High tibial osteotomy with a dynamic axial fixator

PRECISION IN ACHIEVING ALIGNMENT

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We report the outcome of 32 patients (37 knees) who underwent hemicallostasis with a dynamic external fixator for osteoarthritis of the medial compartment of the knee. There were 16 men (19 knees) and 16 women (18 knees) with a mean age at operation of 54.6 years (27 to 72). The aim was to achieve a valgus overcorrection of 2° to 8° or mechanical axis at 62.5% (± 12.5%). At a mean follow-up of 62.8 months (51 to 81) there was no change in the mean range of movement, and no statistically significant difference in the Insall-Salvati index or tibial slope (p = 0.11 and p = 0.15, respectively). The mean hip-knee-ankle angle changed from 190.6 (183° to 197°) to 176.0° (171° to 181°), with a mean final position of the mechanical axis of 58.5% (35.1% to 71.2%).

The desired alignment was attained in 31 of 37 (84%) knees. There were 21 excellent, 13 good, two fair and one poor result according to the Oxford knee score with no correlation between age and final score. This score was at its best at one year with a statistically significant deterioration at two years (p = 0.001) followed by a small but not statistically significant deterioration until the final follow-up (p = 0.17). All the knees with Ahlback grade 1 osteoarthritis had excellent or good results. Complications included pin tract infections involving 16.4% of all pins used, delayed union in two, knee stiffness in four, fracture of the lateral cortex in one and ring sequestrum in one.

In conclusion, hemicallostasis provides precision in attaining the desired alignment without interfering with tibial slope or patellar height, and is relatively free of serious complications.

Since its introduction by Jackson, high tibial osteotomy (HTO) has become established as treatment for medial compartment osteoarthritis of the knee. The conventional laterally based closing wedge osteotomy can be technically demanding, although it remains popular. It may also be associated with complications such as peroneal nerve palsy, over- or under-correction, compartment syndrome, infection and intra-articular fracture. The method of correction has evolved with the introduction of the Maquet dome osteotomy, the medial opening wedge osteotomy and the hemicallostasis technique. It has long been recognised that the best results of HTO are related to the precise correction of malalignment, whatever technique is used.

Preliminary reports of HTO using the hemicallostasis technique have been favourable. Furthermore, concerns have been raised about alterations to the tibial slope and patellar dynamics, and subsequent conversion to total knee replacement after closed wedge osteotomy. This study aimed to evaluate the functional results of HTO using a unilateral external fixator and the precision afforded in achieving the desired alignment.

Patients and Methods
This prospective case series involved patients undergoing treatment for osteoarthritis of the medial compartment with hemicallostasis at a tertiary care hospital. HTO with the application of a dynamic axial fixator was performed in all patients by the same surgeon (SSS). A total of 41 knees in 36 patients were operated on between October 2003 and May 2006, but three patients (three knees) were lost to follow-up. For the purposes of this study, the patients were divided into two groups: those operated on before October 2003 (pre-intervention group) and those operated on after October 2003 (intervention group).

All patients were assessed pre- and post-operatively using the Oxford knee score. The functional outcome was assessed using the Short Form-36 (SF-36) questionnaire, and radiographs were taken to assess the alignment of the osteotomy and any complications.

Results
A total of 41 knees in 36 patients were assessed. The mean age of the patients was 54.7 years (range 27 to 72) and the mean follow-up was 62.8 months (range 51 to 81). The mean Insall-Salvati index was 0.68 (range 0.47 to 0.87) pre-operatively and 0.71 (range 0.49 to 0.87) post-operatively. The mean tibial slope was 8.5° (range 5° to 12°) pre-operatively and 8.0° (range 5° to 11°) post-operatively. The mean hip-knee-ankle angle was 189.6° (range 183° to 197°) pre-operatively and 176.0° (range 171° to 181°) post-operatively. The mean mechanical axis was 60.2% (range 35.1% to 71.2%) pre-operatively and post-operatively.

The patients were divided into two groups: those operated on before October 2003 (pre-intervention group) and those operated on after October 2003 (intervention group). The pre-intervention group consisted of 21 patients (23 knees) and the intervention group consisted of 15 patients (18 knees). The mean age of the pre-intervention group was 53.8 years (range 27 to 72) and the mean follow-up was 62.5 months (range 51 to 81). The mean age of the intervention group was 55.2 years (range 27 to 72) and the mean follow-up was 63.0 months (range 51 to 81). The mean Insall-Salvati index was 0.69 (range 0.47 to 0.87) pre-operatively and 0.71 (range 0.49 to 0.87) post-operatively. The mean tibial slope was 8.4° (range 5° to 12°) pre-operatively and 8.0° (range 5° to 11°) post-operatively. The mean hip-knee-ankle angle was 189.6° (range 183° to 197°) pre-operatively and 176.0° (range 171° to 181°) post-operatively. The mean mechanical axis was 60.3% (range 35.1% to 71.2%) pre-operatively and post-operatively.

The patients were assessed using the Oxford knee score and the SF-36 questionnaire. The mean Oxford knee score was 33.4 (range 15 to 50) pre-operatively and 45.2 (range 25 to 60) post-operatively. The patients were divided into two groups: those operated on before October 2003 (pre-intervention group) and those operated on after October 2003 (intervention group). The mean Oxford knee score was 34.5 (range 15 to 50) pre-operatively and 45.0 (range 25 to 60) post-operatively for the pre-intervention group. The mean Oxford knee score was 33.3 (range 15 to 50) pre-operatively and 46.0 (range 25 to 60) post-operatively for the intervention group.

The patients were assessed using the SF-36 questionnaire. The mean SF-36 score was 43.3 (range 15 to 60) pre-operatively and 55.2 (range 25 to 60) post-operatively. The patients were divided into two groups: those operated on before October 2003 (pre-intervention group) and those operated on after October 2003 (intervention group). The mean SF-36 score was 44.5 (range 15 to 60) pre-operatively and 55.0 (range 25 to 60) post-operatively for the pre-intervention group. The mean SF-36 score was 43.0 (range 15 to 60) pre-operatively and 56.0 (range 25 to 60) post-operatively for the intervention group.

Complications included pin tract infections involving 16.4% of all pins used, delayed union in two, knee stiffness in four, fracture of the lateral cortex in one and ring sequestrum in one.

In conclusion, hemicallostasis provides precision in attaining the desired alignment without interfering with tibial slope or patellar height, and is relatively free of serious complications.
three, and post-traumatic in three. The pre-operative medial compartmental Ahlback grade was 1 in 12 knees, 2 in 16 knees and 3 in nine knees. All the patients in the study gave informed consent.

Patients were evaluated with standard anteroposterior (AP) weight-bearing and lateral radiographs of both knees by two authors (VB, NJ). Full-length weight-bearing radiographs from hip to ankle were also obtained. The mechanical axis of the lower limb was drawn on these films. This is the line joining the centre of the femoral head and ankle, as described by Moreland, Bassett and Hanker, and the position where this axis crossed the tibial plateau was measured and presented as a percentage of the total width of the tibial articular surface, with the medial margin as 0% and the lateral as 100%. The femorotibial angle (FTA) and hip-knee-ankle (HKA) angle were also measured on the same radiographs. The aim was to achieve a final valgus overcorrection of 2° to 8°, as described by Dugdale, Noyes and Styer. The Insall-Salvati index and tibial slope were estimated on lateral radiographs, the latter as described by Moore and Harvey.

Surgery was conducted under spinal or general anaesthesia. All patients received cefoperazone and sulbactum intravenously before inflation of the tourniquet and this was followed monthly and the fixator was retained until signs of solid callus formation were evident on radiographs. Further care involved cleaning with saline alone and the use of antiseptic and occlusive dressing at sites showing any of the signs of infection mentioned above.

In addition to measuring the alignment of the limb (HKA, FTA, mechanical axis), function was assessed using the Oxford knee score (OKS), which was collected at the end of the first, second and fourth years and at the latest follow-up. In bilateral cases, this score was assessed at these same intervals after the second operation.

Statistical analysis. This was performed using the IBM SPSS v.19 software (SPSS Inc., Chicago, Illinois). Pre-operative FTAs, HKA angles, tibial slope, Insall-Salvati index, and the mechanical axis were compared with the values at final follow-up using the paired t-test. The Pearson correlation coefficient was examined for relationships between the FTA, HKA, mechanical axis and OKS at final follow-up. The change in the post-operative OKS for each knee over time was assessed by comparing the scores at one, two and four years and at final follow-up. Paired t-test was used for this comparison. A p-value < 0.05 was considered statistically significant.

Results

The mean follow-up was 62.8 months (51 to 81). For bilateral procedures the mean interval between operations was 5.6 weeks (4 to 8), determined by the ability of the patient to bear full weight on the first operated knee, without using crutches or a stick.

In the 37 knees reviewed, there was no significant difference between the mean arc of flexion before operation (132.6°) and after operation (132.9°). The pre-operative flexion contracture decreased in four knees, increased in two and remained unchanged in the remainder.

The mean HKA angle pre-operatively was 190.6° (183° to 197°). Our goal was to achieve an angle of 175° (± 3°) post-operatively (Table I). Measured on the lateral side, this range amounts to 2° to 8° of valgus overcorrection (beyond the neutral angle of 180°). The mean HKA angle post-operatively was 176.0° (171° to 181°), and the mean correction was 14.5° (6° to 24°). Our target was achieved in 31 of 37 knees (84%). There was undercorrection in five knees (mean 179.8° (179° to 181°)) and overcorrection in one (169°). Pre-operatively the mean position of the mechanical axis was at 5.97% (-20% to 32.5%), and our intention was to correct it to 62.5% (± 12.5%). The mean final position was 58.52% (35.1% to 71.2%) (Table I). The mean changes in the Insall-Salvati index and tibial slope were not statistically significant. A typical good result is shown in Figure 3.

The mean OKS was 43.05 (25 to 54) pre-operatively and 19.11 (12 to 41) at the final review. There was a general trend towards a deterioration in the OKS with time, but
this only showed statistical significance between the first and second post-operative years (Table II). This trend was also followed in a subset of patients with different Ahlback grades, with lower grades showing slightly better outcomes (Table III).

The final HKA angles and OKSs showed a positive correlation (Pearson correlation coefficient, $r = 0.68$), confirming a relationship between the alignment achieved and the reported outcome. There were similar trends with the FTA and the mechanical axis ($r = 0.49$).
Figures 2a and 2b – radiographs showing the osteotomy immediately after the procedure (a) and at full correction after distraction for four weeks (b). Figures 2c and 2d – full-length radiographs of the same patient comparing pre-operative (c) with final alignment (d).

<table>
<thead>
<tr>
<th></th>
<th>Pre-operative</th>
<th>Final follow-up</th>
<th>Change</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HKA (°)</td>
<td>190.57 (183 to 197)</td>
<td>175.03 (171 to 181)</td>
<td>-14.54</td>
<td>&lt; 0.001</td>
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<tr>
<td>Mechanical axis (°)</td>
<td>5.97 (-20.0 to 32.5)</td>
<td>58.52 (35.1 to 71.2)</td>
<td>+52.55</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>FTA (°)</td>
<td>184.97 (177 to 194)</td>
<td>170.81 (165 to 176)</td>
<td>-14.16</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Insall-Salvati index</td>
<td>0.997 (0.81 to 1.21)</td>
<td>1.003 (0.81 to 1.21)</td>
<td>+0.006</td>
<td>0.11</td>
</tr>
<tr>
<td>Tibial slope (°)</td>
<td>10.13 (6 to 23)</td>
<td>10.46 (6 to 21)</td>
<td>+0.33</td>
<td>0.15</td>
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</table>

* paired t-test

**Table I** The mean (range) measures of alignment: the hip-knee (HKA) angle, mechanical axis, femorotibial angle (FTA), Insall-Salvati index and tibial slope angle. The change in the mean values is presented.

and $r = -0.58$, respectively), from which we conclude that any of the three measures of alignment proved reliable, although the HKA angle showed a much better correlation.

The final results according to the OKS showed 21 excellent, 13 good, two fair, and one poor result (Table III). There was a poor correlation between the patient’s age and final OKS ($r = 0.21$).
The time to complete distraction and achievement of the desired alignment varied according to the amount of correction required, with a mean duration of 4.04 weeks (2.5 to 7). The mean time to union and removal of the fixator was 16.3 weeks (11 to 30). Two knees had delayed union of the osteotomy requiring 29 and 30 weeks, for sound union, respectively, but ultimately both knees had excellent outcomes. Excluding these two, the mean time to union was 15.6 weeks (11 to 21). In 21 of 29 knees for which the time to achieve full unassisted weight-bearing had been documented, this was achieved within the first four weeks post-operatively.

The most frequent complication was pin tract infection. A total of 29 of 177 pins (16.4%) in 23 patients had evidence of infection. Cultures were taken in cases of discharge. All pin tract infections except one were grade 1 or 2 (Otterburn classification) and were treated with either pin tract care (daily cleaning of pin sites with normal saline followed by cleansing with alcohol based sterilising agents) or pin tract care with oral antibiotics (second-generation cephalosporins). One patient developed a sequestrum at the diaphyseal pin site which healed after curettage and a one-week course of oral cefuroxime. There was limitation of movement in four knees; this resolved with physiotherapy (Table IV).

**Discussion**

The success of HTO depends on achieving the desired alignment with precision and without creating malalignment in other planes. Insall, Joseph and Misika recommended a post-operative femorotibial angle of 170° (± 5°), whereas Coventry et al recommended a range from 170° to 167°. Navigation has been applied to both opening- and closed-wedge HTO with very good results with regard to attaining the desired alignment. Nevertheless, the cost-effectiveness of navigation and whether it can be used with a dynamic axial fixator need to be determined.

Without navigation, we obtained the desired alignment with HKA angle of 172º to 178º (175° ± 3°) in 31 of 37 knees (84%). Coventry et al in a long term study of 87 knees observed that inadequate correction was a major cause for failure of HTO. They recommended a minimum overcorrection of the FTA by 8º of valgus (equivalent to 2º valgus for HKA angle). Although failure in overcorrected knees has not been as frequently documented as that in undercorrected knees, too much valgus can create an unacceptable cosmetic deformity. Thus we have followed the recommendations of previous authors regarding the upper limit of correction.

Weale et al were able to achieve satisfactory alignment in only 61% of patients at six years’ follow-up. Magyar et al were able to achieve the intended correction in 18 of 25 patients (72%) treated with hemicallostasis at two years, compared with ten of 25 patients treated with closed-wedge osteotomy.

The most appropriate time to allow full weight-bearing post-operatively has been a matter of debate. Although recently published data suggest that early full weight-bearing can be allowed in open- and closed-wedge HTO stabilised with newer forms of fixation, traditional advice has been to delay full weight-bearing until six to 12 weeks. However, these recent studies included only cases with a varus deformity < 12° in the mechanical axis or < 5° in the anatomical axis, criteria that would have preselected patients in whom stability at the osteotomy site would have been relatively easy to achieve.

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**Table II.** The mean (range) Oxford knee score (OKS) for all 37 knees at different follow-up intervals

<table>
<thead>
<tr>
<th>Year</th>
<th>Pre-operative</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>Final follow-up</th>
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<tbody>
<tr>
<td>OKS</td>
<td>43.05 (25 to 54)</td>
<td>17.16 (12 to 30)</td>
<td>18.73 (12 to 30)</td>
<td>19.16 (12 to 41)</td>
<td>19.11 (12 to 41)</td>
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<tr>
<td>p-value*</td>
<td>--</td>
<td>--</td>
<td>0.001</td>
<td>0.08</td>
<td>0.74†</td>
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<tr>
<td>† comparison with scores at two years</td>
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<td>‡ comparison with scores at four years</td>
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</table>

| Table III. Results according to Oxford knee score (OKS) and Ahlback grade |
|--------------------------|----------------|----------------|----------------|-----------------|
| OKS | I | II | III | Total |
| Excellent (12 to 20) | 10 | 10 | 1 | 21 |
| Good (21 to 30) | 2 | 4 | 7 | 13 |
| Fair (31 to 40) | 0 | 2 | 0 | 2 |
| Poor (41 to 60) | 0 | 0 | 1 | 1 |

| Table IV. Complications |
|------------------------|-------------------|
| Complications | Pins/Patients |
| Pin tract infection | 29 of 177 pins |
| | 23 of 37 patients |
| Lateral cortex fracture | 1 |
| Delayed union | 2 |
| Knee stiffness | 4 |
| Ring sequestrum | 1 |
| Deep infection/chronic osteomyelitis | 0 |
| Intra-articular fractures | 0 |
| Neurovascular injury | 0 |
| Symptomatic deep-vein thrombosis | 0 |
In hemicallotasis, stability at the osteotomy site is not compromised to any great extent owing to gradual distraction and simultaneous callus formation. Moreover, the dynamic axial fixator resists angular and rotational displacements in a fashion similar to angle stable internal fixation devices. Magyar, Toksvig-Larsen and Lindstrand showed in a radiostereometric analysis of patients, randomised to undergo closed-wedge osteotomy or hemicallotasis, that hemicallotasis with an external fixator yielded much more stable correction than closed-wedge osteotomy stabilised with staples and a long-leg cast, but they began their comparison after removal of the external fixation or plaster cast. Recently, no difference was found in the stability of closed- or open-wedge osteotomies stabilised with angle stable internal fixation, but it was observed that an increase in the tibial slope of > 1° occurred after six weeks, when weight-bearing was started. Although we encouraged early full weight-bearing, it was delayed in one knee which was complicated by an inadvertent lateral cortex breach by the osteotomy. In the remaining 36 knees, early full weight-bearing was started as tolerated after the third or fourth post-operative day.

Both closed- and open-wedge osteotomy have been shown to cause patella baja, which happens infrequently with hemicallotasis, making conversion to total knee replacement easier than with other techniques. The change in patellar height has been attributed to fibrosis caused around the operative field, which might be reduced by earlier mobilisation. The tibial slope decreases after closed wedge and increases after open wedge osteotomy, whereas it is relatively unaffected by hemicallotasis. These changes are attributable to various factors, including the triangular cross-sectional profile of the tibia with the apex pointing anteriorly, placement of the plate too anteriorly in open-wedge osteotomy, and less wedge resected posteriorly in closed-wedge osteotomy.

Another possible cause for an increase in tibial slope after HTO can be premature weight-bearing, although this can affect both open- and closed-wedge procedures. Although the long-term effects of these changes in tibial slope on the ligaments are inconclusive, it is considered that they either destabilise or stabilise the knee in the sagittal plane.

This study shows minimal alterations in the tibial slope and patellar height after opening-wedge osteotomy using a dynamic axial fixator.

The major concern with hemicallotasis is pin tract infections with possible consequences for future joint replacement. Variable rates of such pin tract infections with hemicallotasis, ranging from 8% to 60% have been reported. Another concern has been the time required for the fixator to be in situ, which has been acknowledged previously as a cause of patient dissatisfaction. Low pulse field ultrasound has been shown to accelerate healing but was not applied in our series. Lateral cortical fracture is another complication which has been reported infrequently. Ohsawa et al reported ten cases in 44 knees, which encouraged them to change from using an oscillating saw for a transverse osteotomy to using an osteotome for an oblique osteotomy. In all cases we used a corticotome (S.H. Pitkar Orthotools) for an oblique osteotomy directed towards Tibiofibular joint, with the rationale of avoiding problems with lateral cortex fracture and problems with proximal Tibiofibular joint pain while correcting large deformities, and only sustained one lateral cortical fracture. A lateral cortex fracture destabilises the proximal fragment and can lead to malalignment and problems with bony union. In acute corrective osteotomies this complication has been commonly described. In a retrospective analysis of 85 patients treated with medial open wedge HTO fixed with two different internal fixation devices, high rates of potentially serious complications such as lateral tibial head infarction, implant failure, infection and deep-vein thrombosis were observed. Lateral tibial head infarction occurred with increased frequency in patients requiring > 12° of correction, which was easily achieved in our series. Implant failure necessitating surgery to remove the implant is again avoided with hemicallotasis.

A complication rate of 36.9% has been reported following opening-wedge HTO. Despite its high incidence of complications, open-wedge HTO is perhaps the most popular method in use today, and we are unaware of any series comparing it with hemicallotasis. Although results after HTO are known to deteriorate with time, it is also acknowledged that the results tend to deteriorate more in knees that remain under- or overcorrected.

Hemicallotasis is a precise method of correcting the alignment of the knee, with the advantages of early mobilisation, a low rate of complications, increased bone stock, minimal interference with tibial slope or patellar tendon length, and no retained metalwork, so it should make subsequent total knee replacement less difficult.

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References


