Computer-assisted revision total knee replacement

A technique for performing allograft-augmented revision total knee replacement (TKR) using computer assistance is described, on the basis of the results in 14 patients. Bone deficits were made up with impaction grafting. Femoral grafting was made possible by the construction of a retaining wall or dam which allowed pressurisation and retention of the graft. Tibial grafting used a mixture of corticocancellous and morsellised allograft. The position of the implants was monitored by the computer system and adjusted while the cement was setting. The outcome was determined using a six-parameter, quantitative technique (the Perth CT protocol) which measured the alignment of the prosthesis and provided an objective score.

The final outcomes were not perfect with errors being made in femoral rotation and in producing a mismatch between the femoral and tibial components. In spite of the shortcomings the alignments were comparable in accuracy with those after primary TKR. Computer assistance shows considerable promise in producing accurate alignment in revision TKR with bone deficits.

Computer-assisted orthopaedic surgery is becoming more widely used. The most rapid advances have been made in total knee replacement (TKR) with small series being reported and controlled trials showing advantages in computer-assisted compared with conventional jig-based operations. In primary arthroplasty the principal object of computer assistance is to produce accurate bone cuts upon which to position the components.

An extension of the computer-aided technique to revision arthroplasty is presented. In revision knee replacement the anatomy is distorted by the presence of the failed prosthesis and bone deficits which result when the prosthesis and any bone cement are removed. It is often impossible to produce clean, stable bone cuts. When bone grafting is needed computer assistance can provide valuable information in the augmentation of deficient bone stock and the alignment of the components on the grafted bed.

Patients and Methods
There were 14 male patients in the study with a mean age of 77.6 ± 7.4 years. Each had a TKR which was mechanically unsatisfactory and not infected. It had to be removed in total which resulted in a bone deficit requiring augmentation. The main symptom in all cases was pain. The reasons for revision included failure of the prosthesis or malalignment (Table I).

The Stryker computer knee navigation system, v1.1 (Stryker, Leibinger, Kalamazoo, Michigan) was used in all cases. This image-free system relies on infrared beacons positioned in the iliac crest, distal femur and proximal tibia to signal relative positions to a camera array. Once an anatomical registration process has been completed the positioning and angles of the bone cuts can be controlled and monitored. The system has been validated in cadavers and in clinical use and the author has experience of its use in over 150 TKRs.

The revision procedure followed a protocol which consisted of the following principal steps. A pre-operative estimate of the required joint level was made. When possible it was referenced to the implant which was in situ. This was usually done using radiographs of standard magnification (115% as required for Duracon templating). When it was difficult to estimate where the joint line should be a radiograph of the contralateral knee was used. The optimum joint level (OJL) was measured in relation to the tibial base plate and the most distal part of the femur, which meant the femoral component. The OJL was then used as a...
guide to estimate how much bone augmentation or resection was needed during the revision procedure.

The joint was exposed through a medial parapatellar incision. If there was difficulty in obtaining adequate exposure an osteotomy of the tibial tubercle was performed and the whole patellar mechanism was reflected laterally without release of the lateral retinaculum or soft tissues.

The pins required for the beacons were placed as far proximally in the femur and distally in the tibia as possible within the constraints of the tourniquet. The software can accommodate a distance for the beacons of 20 cm from the joint line. In practical terms this allowed the use of short (8 cm) stem extensions. These did not necessarily engage the diaphyseal canal and allowed some control of the position of the components as they were introduced through setting cement.

The registration required for the computer navigation process was made on the metal components which were to be removed, namely the femoral component and the tibial base-plate after the polyethylene had been removed. In revision of unicompartmental tibial components the polyethylene surface was used. In all cases both epicondyles could be identified although they needed to be exposed fully. This was done in the initial synovectomy and debridement stage. Whiteside’s line could not be used as the primary reference because rotational prosthetic malalignment obliterated this axis. The centres of the intercondylar region of the femur and of the tibial plateaux were estimated bearing in mind the position of the prosthesis on plain radiographs.

The components and any cement were removed, a radical synovectomy was performed and lytic bone defects were debrided down to bone of good quality.

Short intramedullary tracks were made centrally in both the femur and the tibia to accommodate short stems (extensions of 8 cm on the femoral housing giving a stem of 10 cm). The length of the stems had to be kept short in order to avoid impingement on the computer-navigation beacon pins which were placed in the distal femur and proximal tibia. The tracks had to be sufficiently wide to allow stems to move freely in the canals before cementation.

The relationship between the OJL and the remaining femoral and tibial bone was then determined using the navigation data. The distal bone level of the femur (DBLF) was determined in relation to both the level of the removed femoral component and to the OJL. From this, the amount of augmentation of the femur (AF) or the amount which needed to be resected (-AF) was determined according to the following equation:

\[ \text{DBLF} + \text{AF} = \text{OJL} \]

The augmentation of the femur was made up of the thickness of the implant to be used and any required bone grafting. Similarly, the proximal bone level of the tibia (PBL) required to be augmented by an amount AT to reach the required OJL. The assembly of a trial prosthetic construct and its loose placement were found to be a useful check.
A plastic medullary plug was inserted to the appropriate depth into both the femur and tibia to prevent cement adhering to the screws which held the computer-navigation beacons.

The tibia was grafted up to a level about 3 mm below the level of bone required, with allograft bone, using a mixture of corticocancellous blocks fixed by screws (Fig. 2) and morsellised bone graft.

The optimum rotational position of the tibia was determined manually and the appropriate keel channels were cut.

Low-viscosity cement, loaded with antibiotics, was injected into the stem track and onto the grafted surface. The tibial prosthetic construct was introduced by hand and driven down to about 1 cm short of the required level. The cement was allowed to become doughy, then the tibial construct was progressively driven into the setting cement and the position of the prosthesis on the computer screen was checked (Fig. 3). Adjustments of the position were made by tapping or driving against different parts of the tibial plateau.

If the distal femoral level was too distal, standard clean-up cuts to trim any residual bone were made using the computer-navigation system to control the level, varus/valgus and rotation.

If the distal femoral bone level was too proximal the femur was grafted. In most cases this was done by constructing a peripheral dam (Fig. 4) which allowed morsellised bone to be contained and pressurised. Without a restraining dam graft laid on the anterior surface of the femur would become displaced as the femoral component was being introduced. Occasionally, distal femoral corticocancellous bone grafting was also used. The retaining wall or dam was initially constructed by placing small-fragment AO screws in a line about 5 mm beyond the flange of a trial femoral component. The screws were united by methylmethacrylate cement which, when hardened, allowed morsellised graft to be retained. Later, a thermoplastic strip was used and held temporarily with pins until the implant had been positioned and the cement set.
The grafted surface and stem canal were filled with low-viscosity cement and the femoral construct was driven through this. The position of the implant was checked, continuously, on the computer screen and adjustments were made appropriately. Varus/valgus alignment was easily controlled but rotation was not because it was difficult to get a grip on the femoral component in order to rotate it. The components were reduced with a trial spacer. The soft-tissue balance was checked and the final thickness of the polyethylene plateau was chosen. In most cases a plateau of 9 mm was used. Soft-tissue releases were performed as required.

Loose cement was removed, bone graft washed away and the osteotomy of the tibial tubercle fixed by two staples.

**Assessment of outcome.** Routine plain radiographs were taken in the immediate post-operative period. The patients were mobilised in the normal way. Within the first post-operative year, a CT-based assessment (Table I) of the position of the prosthesis was made and a six-parameter malalignment index was used. This has two components. The first is the sum of the angles which are more than 2˚ beyond the ideal and the second is the number of parameters which are outside the ideal (Table II).

For comparison, a consecutive group of 25 primary TKRs, inserted by the author using the same computer-navigation system and analysed in the same way, is presented. While this is not a valid control it provides a benchmark for the results obtained in revision.

**Results**

All achieved more than 90˚ of knee flexion. The worst result (case 2, Tables II and III) was a malalignment score of 12.3 with the femoral component in 6˚ of internal rotation, 9˚ of tibiofemoral mismatch and 2˚ of reversed (anterior) tibial slope. The patient had an unsatisfactory clinical result, complaining of significant discomfort and some instability. Another patient (case 8) developed anterior knee pain, which was associated with a significantly internally-rotated femoral component (5˚). A lateral release was performed nine months after the operation and he became free from pain.

Radiologically, none of the prostheses was perfectly aligned (Table III). Nine (64%) had one parameter which was not ideal. Three (21%) had a two-parameter malalignment and two (14%) a three-parameter malalignment. When individual parameters were examined it was clear that the greatest difficulty was encountered in rotation. Femoral rotation was ideal only in 8 patients (57%), as was femorotibial matching in 6 (43%). The tibial slope was ideal in 10 patients (71%), femoral valgus/varus in 13 (93%) and
tibial valgus in all 14 (100%). When treated as a group the mean malalignment index was 4.0:1.5.

In the group of 25 sequential primary TKRs operated on using the same computer-navigation system, the mean malalignment index was 2.6:1.3. This indicated that the revision procedures resulted in more malalignment, but that the number of parameters maligned was comparable.

Discussion
In many ways the findings raise more questions than they answer. Computer-assisted revision knee replacement is a very exciting concept for a number of reasons. The greatest of its attractions is that the surgeon has a feeling of control throughout the procedure with instant feedback from the computer on angles and thicknesses of bone cuts and augments.

The fundamental difference between a primary and a revision procedure with bone deficit is the clean, complete bone cut which can be achieved in the primary TKR. In the primary situation the bone cut is usually sufficiently good to allow an uncemented prosthesis to lie on it and assume the alignment which the bone cuts provide. When there is a severe bone deficit the grafting process produces an interface which is variable and difficult to measure or assess quantitatively. This problem may be overcome by resecting more bone and using metal augments, but this produces even greater bone deficits, long soft-tissue envelopes and increases the potential problems for future revisions. In the technique described here, the bone grafting needs to be only approximate. It can be checked at all times, and the final, radiological subtle adjustments made while the cement is setting. However, although the technique produces a satisfactory outcome the control is not as good as it appears at the time. This discrepancy is because it is easiest to judge femoral and tibial valgus/varus alignment, which are the two parameters that are usually satisfactory. Rotation is difficult to judge and unfortunately is most commonly unsatisfactory.

Clearly, the degree of accuracy which is both achievable and desirable is also an issue. An arbitrary value of 2° was taken as acceptable but this is close to the accuracy with which it is possible to divide bone for a primary TKR. Others have used a variation of 3° in the coronal plane as being acceptable and have shown negative outcomes. The technique used here does not use navigation data to establish tibial rotation. It uses the femoral trial component to give an indication of rotation in full extension. Since the tibial component is cemented in first it is not surprising that femorotibial matching is not perfect. Furthermore, soft-tissue releases change the relationship between the femur and tibia. Thus when the prosthesis is fixed into place with perfect rotational relationships, and a soft-tissue release is required, the alignment may be changed.

The failure to obtain an adequate posterior slope of the tibial plateau may also be due to the tibial stem. The longer the stem is the more difficult it is to change the alignment of the component, especially in the anteroposterior plane in which the flanges act as an obstruction. Then the component takes up the alignment of the medullary canal, which is not the same as the mechanical axis.

In conclusion, computer assistance is extremely useful in revision situations in which significant bone deficits are encountered and bone grafting is needed. The anatomical landmarks which remain and the prosthesis which is being removed provide sufficient reference points to allow controlled grafting and cementation to take place. The overall alignment produced is, in most cases, slightly inferior to that of a primary computer-assisted TKR. Errors can occur. These errors may be reduced with better control of both femoral and tibial rotation, at least partly by developing instruments which are specifically designed for the computer-assisted operation.

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References