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CURRENT PROBLEM CASE

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Loss of correction after lateral closing wedge high tibial osteotomy – a human cadaver study

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Abstract In 12 human cadaver tibiae, osteotomies were carried out at two levels (2 and 3 cm from the distal joint line) with three different wedges (5°, 10°, 15°) to evaluate the influence of displacement of the osteotomy fragments on areas of cortical contact. In undisplaced osteotomies (medical cortical edges superposed) cortical contact areas formed 28% (level 2 cm) and 40.5% (level 3 cm) of the cortical circumference of the proximal fragments (NS). Wedge angles and levels of osteotomy displayed no statistical differences. In displaced osteotomies cortical contact decreased significantly ($P < 0.05$). Displacing the distal fragment laterally, medial cortical contact is lost, and weight-bearing leads to revarisation as cancellous bone sustains only 3 MPa, and the measured compressive stresses at the medial edge amounted to 6 MPa on average. Displacing the distal fragment medially leads to a decrease of total cortical contact, too, but at the medial edge of the osteotomy cortical contact areas are still present. As a result of the study, postoperative weight-bearing without additional plaster cast fixation is recommended only in cases with undisplaced fragments.

Introduction

High tibial osteotomy (HTO) is a well-accepted treatment for early stage osteoarthritis of the knee with reliable mid- and long-term results [1–3, 7, 11, 12, 14]. There are various operative procedures [7, 11], but a lateral closing wedge osteotomy is the one most commonly used [2].

Based on static and dynamic studies of the load distribution around the knee joint in normal knees and knees with varus/valgus deformities [9, 10] and proven by mid- and long-term studies, the goal of the operation is to produce a slight overcorrection with the mechanical axis passing through a point 30%–40% of the width of the lateral tibial plateau [11].

Despite correct intraoperative alignment, revarisation or overcorrection is detected frequently in the phase of bony healing. Loss of correction is reported to occur in 33%–68% of cases before bony healing has been established [8, 13, 16].

The aim of this human cadaver study was to define risk factors which inevitably lead to malalignment by analysing the areas of corticocancellous and pure cortical contact after osteotomy. Furthermore, the influence of different planes and wedge angles and medial or lateral displacement of the distal fragment on the cortical contact areas was evaluated.

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Materials and methods

In 12 human cadaver tibiae, we removed three different lateral wedges (5°, 10°, 15°) at two different section planes (2 cm and 3 cm below the tibial plateau). Surgery was carried out with standard operation tools using a jig to define the exact size of the wedges. We followed the operation technique described by Coventry.

The section surfaces were superposed, so that the medial edges coincided with each other and then were shifted medially/laterally by 1, 2 and 3 mm (Fig. 1). We then analysed the length and position of cortical contact (Fig. 2).

Statistical comparison was carried out using a four factorial analysis of covariance with repeated measurements (shifts). The covariable was the width of the tibia and the other three factors were zones, wedge angles and planes. The factor shift was analysed in respect of a linear and a quadratic trend. As there were only two tibiae for each combination of wedges and planes available, the resulting tests were not powerful for small significance levels. Thus, a P value < 0.2 was taken as an indication of statistical difference. For comparison of width and circumference, t-tests were used.

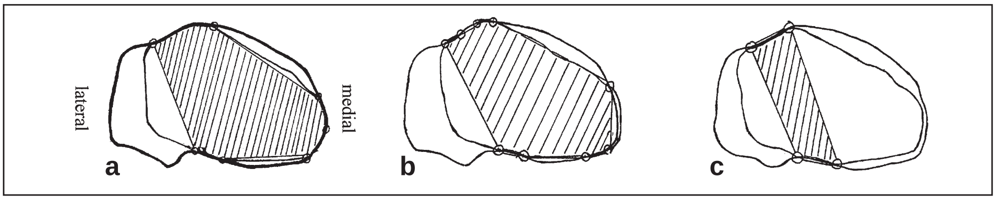

Fig. 1 a–c Schematic drawings of the tibial surfaces after osteotomy (osteotomy at level 2 cm, wedge angle 15°, areas with cortical contact *hatched*). **a** Fragments undisplaced with respect to medial cortex show cortical contact areas up to medial cortical edge. **b** Distal fragment medialized shows reduced cortical contact with contact at medial edge. **c** Distal fragment lateralized shows reduced cortical contact without contact at medial edge

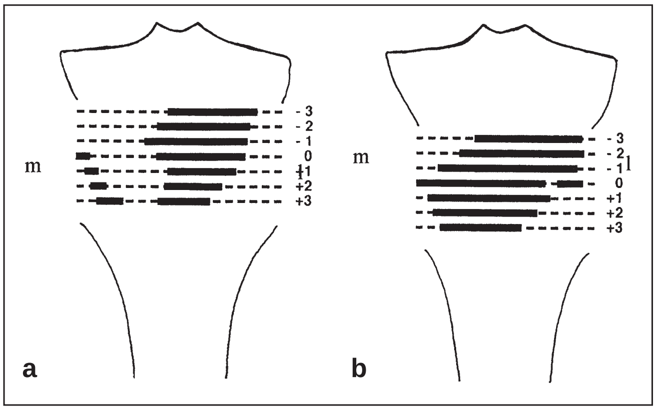

Fig. 2 Synopsis of cortical contact areas [5], section planes 2 cm (**a**) and 3 cm (**b**) below the joint line. *Bold solid lines* contact of cortical bone of proximal and distal fragment, *broken lines* corticocancellous contact; shifting of distal fragment laterally (–) and medially (+), exact superposition of medial cortical edges (0)

Results

The *width* of the 12 cadaver tibiae used for the investigation was mean 7.5 ± 0.5 cm (SD). Comparing the mean width of the tibiae with respect to the section planes 2 and 3 cm below the tibial plateau the results were 7.4 ± 0.5 cm at 2 cm and 7.7 ± 0.4 cm at 3 cm (NS). [Since the covariable width showed a small P-value ($P = 0.18$), all mean values of the tables were adjusted to the mean value of the covariable]. The *circumference* of cortical bone at level 2 cm was 18.5 ± 1.9 cm compared with 16.5 ± 1.5 cm at level 3 cm (difference < 0.05). Taking the cortical circumference of the proximal fragment as 100%, areas of cortical contact between both fragments after removal of the different wedges were 28.7% at level 2 cm and 40.5% at level 3 cm for undisplaced fragment (Table 1).

Medial displacement of the distal fragment up to 3 mm led to a continuous reduction of the cortical contact down to values of 14.2% at level 2 cm and to 21.5% at level 3 cm. *Lateral displacement* of the distal fragment reduced the cortical contact down to 13.1% (level 2 cm) and 26.1% (level 3 cm), respectively. Statistical comparison of the cortical contact reduction with respect to different levels was not significant ($P = 0.17$).

The linear and quadratic contrast of reduction of cortical contact areas resulted in a significant decrease of cortical contact ($P < 0.05$) when the distal fragment was medially or laterally displaced.

When comparing the results with respect to different wedges at level 2 cm, the cortical contact areas varied between 33.8% (5°) and 32.5% (15°) for undisplaced fragments. At level 3 cm the cortical contact areas were between 43.2% (5°) and 43.4% (15°) (Table 2).

Medialisation of the distal fragment reduced the contact areas at level 2 cm down from 13.0% to 21.3% (3 mm

Table 1 Comparison of cortical contact (in %) at different section lines (adjusted values)

	Medialisation (mm)				Lateralisation (mm)		
	–3	–2	–1	0	1	2	3
Level 2 cm	14.2	15.8	19.1	26.1	19.2	14.8	13.1
Level 3 cm	21.5	33.2	36.6	43.2	30.9	27.5	26.1

Table 2 Comparison of total cortical contact (in %) at different section lines and different angles

	Wedge angle	Medialisation (mm)				Lateralisation (mm)		
		–3	–2	–1	0	1	2	3
Level 2 cm	5°	13.8	15.6	18.6	33.8	31.1	20.8	18.1
	10°	13	14.6	11.5	19.9	17.2	12.5	11.2
	15°	21.3	24	28.8	32.5	21.8	18.6	13.3
Level 3 cm	5°	30	30.9	31.6	43.2	35.1	31.1	18.1
	10°	14.1	30.5	28.4	35	27.1	20.7	21.6
	15°	19.5	22.9	27.3	43.4	38	31.4	30.2

Table 3 Statistical analysis

Factor	*P* value
Level osteotomy	0.17
Wedge angle	0.57
Interaction Level osteotomy*Wedge angle	0.71
Covariable Width of tibiae	0.18
Displacement	0.10
Linear trend	< 0.05
Quadratic trend	< 0.05
Other trends of higher order	> 0.05

displacement). At level 3 cm the contact areas were between 14.1% and 30.0%.

Lateral displacement of the distal fragment, in comparison, reduced cortical contact down to 11.2%–18.1% (level 2 cm) and 18.1%–30.2% (level 3 cm). Statistical comparison of the cortical contact reduction with respect to different levels did not reveal a significant variation ($P = 0.71$) (Table 3).

Statistical analysis of the results with respect to the *levels of the osteotomy* (2 or 3 cm distal to joint line) showed more total cortical contact area at level 3 cm than 2 cm ($P = 0.17$) when the fragments were undisplaced. The factors *wedge angle* ($P = 0.57$) and the interaction *level of osteotomy vs wedge angle* ($P = 0.71$) were statistically insignificant.

When comparing the cortical contact areas in displaced cases, the linear and the quadratic components were significantly different ($P < 0.05$) and showed maximal cortical contact in undisplaced cases, and higher cortical contact when the distal fragment was displaced medially compared with laterally.

Discussion

In addition to other factors such as preoperative extent of osteoarthritis and body weight of the patients, good long-term results after HTO depend to a great extent on the correct postoperative alignment of the leg. After a follow-up period of 11.5 years, Hernigou et al. [7] reported 100% good results where the knee axis was aligned correctly and only 26% good results in the group of patients who were under- or overcorrected. Rudan and Simurda [14] after 5.8 years found a success rate of HTO in 88% for correctly aligned and only 37.5% for incorrectly aligned patients. In a 10-year follow-up examination, Coventry et al. [3] found 87% good results in correctly aligned and only 63% good results in incorrectly aligned HTOs. These three reports emphasize the need for correct alignment for good mid- and long-term results.

In the literature, there are different operative techniques concerning the medial cortical edge. While some authors favour a surgical technique which leaves the medial cortex intact [11], others [2] describe the medial cortex being broken in a greenstick manner by exerting a valgus force after completion of the osteotomy. Engel and Lippert [4] in their analysis of the pitfalls of valgus tibial osteotomy advise making multiple drill holes into the medial cortex after removal of the wedge in order to produce a greenstick fracture.

Our clinical experience with HTOs is that only in cases with correction angles of less than 10° was it possible to leave the medial cortical edge without displacement. In all other cases a medial displacement of the distal fragment took place when driving in the staples to perform osteosynthesis. Lateralisation of the distal fragment, in contrast, occured at the time of inserting screws and compressing the osteotomy.

As osteosynthesis after HTO is usually performed with staples or blade-plates without sufficient stability, many authors prefer an additional plaster immobilisation of the operated leg for 6–8 weeks to avoid revarisation or overcorrection.

Although osteotomies performed 2 cm distal to the joint line show a significantly greater cortical circumference, cortical contact areas after osteotomy were higher in osteotomies performed at level 3 cm (NS).

The amount of the wedge removed has no significant influence on the cortical contact areas.

The main problem is a lateral displacement of the distal fragment. In this situation the cortical contact areas are significantly reduced (Figs. 1 and 2) and combined with loss of cortical contact areas at the medial edge of the osteotomy. This is different in cases with a medially displaced distal fragment where there is still sufficient cortical contact at the medial edge.

In a laterally displaced position, the cancellous bone cannot sustain the compressive stress of weight-bearing, which is about 6 MPa. This consequently leads to a caving-in on the medial side and loss of correction as the maximal compressive stress sustained by cortical bone is 175 MPa, whilst cancellous bone only sustains 3 MPa [5].

If the medial cortical edge shows any *signs of displacement* of the fragments on intraoperative X-rays, the patient should not bear weight on the operated leg until bony healing is evident on follow-up X-rays. Additional fixation in a plaster cast is recommended.

If the fragments of the osteotomy are *not displaced*, weight-bearing may be allowed sooner due to the cortical contact at the medial edge. Additional plaster fixation is not necessary.

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