The effect of closed- and open-wedge high tibial osteotomy on tibial slope
A RETROSPECTIVE RADIOLOGICAL REVIEW OF 120 CASES

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Radiographs of 110 patients who had undergone 120 high tibial osteotomies (60 closed-wedge, 60 open-wedge) were assessed for posterior tibial slope before and after operation, and before removal of the hardware. In the closed-wedge group the mean slope was 5.7° (SD 3.8) before and 2.4° (SD 3.9) immediately after operation, and 2.4° (SD 3.4) before removal of the hardware. In the open-wedge group, these values were 5.0° (SD 3.7), 7.7° (SD 4.3) and 8.1° (SD 3.9) respectively, when stabilised with a non-locking plate, and 7.7° (SD 3.5), 9.4° (SD 4.1) and 9.1° (SD 3.8), when stabilised with a locking plate. The reduction in slope (-2.7° (SD 4.1)) in the closed-wedge group and the increase (+2.5° (SD 3.4), in the open-wedge group was significantly different before and after operation (p = 0.002, p = 0.003). In no group were the changes in slope directly after operation and before removal of the hardware significant (p > 0.05). There was no correlation between the amount of correction in the frontal plane and the post-operative change in slope.

Posterior tibial slope decreases after closed-wedge high tibial osteotomy and increases after an open-wedge procedure because of the geometry of the proximal tibia. The changes in the slope are stable over time, emphasising the influence of the operative procedure rather than of the implant.

In patients with unicompartmental medial osteoarthritis of the knee, high tibial osteotomy improves alignment and weight distribution in the frontal plane.1,4 Following the paper by Jackson in 1958,5 high tibial osteotomy was usually performed by removing a lateral bony wedge from the proximal tibia.1,2,4 The procedure also required an osteotomy of the fibula or release of the proximal tibiofibular joint and internal fixation, most frequently using conventional plates.1,2 An open-wedge procedure3 was also practised to a lesser degree, but has become more popular during the last few years, especially with the development of interlocking plates.6,7

Both methods primarily involve the frontal plane, but also affect the posterior tibial slope.

Closed-wedge high tibial osteotomy reduces the tibial slope by approximately 5°8 and open-wedge procedure increases the slope by approximately 3° to 4°,9,11 which in neither case significantly alters the forces on intact cruciate ligaments.12 However, in cruciate deficiency, the tibial slope is biomechanically relevant to femorotibial translation. With anterior cruciate ligament (PCL) deficiency an increased tibial slope reduces posterior tibial subluxation by shifting the resting position of the tibia anteriorly, and has a beneficial effect.12,13 With cruciate deficiency, the altered tibial shift can also change the pressure distribution and thus has a positive effect on damage to the local cartilage.9,12

The purpose of this study was to compare changes in the posterior tibial slope after lateral closing- and medial opening-wedge high tibial osteotomies in a statistically significant number of patients. Our hypotheses were a) the posterior tibial slope decreases after closed-wedge high tibial osteotomy and increases after open-wedge high tibial osteotomy; b) in closed-wedge high tibial osteotomy the reduction in posterior tibial slope is stable over time; c) in open-wedge high tibial osteotomy the increase in posterior tibial slope is stable over time if interlocking implants are used and with non-interlocking implants, the increase changes with time; and d) there is no correlation between the amount of correction in the frontal plane and the degree change in the posterior tibial slope.

Patients and Methods
We analysed the radiographs of 120 knees in 110 patients with medial compartment...
osteoarthritis treated by high tibial osteotomy. There were 79 men with a mean age of 45 years (SD 5.7) and 31 women with a mean age of 47.2 years (SD 3.6). There were 57 right knees, 63 left, and ten cases were bilateral. Standard anteroposterior and lateral radiographs were obtained pre-operatively, directly after operation (SD 3 days), at the time of bony consolidation and in most cases at the time of removal of the hardware at a mean of eight months (SD 15.0). On the lateral radiograph, the posterior tibial slope was measured according to the method of Brazier et al14 (Fig. 1), with the knee in 30° of flexion without rotation of the limb and with the beam centred at the joint line. The aim was congruency of the posterior condylar lines with a tolerance of 5 mm. Otherwise, the radiographs were repeated or the patients excluded to avoid errors of measurements. On the post-operative anteroposterior radiograph with the knee straight and the patella directed anteriorly, angulation in the frontal plane was measured using digital X-ray software (Sectra Image Viewer, Philips medical systems, Best, Netherlands).

The indications for high tibial osteotomy were medial osteoarthritis with varus malalignment in 111 cases, and
localised cartilage damage in the medial compartment with varus malalignment in nine. It was a single procedure in 113 cases and combined with cartilage treatment in seven. A total of 60 knees underwent closed-wedge high tibial osteotomy, and 60 an open-wedge procedure (30 cases with non-interlocking and 30 with interlocking implants). The operations were performed between January 2000 and December 2006. Before 2003, closed-wedge high tibial osteotomy was the preferred technique but the development of implants, instrumentation and operative technique has made open-wedge high tibial osteotomy more popular. The mean angle of correction overall was 5.7° (SD 2.1).

In closed-wedge high tibial osteotomy, the proximal tibiofibular joint was preserved through an oblique osteotomy of the head of fibula after release of the extensor muscles. The transverse tibial osteotomy runs approximately 2 cm below the joint line. The wedge was resected with a calibrated cutting device (Zimmer Germany GmbH, Freiburg, Germany) and the osteotomy fixed with a conventional compression plate (L-plate, Zimmer Germany GmbH, Freiburg, Fig. 2). Open-wedge high tibial osteotomy was performed medially approximately 4 cm below the joint line, with gradual opening of the osteotomy to preserve a bony bridge laterally. The osteotomy was fixed with a non-locking plate in 30 cases (Puddu Plate, Arthrex, Karlshfeld, Germany, Fig. 3) and a locking compression plate (Tomofix, Synthes, Umkirch, Germany) in 30 cases (Fig. 4).

**Statistical analysis.** The three values for posterior tibial slope (before and immediately after operation and before removal of the hardware) were compared in each group with a paired t-test. A simple regression analysis (Statview 4.5, Abacus Concepts, Berkeley, California) determined whether the degree of correction in the frontal plane had a significant effect on the change in posterior tibial slope after operation in each of the three groups.
Results

The mean posterior tibial slope of the 120 knees before operation was 6.0° (SD 3.8). In the closed-wedge group, the mean slope was 5.7° (SD 3.8) before and 2.4° (SD 3.9) after operation, and 2.4° (SD 3.4) before removal of the hardware. In the open-wedge group, the mean slopes were 6.4° (SD 3.8), 8.5° (SD 4.2) and 8.6 (SD 3.8) respectively (Table I).

The reduction in the slope in the closed-wedge group (-2.7° (SD 4.1)) was statistically significant between before and directly after operation (p = 0.002), but was not significant between the latter and before removal of the hardware (-0.1° (SD 3.8); p = 0.91, Table I). In the open-wedge group, those high tibial osteotomies stabilised with a non-locking plate showed a mean posterior tibial slope of 5.0° (SD 3.7) before operation, 7.7° (SD 4.3) directly after, and 8.1° (SD 3.9) at the time of removal of the hardware. In those cases stabilised with a locking plate the values were 7.7° (SD 3.5), 9.4° (4.1) and 9.1° (SD 3.8), respectively. The increase in the slope in the open-wedge group (2.5° (SD 3.4)) was statistically significant between before and directly after operation (p = 0.003), but was not significant between the latter and before removal of the hardware (0.4° (SD 2.8), p = 0.83; Table I).

The magnitude of the change in the frontal plane did not correlate with the change of posterior tibial slope in each of the three groups (closed wedge: p = 0.74; open wedge, non-locking plate: p = 0.78; open wedge, locking-plate: p = 0.90, Fig. 5).

Discussion

Our hypotheses were largely confirmed. The posterior tibial slope decreases after closed-wedge and increases after open-wedge high tibial osteotomy. The changes in slope after both methods are stable over time. The degree of correction in the frontal plane does not correlate with the change in slope. We were wrong to suggest that the increase in the slope after open-wedge high tibial osteotomy is greater over time with non-interlocking implants than with interlocking implants.

A possible explanation for the reduction in the slope after closed-wedge osteotomy is the geometry of the proximal tibia, which is triangular with the apex directed anteriorly. As the wedge is not excised strictly laterally and perpendicular to the anatomical axis, a wedge from the anterolateral part of the proximal tibia results in more bone being removed anteriorly, leading to a reduction in the slope. This effect might be enhanced by subsequent compression during loading.8,15

The explanation for an increase in slope after open-wedge high tibial osteotomy is also anatomical; the anteromedial cortex of the proximal tibia is angulated 45° to the posterior cortex, whereas the lateral cortex is nearly perpendicular to the anatomical axis, a wedge from the anterolateral part of the proximal tibia results in more bone being removed anteriorly, leading to a reduction in the slope. This effect might be enhanced by subsequent compression during loading.8,15

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Alterations in the tibial slope showed a decrease after closed-wedge high tibial osteotomy by 2.7° and an increase after open-wedge high tibial osteotomy by 2.5°, both directly after operation and at the time of removal of the hardware. Our results correspond to those of Hohmann et al.8 who found a mean reduction in posterior tibial slope of 4.9° after closed-wedge high tibial osteotomy. Our open wedge results are similar to those of Giffin et al.12 who demonstrated increases of the posterior tibial slope of 3.5° to 4.2° in open-wedge high tibial osteotomy. We found no data on the effect of non-interlocking versus interlocking implants with regard to changes in slope after open-wedge high tibial osteotomy.

Many authors have discussed the consequences of changes in the tibial slope after high tibial osteotomy. Hernigou et al.3 considered that changes in the angle of inclination of the tibial plateau cause instability and excessive tibial translation in the sagittal plane and may be another cause of progression of osteoarthritis. Also, unintended alterations of posterior tibial slope after high tibial osteotomy in stable knees cause changes in biomechanics and kinematics, with relatively negative consequences because of concentration of load in a particular region.3

Biomechanical studies have shown three main effects of changes in slope after high tibial osteotomy. The first is, either anterior or posterior tibial translation. Agneskirchner et al.10 and Giffin et al.12 showed a linear relationship between tibial slope and tibial translation during unilateral weight-bearing: the greater the angle of slope the greater the anterior translation in ACL-intact and ACL-deficient knees. Consequently, the lower the angle, the lower the anterior translation of the tibia.9,12 The second effect is a change in distribution of the mechanical load on the articular surface. The increased slope after open-wedge high tibial osteotomy results in anterior translation of the tibial plateau, leading to an anterior shift of the tibiofemoral contact area with decompression of the posterior femoral condyle, whereas a reduction of the tibial slope in closed-wedge high tibial osteotomy results in exaggerated loading posteriorly.9 The third effect is on extension of the knee, which is reduced after open-wedge and increased after closed-wedge high tibial osteotomy. This effect should be considered preoperatively in patients with limited extension.16 Notwithstanding all these considerations, there is a notable limitation associated with most studies involving radiological measurement of the posterior tibial slope. Radiographs that are not truly lateral may include errors. The posterior tibial slope measured with a conventional technique shows variations depending on the rotation of the tibia in the lateral view.17 This problem could be overcome by CT scans, which are independent of rotation but not suitable for routine clinical use. Therefore, exact lateral radiological views as described earlier are essential.

Although it seems difficult to combine patients with different corrections, we among others,8,10 confirmed that in both closed- and open-wedge high tibial osteotomy, the magnitude of bony correction in the frontal plane has no significant effect on the post-operative posterior tibial slope.

How does one maintain the normal slope when alteration is not indicated? Giffin et al.12 recommended that the height of the osteotomy should always be greater at the posteroomedial cortex than at the tibial tuberosity. Noyes et al.11 advised that the opening gap at the tibial tuberosity should be approximately half of the gap at the posteroomedial cortex in order to maintain the normal slope. Earlier, Hernigou et al.3 emphasised that to minimise changes in the posterior tibial slope it is necessary to place the plate as close as possible to the posteroomedial corner and perform a complete posterior osteotomy.

Our findings may help resolve the uncertainties regarding the tibial slope in high tibial osteotomy.16

References