateral base, including the lesser trochanter. This is defined as the posteromedial buttress.

Fig. 2. The adjunctive cerclage cable configurations to intramedullary nailing.

The four groups, differing regarding any adjunctive cerclage to long cephalo-medullary nailing of subtrochanteric fractures with a posteromedial bending wedge.

From left Group A: Without fixation by cerclage the bony wedge was removed simulating malreduction or comminution. Group B: Lateral tension-band cerclage cable configuration without bony wedge. The cerclage allows increased lateral tension offloading the wedge posteromedially. Group C: Circular cerclage cable configuration around the proximal femur and wedge-shaped fragment, converting the fracture to a simple, oblique type. The cerclage keeps the posteromedial fragment reduced, enabling posteromedial compression.

Group D: The innovative figure-of-8 cerclage cable configuration crossing the posteromedial fragment proximally and distally, compressing the entire fracture gap by securing the reduced posteromedial buttress, and theoretically regaining the tolerance to posteromedial compression.

Fig. 3. The test set-ups.

To the left: Test set-up for the quasi-static sitting test with specimens oriented horizontally and with axial compression on the anterior aspect of the femoral head, simulating the direction of the hip contact force vector when sitting down. The jig-fixation just beneath the fracture isolates the deformation of femur down to the fracture site, while the nail was locked distally. To the right: Test set-up for the standing test with femur mounted vertically in 7° adduction corresponding to the direction of the joint reaction force during one leg stance phase. Proximally, the machine's actuator transferred axial compression on the femoral head by a piston simulating varus stress during weight bearing.

Tables

Table 1

Results from biomechanical tests of intramedullary nailing for subtrochanteric fractures

Adjunct (Group)		Initial stiffness sitting (N/mm)	Initial stiffness standing (N/mm)	Final deformation standing (mm)
No cerclage	A	7.4 (2.4)	308.5 (145.6)	1.3 (0.8)
Tension-band	B	8.1 (1.8)	298.3 (143.9)	1.6 (0.6)*
Circular cerclage	C	15.0 (9.8)	366.0 (85.0)	1.3 (0.4)
Figure-of-8	D	47.1 (16.5)*	631.2 (47.6)*	0.9 (0.3)*

Mean values with standard deviation (SD) in parentheses

An asterix in columns 2 and 3 indicates a statistically significant difference ($p < 0.05$) with

Bonferroni correction between Group D and each of the other Groups A-C.

In the last column the only difference is between Groups B and D, marked with an asterix

Mean pairwise comparisons showed a significant change with increasing cerclage

configuration levels B-D for each tested parameter ($p < 0.05$)

665 **Figures**

666

667 Fig. 1.

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Fig. 2.

Fig. 3.