The benefit of wire cerclage stabilisation of the medial hinge in intramedullary nailing for the treatment of subtrochanteric femoral fractures: a biomechanical study

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Abstract

Purpose Reduction and intramedullary fixation of subtrochanteric fractures is often challenging. Osteosynthesis frequently fails and a higher rate of non-unions is found. The aim of this study was to evaluate the benefit of an additional cerclage to anatomically reduce and support the medial hinge. The application is based on the experience of the surgeon; as yet no biomechanical data are available.

Methods Ten pairs of human cadaveric femora were used to determine the biomechanical and clinical advantage of an additional cerclage. All femora were tested in a materials testing system after osteotomy, osteosynthesis with the Gamma III nail and randomisation into two groups with or without additional cerclage.

Results After cyclic loading the compressive load to reach plastic deformation of 5 mm was 2,160 N on average in the group without cerclage vs 2,330 N on average in the group with cerclage. This biomechanical advantage showed no statistical significance ($p=0.2$). Radiological examination when the abort criterion was reached revealed that use of the additional wire cerclage could significantly decrease the failure of osteosynthesis (100 vs 10%) after intramedullary nailing of subtrochanteric fractures ($p<0.05$).

Conclusion In view of the more invasive operative approach with additional soft tissue injuries, application of an additional cerclage should still be considered carefully. Nevertheless, a mini-open approach to difficult fractures could be helpful in reducing the fracture with a clamp and is sometimes essential.

The damage to the soft tissue must be weighed against the benefits of the procedure. An additional cerclage in oblique subtrochanteric fractures is a good option to ensure the reposition and cortical medial support if appropriate and to decrease osteosynthesis failure and rates of non-unions.

Introduction

Fractures of the proximal femur are very common in elderly patients. Due to the population now enjoying a higher life expectancy the incidence of these fractures is increasing. In 2010, 26% of the population in Germany was older than 65 years of age. The Federal Statistical Office of Germany estimates that this percentage will almost double to 48% in 2050 [1]. This will inevitably lead to an increased number of patients with injuries of the proximal femur. These changes will similarly affect other nations. In 2008 in Germany 98,870 patients with proximal femoral fractures were documented by the Institute for Quality and Patient Safety; 93.7% of these patients were older than 60 years [2]. In the same year the mortality after operative treatment of this type of fracture was 4.7% in Germany [2]. Therefore sub- and pertrochanteric fractures still represent severe injuries in the elderly. In younger patients subtrochanteric fractures are caused by high-energy trauma; in elderly patients they occur as a consequence of low-energy trauma, for example by a fall. Due to the instability of the bone fragments and the interacting tension forces of the muscles, the operative treatment of subtrochanteric fractures is demanding. Subtrochanteric fractures tend to displace into a varus deformity due to comminution of the medial cortical buttress of the proximal femur. The strong abductors, the iliopsoas and the adductors pull the proximal fragment out of alignment and resist anatomical replacement of the fracture. Studies have

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shown that the medial buttress is key to minimise stress on the implant and to reduce fatigue fractures [3]. Depending on the classification used, 7–44% of all proximal femoral fractures can be categorised as subtrochanteric fractures according to the current literature [4, 5]. In a recent review Loizou et al. identified 15 different classification methods for subtrochanteric femoral fractures in a MEDLINE search which explains this range of incidence [6]. To achieve a stable fixation many authors recommend that subtrochanteric fractures be treated with modern intramedullary implants. Despite the use of these implants for subtrochanteric fractures, osteosynthesis frequently fails, following a cutout of the blade screw in the femoral head. In addition to this a higher rate of non-unions is found, due to varus displacement of the fragments.

A possible approach to establish a stable osteosynthesis with an intramedullary implant in subtrochanteric fractures is the application of an additional cerclage to anatomically reduce and support the medial hinge. This cerclage can help to avoid displacement of the proximal fragments or cutting out of the blade screw in the femoral head. The modification is based on experience gained in daily clinical practice. To abandon the minimally invasive approach by opening the fracture and enlargement of the surgical access certainly is a disadvantage. The benefit of an additional cerclage has not been biomechanically proven. This study intends to clarify whether there is a significant benefit in adding a wire cerclage to the fixation in subtrochanteric fractures.

Materials and methods

Ten pairs of intact, matched, adult human cadaver femora without defects were available for the study and stripped of soft tissue. They were wrapped in moist towels and stored frozen in plastic bags at -20°C until use. The femora came from the Institute of Anatomy of the University of Marburg, Germany. All body donors had consented of their own free will to the use for research purposes. The specimens were obtained from two male and eight female adults with an average age of 85.5 years. The biomechanical study was performed on a materials testing machine (series 5566, Instron Corp., Darmstadt, Germany). To assess bone quality and pathological defects an X-ray in two planes was taken of each femur before testing. Subsequently all femora were shortened to a length of 30 cm, measured from the top of the femoral head. The distal condyles were removed and the femoral shaft potted in Technovit 3040 (Heraeus, Wehrheim, Germany) into special containers. During loading the distal ends of the bone construct were statically fixed in a metal cylinder at an angle of 7° to ensure physiological conditions. The femoral head was loaded through a congruently shaped cast

acetabulum with spherical excavation. This artificial acetabulum was movable in two directions to allow eluding movements of the femoral head during loading (Fig. 1). Baseline intact stiffness was calculated (slope of displacement/load curve) for each specimen. For this purpose the intact femurs were tested with 20 compressive cyclic loads at 0.25 Hz, ramping between 200 and 1,000 N. Afterwards the regression line was calculated through the crude data points. The femora were randomised into two groups, so that five left and five right femora, respectively, were included into a group of osteosynthesis with cerclage (group A) and a group of osteosynthesis without (group B) cerclage. Before insertion of an implant a circumferential saw cut was made at an angle of 60° to the horizontal line from the bottom edge of the lesser trochanter, downwards to the lateral cortex to simulate a subtrochanteric fracture. The femora were then stabilised with a reconstruction femoral nail (200 mm $\times$ 130°, Gamma III, Stryker, Duisburg, Germany) and distally locked. According to the randomisation protocol, five left and five right femora of group B were supported by a 1.5-mm wire cerclage, 3 cm above the distal end of the osteotomy. After osteosynthesis, the femora were subjected to cyclic loading at 0.25 Hz. Ramping started between 100 and 1,500 N for 50 cycles. The maximal load was always increased after 50 cycles by 100 N without disruption; the lesser debt limit

Fig. 1 Engineering drawing of the breadboard construction. Designed with MegaCAD 3D 2009

Fig. 2 Stiffnesses (mm/kN) of the ten paired cadaveric femora in right to left comparison

remained constant during the whole loading phase. The specimens were loaded under continuous cyclic loading increases until a compression set of 20 mm was reached. This was determined as the abort criterion, just as a failure of osteosynthesis, for example a premature cutout in the femoral head. Loading dose (N), compression set (mm) and number of cycles were registered. Based on the crude data these values were determined for the calculated point of time when a plastic deformation of 5 mm was reached. The data collection was performed with the company-owned specific Instron Bluehill Software at intervals of 100 ms. The data were statistically analysed using the *t* test. The significance level was set at 0.05. After biomechanical testing a final X-ray in two planes of each femur was taken to assess the fracture behaviour. The observed results were statistically reviewed with Levene's test for equality of variances. The significance level was also set at 0.05.

Results

Stiffness testing—before osteosynthesis

In comparison with the contralateral side the stiffness testing for each sample showed a comparable stiffness with

a correlation of 0.929 in the *t* test for paired samples. Figure 2 shows the calculated bone stiffness of the ten paired femora in right to left comparison. Evaluating the absolute values, one right sample showed the greatest stiffness with 0.96 mm/kN. The least stiffness was shown also by a right sample with 1.93 mm/kN. In this connection the paired samples were comparable. The difference in comparison with the contralateral side was 0.12 mm/kN on average (range 0.01–0.35 mm/kN). In all, left samples were six times stiffer than right samples. We could not show intraindividual differences.

Cyclic load—after osteosynthesis

In this testing the abort criterion was defined as a compression set of 20 mm of the sample or a sudden loading drop of more than 20% due to failure of osteosynthesis, for example by premature breakout. With all samples the cyclic loadings were performed until the compression set of 20 mm was reached. Abortion due to failure of osteosynthesis as with a complete avulsion did not appear. The maximal compressive load at reaching a compression set of 20 mm was 2,810 N on average in group A (without cerclage). In group B (with cerclage) a related value of 2,790 N on average was reached. In this experimental design we could not find a significant difference in the loading tolerance ($p=0.87$) (Table 1). The maximum load of 4,100 N was tolerated by one sample in group B. The minimum load of 1,800 N by reaching the abort criterion was also seen in group B. Intraindividually we only saw discrete differences; abort criteria were often reached at the same load (Fig. 3).

An important biomechanical value is the plastic deformation (PD) as a measure for irreversible deformation. For all specimens we calculated the loading tolerance when a PD of 5 mm was reached because a cutout of the blade screw in the femoral head appears relatively late. Furthermore the elastic properties of the construction have to be considered. The compressive load when reaching a PD of 5 mm was 2,160 N on average in group A (without cerclage) and 2,330 N on average in group B (with cerclage). The difference of 170 N on average showed no statistical significance ($p=0.2$) (Table 1). The maximum

Table 1 Biomechanical results of the osteosynthesis of subtrochanteric fractures after loading with and without additional wire cerclage (*t* test for paired samples)

	Cerclage	Mean value	<i>n</i>	SD	Paired differences	
					Mean value	<i>p</i>
Compressive load (N) at plastic deformation of 5 mm	With	2,330	10	598.2	170	0.2
	Without	2,160	10	653.5		
Compressive load (N) when reaching the abort criterion	With	2,790	10	821.2	−20	0.875
	Without	2,810	10	633.2

Fig. 3 Compressive load (N) when reaching the abort criterion

compressive load was measured in one specimen from group A and one from group B with 3,400 N. These femora were paired. The minimum compressive load when reaching a PD of 5 mm was measured at two specimens from group A each with 1,600 N. In six of ten cases in paired comparison a higher load was required in group B (with additional cerclage) to reach a PD of 5 mm. Here the loading differences were low, except for one sample. However, they were 350 N on average. In two of ten cases the 5-mm PD were reached with the same loading compression in group A and group B at 1,900, and 3,400 N. In two of ten cases a higher load on specimens from group A (without cerclage) was necessary to reach the same PD. In these specimens the necessary additional load differed by 250 N on average. Figure 4 shows the statistical distribution of the loading compression (N) when a PD of 5 mm was reached after intramedullary osteosynthesis without (group A) and with (group B) additional cerclage.

Analysis of the samples when reaching the abort criterion

After cyclic loading all specimens were radiologically examined to evaluate the fracture behaviour when the abort criterion was reached. In group A in nine of ten cases the proximal fragment moved into varus tipping with clear widening of the fracture gap (Fig. 5). In one of ten cases the femoral shaft broke in the area of the distal locking screw. In 100% of the cases the osteosynthesis by intramedullary nail without additional cerclage failed after cyclic loading until the abort criterion was reached.

In group B, with wire cerclage, in seven of ten cases the medial buttress broke above the cerclage (Fig. 5). In two of ten cases the femoral neck fractured because of the excessive load. However, in all cases the osteosynthesis remained without failure. Varus tipping or fragment displacement did

Fig. 4 Box plot analysis of the compressive load (N) (y-ordinate) at plastic deformation of 5 mm after osteosynthesis of subtrochanteric fracture without cerclage (group A) or with cerclage (group B)

not occur. In 10% of the cases osteosynthesis failed due to cutout of the blade screw in the femoral head.

In our study the additional wire cerclage of the specimens in group B could significantly decrease the failure of osteosynthesis after intramedullary nailing of subtrochanteric fractures ($p=0.037$, Table 2).

Discussion

If axial loading forces of the proximal femur are applied, the medial cortex is under pressure and the lateral under

Fig. 5 **a** In group A in nine of ten cases the proximal fragment moved into varus tipping with clear widening of the fracture gap during cyclic loading. **b** In group B, with supplemented cerclage, in seven of ten cases the medial buttress broke above the cerclage; in all cases the osteosynthesis remained without failure

tensile loading [7, 8]. The Gamma nail acts as an intramedullary fixation. Mahomed et al. described in 1994 that the load transmission in subtrochanteric femoral fractures depends on the medial pillar when using an intramedullary nail. The medial buttress is fundamental for the stability of the osteosynthesis [9]. These modern methods of fixation offer a crucial advantage for the treatment of unstable sub- and pertrochanteric fractures in geriatric patients [10, 11]. The patients depend on immediate full weight-bearing. The multimorbidity of most of these geriatric patients means that partial weight-bearing is extremely difficult, if not impossible to practice. In addition, several studies have shown that postoperative early mobilisation after intramedullary osteosynthesis significantly reduces complications such as thromboembolism and respiratory or urinary tract infections [12–14]. Another benefit of this kind of osteosynthesis is the reduction of complications such as osteosynthesis failure, non-unions, blood loss and duration of the operation [9, 15–21]. Despite the significant reduction of complications when using an intramedullary nail, the reduction failure remains an important risk in the treatment of subtrochanteric geriatric fractures due to the challenging osteoporotic conditions of the bone.

Hohendorff et al. investigated a group of 133 patients with per-, inter- and subtrochanteric fractures and reported implant failure in 27.3% of the cases. In 8% of the cases a cutout of the neck screw occurred, and in two cases a perioperative femoral neck fracture occurred after internal fixation [22]. Fogagnolo et al. reported that the rate of cutout is about 11% [23]. Spiral fractures, in particular are very unstable, lacking the support provided by the medial buttress or the subtrochanteric comminuted area. Varus malformation increases the forces of displacement by lateralisation of the anatomical axis. Such varus bending in the fracture zone can be prevented by wire cerclage which, by reconstruction of the medial pillar restores the medial buttress. The stability of the bone-implant is particularly important for the period of postoperative early mobilisation until fracture healing. In patients with displaced medial fracture fragments, stress on the implant is

higher and healing time of bone is longer because of the large fracture gap; both predisposing to implant failure. The osteosynthesis should stabilise the fracture during a full weight-bearing period of 12 weeks, until bone healing is achieved. The implantation of an additional wire cerclage is a more invasive procedure which may lead to further complications as a consequence of additional soft tissue injuries. Furthermore, it is contrary to the concept of the minimally invasive intramedullary nailing of femoral fractures. The displacement of the proximal fragments in subtrochanteric fractures is caused by the muscle traction of the gluteus medialis and the iliopsoas. To achieve anatomical reduction in subtrochanteric fractures a mini-open approach to reduce the fracture with a clamp in combination with a fracture table can be helpful. After reduction the clamp can be replaced by a cerclage to allow uneventful insertion of the nail.

In that respect this study shows that additional cerclage makes fracture reduction more stable when reaching a plastic deformation of 5 mm. When supplying the load without cerclage, the axial load tolerance at a plastic deformation of 5 mm is 170 N lower on average. These values indicate an increase in stability in the group with cerclage, but the results are not significant. Perhaps this is related to the fracture model, in which the medial buttress is still present. Upon reaching a maximum compression set of 20 mm, which was defined as an abort criterion, there was no difference in load tolerance, which can be explained by the testing protocol after analysing the samples. Pauwels showed in 1965 that the total load on the hip joint during walking is up to two and a half to three times the body weight for the phase of the supporting leg [24], which is a load of about 2,000 N. The cyclic loading in our experiment was carried out with unrealistically high loads. Each sample had reached the termination criteria at a mean of 2,800 N. For a real fatigue test setup, obviously the number of cycles performed was too low, and the increase of the load was too high. The analysis of the samples after reaching the termination criteria showed a varus displacement with a cutout of the neck screw in 90% of the samples

Table 2 Fracture behaviour when reaching a compression set of 20 mm, which was defined as the abort criterion after cyclic loading (Levene's test for equality of variances)

	Group A without cerclage (n=10)	Group B with cerclage (n=10)	<i>p</i>
Cutout of the blade screw in the femoral head		1×	
Varus tipping	9×		
Fracture of the shaft	1×		
Fracture of the medial buttress		7×	
Fracture of the femoral neck without failure of osteosynthesis		2×	
Failure of osteosynthesis	100%	10%	0.037

without cerclage. A cutout of the neck screw in the samples with cerclage was only found in one (10%) case. This cutout phenomenon corresponds to realistic failure of proximal femur nailing, which is described in the literature as 9–15% [25]. In our study design we used the Gamma III nail, one of the most common implants, for osteosynthesis. Perhaps higher stability could be reached with two screws in the femoral head and neck fragment instead of one, as in other implant designs. This was not tested in this study. Skála-Rosenbaum et al. did not encounter any cases of cutout of screws after osteosynthesis of pertrochanteric fractures with two head screws [26]. In our samples with additional cerclage a fracture of the medial cortex was found in 70% of the cases without varus dislocation or a cutout, because the medial buttress remained (Fig. 5). In 20% of the cases an additional fracture of the femoral neck was found due to the high loading tolerance of the overall construct. In our study the additional wire cerclage can significantly decrease the failure of osteosynthesis after intramedullary nailing of subtrochanteric fractures ($p=0.037$). This represents the main result of our investigation. The additional cerclage increases the load tolerance by maintaining the medial buttress without varus deformation. It can prevent the varus displacement of the proximal femur and cutout of the neck screw. The realistic failure criteria of the samples, especially those without cerclage, affirm the fracture as well as the bone model. The initial stiffness testing of the bones showed the comparability of each right and left femur of the ten paired cadaver bones. The shaft fracture and the femoral neck fractures could be explained by the unrealistically high testing forces. Fatigue was due to the small numbers of cycles not achieved.

Conclusion

One hundred per cent of cases with intramedullary femoral osteosynthesis without cerclage failed after cyclic loading. Displacement of the fracture gap with varus deformation and cutout resulted. The wire cerclage is able to avoid these complications in subtrochanteric fractures and preserves the biomechanically important medial buttress. Despite being more invasive, the additional wire cerclage may substantially reduce the risk of osteosynthesis failure in complex fractures. The cerclage ensures the reposition and the cortical medial support enabling a better fracture healing by reducing lateral fracture opening.

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Conflict of interest The authors declare that they have no conflict of interest.

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