Triplate fixation
A NEW TECHNIQUE IN LIMB-SALVAGE SURGERY

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Massive endoprostheses using a cemented intramedullary stem are widely used to allow early resumption of activity after surgery for tumours. The survival of the prosthesis varies with the anatomical site, the type of prosthesis and the mode of fixation. Revision surgery is required in many cases because of aseptic loosening. Insertion of a second cemented endoprosthesis may be difficult because of the poor quality of the remaining bone, and loosening recurs quickly.

We describe a series of 14 patients with triplate fixation in difficult revision or joint-sparing tumour surgery with a minimum follow-up of four years. The triplate design incorporated well within a remodelled cortex to achieve osseomechanical integration with all patients regaining their original level of function within five months.

Our preliminary results suggest that this technique may provide an easy, biomechanically friendly alternative to insertion of a further device with an intramedullary stem, but may be soundly fixed using this method.

Massive prostheses are now the most acceptable way of filling defects after resection of a primary bone tumour. While they enable the patient to return to an almost normal lifestyle, aseptic loosening has limited the long-term durability of these implants. The mechanical demands placed on these prostheses are large as they are longer than standard joint replacements and muscle control is often compromised after a major soft-tissue resection.

Osteoarticular allografts have a high complication rate and, although the alternative of an allograft-prosthesis composite has some theoretical advantages, in practice it also has a significant rate of complications.

Recently, the revision rate of 70% for proximal tibial replacements seen in the early days of limb salvage has been reduced. While the current generation of cemented massive replacements with hydroxyapatite collars may fare better, the historical results for cemented distal femoral replacements have been equally poor, with 55% becoming loose by ten years. Revision replacements in both groups are even less successful. One of the factors which contributes to the comparatively high rates of aseptic loosening for both types of prosthesis is that in most patients the intramedullary stem is inserted into diaphyseal bone. In this area there is relatively little cancellous bone available for the penetration of acrylic cement. Failure at the cement-bone or prosthesis-cement interfaces may occur and can result in significant loss of bone.

Revision to another cemented device is feasible if there is a sufficient amount of bone remaining to achieve rigid fixation, but the procedure is difficult and the second implant is less successful. Bone remodels in response to a cemented intramedullary stem, leading to a reduction in Young’s modulus. The increase in the diameter of the bone and the weakening of the cortical layer lead to the predictable failure of a further revision intramedullary stem. Amputation has been advised if bone stock is inadequate.

Triplate fixation provides an alternative method for revision of a prosthetic component, and enables an implant to be secured in a short segment of bone. Altering the technique of fixation of the implant changes the remodelling stresses applied to the bone and encourages reconstitution of bone stock. Before the development of bone cement in the 1950s, eight cases were reported in which custom-made massive endoprostheses were secured using two side plates. In 1954 a distal femoral replacement with two side plates was inserted.
in one patient, only being revised 21 years later after fracture of the prosthesis. During this time the patient led a full and active life. This case was the inspiration for investigating the use of extracortical plates as an alternative method of fixation. An experimental model was developed in goats with various designs of plate.14 Three more flexible slotted plates integrated into a new, wider remodelled cortex and were found to provide better early stability, ease of insertion and achieved consistent longer term fixation. The triplate approach was therefore adopted and we now present our experience of this technique.

**Patients and Methods**

We carried out triplate fixation in 14 patients with a mean follow-up of 4.6 years (1.0 to 7.8) at three main sites (Table I). There were eight males and six females with a mean age of 32 years (9 to 72). Ten patients had osteogenic osteosarcoma (Enneking stage IIB), two had giant-cell tumours, one a Ewing’s sarcoma and one had a renal-cell metastasis.

The predominant indication for surgery using the triplate system was revision surgery for aseptic loosening (11 patients). All of these patients had received their initial cemented stemmed endoprosthesis between August 1987 and January 1988, with a mean lifespan of the original prosthesis of 11.2 years (6 to 17).

Four of these 11 patients were revised using another cemented prosthesis, but at a mean of 4.2 years (3 to 6) after their revision surgery, all these prostheses loosened once more. In the remaining three patients, the indications for the technique were expanded to include difficult primary cases in any bone in which the remaining bone after resection of the tumour would not accept an intramedullary stem of a length which would allow satisfactory fixation. In the distal tibia, where loosening leaves very little bone stock, fixation was obtained in the last 80 mm (Fig. 1). In the distal femur, secure fixation was achieved in the last 50 mm (Fig. 2) and in the proximal femur, within 50 mm of the lesser trochanter without any stem. Above the elbow the humeral shaft only develops a lumen after the olecranon fossa, making insertion of an endoprosthesis impractical for tumours close to the elbow. Secure fixation into the last 40 mm of the humerus has been achieved using this extracortical plate technique.

**Design of the plates.** The design of the plates and their orientation were based on implants used in the goat animal model14 and achieved using computer-aided techniques based upon radiographic measurements. The implants were designed and made by Stanmore Implants Worldwide, a section of the Centre for Biomedical Engineering of University College, London. The biplate design was easier to make but did not provide enough stability and allowed migration. A triplate design was therefore developed, which provided firm fixation to the tibia by its triangular cross-section. The hydroxyapatite-coated plates were slotted to increase the surface area for ingrowth of bone and to improve the vascularity. These plates were 12 mm wide and of tapering thickness, starting at 3 mm at the base and

### Table I. Details of triplate fixation in the 14 patients

<table>
<thead>
<tr>
<th>Case</th>
<th>Diagnosis and site</th>
<th>Indication for operation</th>
<th>Plate number, maximum length (mm)</th>
<th>Screw type, number</th>
<th>Enneking score</th>
<th>Follow-up (mths)</th>
<th>Complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ewing’s sarcoma, distal femur</td>
<td>Joint sparing</td>
<td>3, 40</td>
<td>Unicortical, 6</td>
<td>27</td>
<td>11</td>
<td>Died from pulmonary metastases</td>
</tr>
<tr>
<td>2</td>
<td>Osteosarcoma, distal femur</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>3, 65</td>
<td>Unicortical, 4</td>
<td>27</td>
<td>84</td>
<td>Early failure: drifted into varus, requiring revision. Now functioning well</td>
</tr>
<tr>
<td>3</td>
<td>Osteosarcoma, distal femur</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>3, 50</td>
<td>Bicortical, 6</td>
<td>30</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Osteosarcoma, proximal tibia</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>2, 55</td>
<td>Unicortical, 6</td>
<td>28</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Osteosarcoma, proximal tibia</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>3, 45</td>
<td>Unicortical, 4</td>
<td>29</td>
<td>86</td>
<td>Haematogenous infection. Resolved 42 months after debridement</td>
</tr>
<tr>
<td>6</td>
<td>Osteosarcoma, proximal tibia</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>2, 50</td>
<td>Unicortical, 5</td>
<td>25</td>
<td>71</td>
<td>Migrated. Stable at re-exploration</td>
</tr>
<tr>
<td>7</td>
<td>Osteosarcoma, distal femur</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>3, 70</td>
<td>Unicortical, 6</td>
<td>28</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Osteosarcoma, distal femur</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>3, 70</td>
<td>Unicortical, 5</td>
<td>27</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Giant-cell tumour, proximal tibia</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>3, 45</td>
<td>Bicortical, 7</td>
<td>27</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Giant-cell tumour, distal femur</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>3, 65</td>
<td>Bicortical, 6</td>
<td>28</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Renal-cell metastasis, midshaft humerus</td>
<td>Joint sparing</td>
<td>3, 55</td>
<td>Unicortical, 6</td>
<td>24</td>
<td>14</td>
<td>Died from pulmonary metastases</td>
</tr>
<tr>
<td>12</td>
<td>Osteosarcoma, proximal tibia</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>3, 60</td>
<td>Bicortical, 4</td>
<td>29</td>
<td>59</td>
<td>Early failure: drifted into varus, requiring re-fixation, now stable for over four years</td>
</tr>
<tr>
<td>13</td>
<td>Osteosarcoma, distal humerus</td>
<td>Joint sparing</td>
<td>3, 40</td>
<td>Bicortical, 4</td>
<td>30</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Osteosarcoma, proximal tibia</td>
<td>Aseptic loosening of endoprosthesis</td>
<td>3, 55</td>
<td>Bicortical, 6</td>
<td>29</td>
<td>51</td>
<td></td>
</tr>
</tbody>
</table>
reducing to 2 mm towards the tip. The length of the plates used depended on the bone and site within the bone (Table I), although those closer to the midshaft, and attached to pure cortical bone, required a longer interface because of the increased bending moment. We aimed for an osseointegration zone of 60 mm in these cases, as an extrapolation of the work on the animal model. Fixation zones closer to the joint are subjected to less bending moment, and therefore could safely be fixed by shorter plates. In our series, plates of 40 mm provided quite stable fixation in the metaphysis.

The screws used for early fixation were initially unicortical for theoretical reasons. Screws locking the plates to both cortices are theoretically less attractive, but provide significantly better fixation in the short term, particularly when the underlying bone may be very thin, or even deficient in revision cases. We believe that there is an optimum number of anchorage points needed to provide sufficient initial stability to an endoprosthesis that is secured by an extracortical plate. Our aim was to insert four bicortical screws (eight anchorage points) for the tibia and humerus, with six bicortical screws (12 anchorage points) for the femur to ensure initial fixation. Insertion of distal screws sometimes requires additional dissection, but failure to obtain sound primary fixation may result in loosening.

**Operative technique.** Eleven patients had triplate and three had biplate extracortical fixation. The original incisions were opened throughout their length in the ten patients
who had revision surgery for aseptic loosening. Minimal additional soft-tissue dissection was required to enable the plates to be placed subperiosteally with most soft-tissue dissection occurring through old scar tissue. The loose components and the extensive wear products were removed. Seven patients required no further bony resection and the remaining three had approximately 15 mm of tibia resected. Any solidly adherent intramedullary cement was left untouched to enhance fixation of the screws. The four remaining patients had their primary resection using a standard technique which aimed to obtain a wide surgical margin. In all cases the triplate fixation was hammered into place after minimal shaping of the residual bone with excellent purchase being achieved in all 14 patients. The plates were then stabilised using unicortical or bicortical pure titanium screws. Placement of the screws was not symmetrical. In some sites, access required extra dissection, particularly for the posterior plate on the tibia and the posteromedial plate on the femur. These screw holes were routinely left unfilled without mishap. Post-operatively, the 12 patients who had lower-limb surgery were allowed partial weight-bearing for six weeks and the two patients with humeral prostheses began active assisted exercises immediately.

All patients were followed prospectively as for all those with massive implants inserted by the London Bone Tumour Service. Functionally, they were assessed at their clinic visits using the Enneking scoring system. Plain radiographs were taken of the implants to document the evolution of the bone-implant interface with time.

**Statistical analysis.** Survival of the implants was calculated using the Kaplan-Meier method, and expressed graphically using SPSS version 11 for Windows (SPSS Inc, Chicago, Illinois).

**Results**

In all 14 patients the wounds healed well after operation and the 12 who had surgery on a lower limb were fully weight-bearing after six weeks. All nine patients who were employed returned to work within six months and one with distal humeral fixation was again able to shovel cement.

Four patients required additional surgery. Revision of a distal femoral replacement secured using a triplate design and four unicortical screws was required in one patient whose fixation failed while he was doing leg presses in the gym to improve muscle definition in the third month after surgery. The level of resection was in the mid-femur, and triplate fixation had been selected because the original tip of the stem had eroded the anterior cortex, making re-cementation difficult. At revision surgery, the plates were found to have pulled off the femur, but the patient’s bone stock was noted to have improved significantly. Revision to an implant with an intramedullary stem and a hydroxyapatite collar was achieved without difficulty since the defect in the anterior cortex had sealed in the intervening three months. The patient’s muscle definition returned, and five years after the revision his Enneking score was 27 out of 30.

One patient required adjustment to the triplate fixation. Only five screws had been used, and distal fixation had
been omitted since it required further dissection. At re-
operation, refixation was not difficult, although the patient
remained on crutches partially weight-bearing for three
months. These provided sufficient mechanical stability to
allow solid osseomechanical integration of the plates. This
patient achieved an Enneking score of 26 out of 30, with
the prosthesis remaining stable six years later (Fig. 3).

Another patient with radiological evidence of migration
had biplate fixation which migrated 4 mm distally in the
first six months. He failed to attend for follow-up while
held in custody, but on his release 12 months after opera-
tion the implant was re-explored. At this time, the bone was
found to have incorporated the prosthesis solidly and no
revision was required. In the fourth case there appeared to
be some settling of the prosthesis with bending and break-
age of screws evident on serial radiographs. This did not
affect the incorporation of the prosthesis into the cortex.

One patient developed haematogenous infection four
years after extracortical plate fixation. This was success-
fully treated by aggressive debridement and copious lavage,
leaving the implant in situ and with no subsequent require-
ment for antibiotics.

Two patients died from metastases during the period of
study at 11 and 13 months. Both had achieved good Enne-
king functional scores (24, 26) at their last follow-up
appointment.

Functionally, all patients were assessed at their last follow-
up, at a mean of 4.7 years after surgery, using the
Enneking scoring system. The mean score was 27.3 (22 to
30) of a possible score of 30 which is encouraging. After the
early technical failures, the absence of late failures made the
prospect for long-term fixation good. Figure 4 shows the
survival curve with the two early failures, and two deaths,
and the remaining cases followed for a minimum of five
years.

Plain radiography showed two reliable findings. First,
there was excellent incorporation of the triplate extracorti-
cal prostheses at either end of each of the long bones (Figs
1 and 2), and also continued evolution of the bone at the
level of the interface with the plates (Fig. 3). The sequential
images showed that bone was actively developing within
the zone of transition of bone to metal, with more bone
being present later in the follow-up period.

Discussion
Triplate fixation provides an alternative method of fixation
of prostheses with the advantage that it appears to allow
incorporation of the prosthesis into the load-bearing struc-

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**Fig. 5**

Diagram explaining the rationale for triplate fixation.
ture of the bone as it remodels. It takes advantage of the biological phenomenon shown by callus at a fracture or in a loose massive replacement, in which bone is laid down outside the cortex away from a loosening prosthesis (Fig. 5). Bone forms on the periosteal surface in a centripetal fashion incorporating the plates into the new expanded cortex. Three important features facilitate this incorporation as follows: 1) slots within the plates, encouraging incorporation with the bone; 2) plates of different lengths and tapering thickness allowing a gradual transfer of load and 3) hydroxyapatite coating of the inside and outside of the plates and collar of the implant using a plasma spray process.

Our results at a mean of five years after operation precisely reproduce the findings of extracortical plate fixation in the animal model. In the longer term it is hoped that this method will provide secure durable fixation avoiding the current problems of loss of bone stock and instability at the bone-implant interface when conventional intramedullary fixation is not possible. The prosthesis should become fully osseointegrated with a gradual sharing of load between plates and bone at their junction.

The operative technique is straightforward. There is no need to remove well-fixed cement from the intramedullary canal, which may compromise the integrity of the remaining bone. In a primary procedure, the medulla is not violated at all, preserving the intraosseous blood supply. Minimal additional soft-tissue dissection is required at revision and primary resection uses a standard technique to obtain a wide surgical margin. Some additional periosteal stripping is required. After smoothing off the edges at the level of transection, the prosthesis engages easily onto the remaining bone. Sometimes it is pushed off the bone on full engagement, but the screws hold it closely to the bone surface. It does inevitably violate the periosteum, which is unable to accommodate the bulk of the plate, and muscle is stripped when necessary in order to obtain fixation.

There are a number of concerns about this procedure. First, application of three extracortical plates may disrupt the periosteal blood supply to the remaining bone and lead to cortical necrosis. However, our study showed vigorous formation of new bone both at surgery and on radiographs, indicating that viability of the bone was not significantly impaired. Secondly, fatigue fractures of the implant similar to those experienced by Burrows et al may limit the lifespan of the prosthesis. The triplate design makes these less likely, as the presence of a nearby joint reduces the peak loads absorbed by the implant-bone interface. Finally, late loosening of the prosthesis could theoretically occur to reduce the usefulness of this technique. We have found no sign of this. In fact the opposite was apparent with adaptive bone remodelling exactly as predicted, making the interface even more secure after five years than it was after only one.

Our results are, therefore, very encouraging at a short- to medium-term follow-up for these primary and demanding revision patients for whom amputation has been a real possibility. It appears that the prosthesis has a lower rate of failure than would be predicted by the literature in this challenging biomechanical environment.

Only one case of failed fixation occurred early and required a change of prosthesis. This was at the start of the series, as a result of the use of too few cortical contact points in the triplate construct to achieve secure initial fixation in the face of relentless work in a gymnasium. In this case four unicortical screws were used in a triplate design. Three prostheses migrated a mean of 3 mm before solidly integrating with the bone as seen on serial radiographs.

Although this method of secure fixation was developed for the revision of failed conventional prostheses we found that its indications could be extended into areas where conventional approaches were difficult. A clear benefit of this technique is for joint-sparing surgery in which the use of extracortical plates allows secure fixation into smaller, remaining sections of bone while still retaining the joint. Secure fixation has been achieved in the last 50 mm of the distal femur and the last 40 mm of the humerus in our series. The probability of survival at 99 months of 86%, with no failures after 11 months, is encouraging (Fig. 4). Even shorter segments are now being saved. All patients appeared to tolerate the newly-designed prosthesis well and achieved high functional scores.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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