We report our results in 24 children with malignant primary bone tumours of the distal femur treated with a Stanmore extendible endoprosthesis (SEER). This consists of a femoral component that can be lengthened, a constrained knee and an uncemented sliding tibial component which crosses the proximal tibial physeal plate perpendicularly.

The average age of the patients at diagnosis was ten years and the mean follow-up was 4.7 years (2.5 to 7.9). The mean growth of the affected tibia was 76% (18 to 136) and of the fibula 83% (15 to 750) of the growth of the unaffected limb.

Measurement of growth arrest lines showed that the mean growth of the proximal tibial physis on the affected side was 69% (43 to 100) of that of the normal side. The great variability in the growth of the physis cannot yet be explained.

Limb salvage is now an acceptable alternative to amputation for the treatment of primary bone tumours. This is mainly due to advances in diagnostic imaging, neoadjuvant chemotherapy, biomedical engineering and operative techniques. In children, this is more difficult because the limb has to be extended to match the growth on the normal side. Amputation and rotationplasty are therefore still used to some extent.1,2 Massive allografting has been described, but this has a limited application in growing children.3 Growth arrest of the normal side is sometimes used, but in general it is better not to interfere with an otherwise normal limb. Since 1976 we have used extendible prosthetic replacements for the treatment of primary bone tumours of the distal femur in skeletally immature patients.

The Stanmore extendible endoprosthetic replacement (SEER) of the distal femur consists of a femoral component, a constrained knee and a tibial component (Fig. 1). The femoral component can be lengthened using one of several methods.4,5 The tibial component is designed to preserve as much of the proximal tibial physis as possible, and has an intramedullary stem which crosses the proximal tibial physis perpendicularly. It is not cemented, but secured in the tibial cavity by a polyethylene sleeve placed through the proximal tibial physis (Fig. 2). This allows the tibial component to slide in the polyethylene sleeve and growth to continue at the proximal tibial physis.6,7 The SEER aims to achieve a reasonably normal functional limb and to allow the maintenance of limb-length equality throughout growth, without compromising survival.

A child with an extendible replacement will probably need many operations for limb lengthening, the treatment of complications and eventual revision to an adult type of endoprosthetic replacement. The patients and the family are made aware of this and accept this as an alternative to high thigh amputation.

It has been shown previously that growth continues despite an intramedullary stem which crosses the proximal tibial physis,6,7 but there have been no studies to quantify the amount of growth. Our aim was to estimate the growth in the lower limb after extendible endoprosthetic replacement of the distal femur in skeletally immature patients, with particular emphasis on growth at the proximal tibial physis.

PATIENTS AND METHODS

Between 1976 and January 1993, we performed 53 SEERs of the distal femur in 52 patients. Patients were excluded from this study if they had a follow-up of less than 2.5 years (14), bilateral osteosarcoma (2), a subsequent ampu-
The diagnosis was osteosarcoma in 20 patients and Ewing’s sarcoma in four. There were 16 boys and eight girls. There was a left-to-right ratio of 1.4 in all patients and 1.22 in those with osteosarcoma, and there were three left-sided Ewing’s sarcomas. The mean chronological age at diagnosis was 10.1 years (5.8 to 14) and the mean bone age 9.6 years (5 to 12.5).

After diagnosis all patients were fully staged and started on appropriate chemotherapy. Staging included radiographs of the lesion, a bone scan, CT or MRI of the lesion and CT of the chest. If the patient was suitable for limb-salvage surgery bone age was estimated by the method of Greulich and Pyle. An extendible prosthesis was used only if the expected growth in the distal femoral physes exceeded 3 cm. This corresponds to a maximum bone age of 13 years in boys and 11 years in girls.

The prostheses were designed and manufactured at the Department of Biomedical Engineering, University College, London. The amount of extension required was calculated to allow for full ‘growth’ of the prosthesis, so that at skeletal maturity the limb lengths would be equal. Allowance was made for the tibial physes to continue growing despite the prosthesis crossing it.

There were three cycles of neoadjuvant chemotherapy for osteosarcoma and four for Ewing’s sarcoma lasting 9 and 12 weeks respectively after the initiation of treatment. Following this treatment the patients were restaged and underwent surgery.

A medial parapatellar approach was used for the distal femur. The vasti were reflected, the knee opened and the distal femur mobilised. The femur was transected at a previously identified level and the femoral component was cemented in place.

The tibia was prepared by resecting the articular cartilage horizontally. Graduated reamers were passed across the growth plate into the medullary cavity. The tibial component of the Stanmore prosthesis was passed across the growth plate and stabilised with a polyethylene sleeve (Fig. 2). Pegs on the undersurface of the tibial component prevented rotation.

The patients were discharged after two weeks, resumed their chemotherapeutic regime and were readmitted at six weeks for intensive physiotherapy. They were all kept under review in an outpatient clinic.

![Radiograph of a Stanmore extendible endoprosthetic replacement of the distal femur. This massive replacement can be lengthened and has a constrained knee and a sliding tibial component.](image1)

![Diagram of the sliding tibial component. The tibial intramedullary stem crosses the proximal tibial physes perpendicularly, and a polyethylene sleeve through the growth plate gives lateral stability.](image2)
At diagnosis, the tibial, fibular and total leg lengths in both legs were measured as shown in Figure 3. The tibia was measured from the top of the tibial spine to the tip of the medial malleolus, the fibula from the top to the lateral malleolus and the total leg length from the top of the femoral head to the tip of the medial malleolus.

At review, the tibial, fibular and total leg lengths in the unaffected leg were estimated similarly. In the affected leg, the tibial length was found by adding the length of the tibia between physes to the height of the plateau and the height of the malleolar complex. The height of the tibial plateau was also estimated from an immediate postoperative radiograph to allow correction for the loss of bone due to insertion of the tibial component (Fig. 3). We calculated the growth in the affected tibia, fibula and total leg as proportions of growth in the unaffected leg.

Measurements on radiographs were made using a radiopaque ruler to eliminate problems of magnification. The ruler was calibrated in quarters of a centimetre allowing measurements to be made to the nearest eighth of a centimetre with minimal intraobserver error. All measurements were taken by one observer, thus eliminating interobserver error.

Growth arrest lines (Fig. 4) are commonly seen after cytotoxic chemotherapy. These lines were measured to their nearest physes as indicated in Figure 5. The amount of proximal tibial growth in both affected and unaffected legs was calculated as a proportion of the total tibial growth.

Fig. 3
Diagram to show the measurements taken from long-leg radiographs to calculate the growth in the affected and unaffected legs.

Fig. 4
Radiograph showing a proximal tibial growth arrest line and the physes around a sliding component.
During follow-up, the bone age was checked for all patients and lengthening operations were performed as necessary to maintain limb-length equality.

RESULTS

The mean follow-up was 4.7 years (2.5 to 7.9). One patient died as a result of adriamycin-induced cardiomyopathy three years after diagnosis. All other patients are alive and free from disease.

Five patients had revision to a second SEER because of aseptic loosening (3), a fractured prosthetic stem after a fall (1) and infection of the implant (1).

At review 13 patients were skeletally mature and four had expected residual growth in the distal femur of less than 1 cm (bone age greater than 14.5 years in boys and 13 years in girls). Seven patients had an expected growth in the distal femur of more than 1 cm. Seventeen patients had equal limb length, five a leg-length discrepancy of less than 2 cm and two discrepancy of 2 cm or more. In the last two patients, one who had a discrepancy of 2.5 cm had severe adriamycin-induced cardiomyopathy from which he later died. The other had shortening of 2 cm and refused further lengthening procedures.

Figures 6 and 7 show the growth in the affected leg as a proportion of that in the unaffected leg. The mean tibial growth was 76% (18 to 136), the mean total leg growth 84% (46 to 130) of that in the unaffected leg. In one patient the tibia of the affected leg was too dark on the radiograph to make an accurate measurement possible, and these values are therefore based on 23 patients.

In one patient (case 4) growth in the tibia, fibula and the total leg was greater than that in the unaffected leg. At diagnosis, the affected leg in this patient was 3.75 cm shorter than the unaffected leg, but the leg lengths were equal at review. This indicates that growth in the affected leg actually compensated for the loss before the diagnosis was made.

Thirteen patients had clear proximal and distal tibial growth arrest lines in the affected leg. Nineteen had these in the unaffected leg. These growth arrest lines were used to calculate the proximal and distal tibial growth as a proportion of the total tibial growth in these patients. The mean proximal tibial growth in the unaffected leg was 58% (50 to 64) and the mean distal tibial growth 42% (36 to 50) of the total tibial growth. In the affected leg, the mean proximal tibial growth was 69% (43 to 100) of the proximal tibial growth in the unaffected leg. The mean distal tibial growth was 96% (83 to 100) of that on the unaffected side. The tibia of the affected leg grew on average 48% proximally (39 to 61) and 52% distally (39 to 61).

In all unaffected legs the proximal tibial growth was larger than the distal tibial growth. In eight affected legs, the proximal tibial growth in the affected leg was less than the distal tibial growth, but this distal tibial growth never exceeded that of the unaffected leg. The distal tibial physes therefore do not seem to compensate for the loss of proximal growth in these patients.

We found no correlation between the growth of the proximal tibial physis and age at insertion, expected growth, function and the proportion of physis destroyed by the implant.
DISCUSSION

Our study has shown that after a SEER in a skeletally immature child, the longitudinal growth in all the long bones of the affected leg is retarded. More importantly, growth continues in the proximal tibial physis despite the presence of a considerable defect in the middle of the physis crossed by a polyethylene sleeve and a metal implant. Analysis of the growth arrest lines in the unaffected leg showed that the mean growth in the proximal tibial physis was 58% of the total tibial growth and that of the distal tibial physis 42%. This is similar to the 55% and 45%, respectively, reported by others.5

There have been other studies on the use of extendible endoprosthetic replacements, 6 but none has a long-term follow-up. Schiller et al13 recently reported six children who had been treated by an extendible endoprosthetic replacement and reached skeletal maturity. They also noted that growth continued at the site of the passive growing (sliding) component, but they did not measure growth and gave no quantitative data.

Safaran et al10 reported that growth at the proximal tibial physis continues despite the presence of a cemented intramedullary stem in the proximal tibia and that the growth pressure was large enough to break polymethylacrylate cement. We do not use cement but instead insert a sliding tibial component which could accommodate proximal tibial growth. The mean proximal tibial growth of the affected leg was 69% of that on the normal side. This confirms that growth at the proximal tibial physis continues despite the presence of an intramedullary stem crossing the physis. We conclude therefore that the sliding tibial component works, but that growth is slightly retarded. The distal tibial growth in the affected leg was never larger than that of the unaffected leg, and did not help to compensate for the lack of proximal tibial growth.

In another study we have shown that less than 13% of the proximal tibial physis is damaged by the polyethylene sleeve of the sliding component.10 The proportion of the growth plate that was damaged did not correlate with the growth of the physis, and the reason for the variability in the growth of the proximal tibia is not clear. Bailey and Dubow 15 reported that in dogs the longitudinal growth in the distal femur continued despite an intramedullary stem crossing the distal femoral physis. They also noted that the intramedullary device had a straightening effect on the anterior convexity of the dog femur. None of our patients had any deformities, probably because the human tibia is relatively straight. Deformities do not seem to occur when the intramedullary device crosses the physis perpendicularly.

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.

REFERENCES


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