

Extensible endoprostheses of the humerus after resection of bone tumours

K. S. Ayoub, F. Fiorenza, R. J. Grimer, R. M. Tillman, S. R. Carter

From the Royal Orthopaedic Hospital, Birmingham, England

We carried out extensible endoprosthetic replacement of the proximal or total humerus in 18 children aged between six and 12 years, after resection of primary bone tumours mainly for osteosarcoma and Ewing's sarcoma. In 11 patients we performed 44 lengthening procedures, with an average of two per child annually and a mean total extension of 29.9 mm per patient. We were able to achieve lengthening of the operated limb with few complications and a mean functional rating of 79.3% according to the Enneking system. Progressive lengthening of these prostheses does not adversely affect the overall function of the arm, and superior subluxation of the head of the prosthesis has not been a problem.

*J Bone Joint Surg [Br] 1999;81-B:495-500.
Received 8 June 1998; Accepted after revision 8 September 1998*

The proximal humerus is the fourth most common site for primary bone tumours, with 10% to 15% of osteosarcomas and 10% of Ewing's sarcomas arising at this location.¹⁻³ Limb salvage for the treatment of primary bone tumours is now common.⁴⁻⁶ Tumours of the humerus pose problems in reconstruction because many of the important structures, especially the rotator cuff and/or the deltoid, are resected after excision of a high-grade lesion around the shoulder. This usually results in poor function,⁷⁻⁹ but maintains use of the forearm and hand.

In children, the problems are compounded by loss of the capacity of bone for growth. The proximal humeral physis is responsible for 80% to 82% of the total growth of the humerus,¹⁰⁻¹² and therefore for a seven-year-old boy there

is about 104 mm of growth remaining, while girls will achieve a further 80 mm.¹³ Removal of the proximal humerus during resection of the tumour will prevent that growth. In a child nearing skeletal maturity it may be acceptable to replace the involved segment of bone leaving the limb permanently short by a few centimetres. In younger children inequality of arm length cannot be justified, particularly if the discrepancy is likely to be more than 50 mm. We believe that an attempt should then be made to achieve equalisation of limb length.

We have found that limb salvage is now possible in 85% of patients with primary bone tumours. When the end of a bone is resected the preferred method of reconstruction is with an endoprosthesis. In children, we have used extensible endoprostheses as a method of restoring limb length and have reported our experience with this method of reconstruction in the lower limb.¹⁴ Such implants are rarely required in the upper limb and their use has given rise to complications.¹⁵ We describe the results of our experience which is reasonably encouraging.

Patients and Methods

We studied 18 patients who had endoprosthetic replacement of all or part of the humerus between January 1983 and July 1997. Information was obtained from our computerised database, supplemented by review of case notes, collected at regular clinic attendances or by a postal questionnaire, to obtain a functional assessment up to March 31, 1998.

There were ten boys and eight girls whose mean age at the time of initial surgery was 9.4 years (6 to 12). Nine had osteosarcoma, eight Ewing's sarcoma and one a peripheral nerve-sheath tumour of bone. There were nine lesions in each humerus. Table I shows the details.

Prosthesis. Six patients had total humeral and 12 proximal humeral replacements. The prosthesis used to replace the resected total or proximal humerus was the Stanmore implant (Stanmore Implants Worldwide Ltd, Centre for Biomedical Engineering, Stanmore, UK) as shown in Figure 1. There were three types of extending mechanism utilising ball-bearings, a 'C' collar or a minimally invasive worm-drive.¹⁶ The implants were custom-made and the maximum possible lengthening ranged from 38 to 78 mm.

K. S. Ayoub, FRCS, Research Registrar
F. Fiorenza, MD, Research Fellow
R. J. Grimer, FRCS, Consultant Orthopaedic Surgeon
R. M. Tillman, FRCS Orth, Consultant Orthopaedic Surgeon
S. R. Carter, FRCS, Consultant Orthopaedic Surgeon
Royal Orthopaedic Hospital Oncology Service, The Royal Orthopaedic Hospital, Bristol Road South, Northfield, Birmingham B31 2AP, UK.

Correspondence should be sent to Mr R. J. Grimer.

©1999 British Editorial Society of Bone and Joint Surgery
0301-620X/99/39178 \$2.00

Table I. Details of 18 patients who had either total or proximal extensible endoprostheses in the humerus

Case	Age (yr)	Gender	Diagnosis	Type and date of operation (month/year)	Number of lengthenings	Lengthening achieved (mm)	Functional score	Oncology outcome	Patient status and follow-up	Complications
1	10	F	Ewing's sarcoma	Total humerus 5/83	7	49	21		Alive, 182 mths	
2	8	F	Ewing's sarcoma	Total humerus 5/84	0	0	N/A*		Alive, 144 mths	13 months later she had forequarter amputation for pain
3	11	F	Osteosarcoma	Total humerus 9/84	1	6	N/A	Skeletal and pulmonary metastases	Died after 24 mths (7/86)	
4†	11	M	Ewing's sarcoma	Prox humerus 1/85	6	42	N/A	Skeletal and pulmonary metastases	Died after 30 mths (6/87)	
5	11	M	Osteosarcoma	Total humerus 8/88	0	0	N/A	Skeletal and pulmonary metastases	Died after 12 mths (6/89)	Temporary postoperative radial nerve palsy
6	6	F	Osteosarcoma	Total humerus 4/89	0	0	N/A	Skeletal and pulmonary metastases	Died after 35 mths (12/91)	
7	12	M	Osteosarcoma	Prox humerus 7/89	3	24	22	Pulmonary metastases	Alive, 100 mths	
8	7	M	Ewing's sarcoma	Prox humerus 1/90	6	36	24		Alive, 97 mths	Wound dehiscence
9	11	F	Osteosarcoma	Prox humerus 4/90	0	0	N/A	Skeletal and pulmonary metastases	Died after 25 mths (2/92)	
10	11	F	Ewing's sarcoma	Total humerus 2/91	4	42	27		Alive, 86 mths	
11	8	M	Ewing's sarcoma	Prox humerus 11/91	6	36	26		Alive, 79 mths	
12	11	F	Nerve sheath tumour	Prox humerus 1/93	3	30	25		Alive, 61 mths	
13	9	M	Osteosarcoma	Prox humerus 8/94	4	34	N/A	Local recurrence (4/95)	Alive, 41 mths	Simple superficial wound infection
14	10	M	Osteosarcoma	Prox humerus 9/96	2	18	21		Alive, 18 mths	
15	7	M	Osteosarcoma	Prox humerus 3/97	2	12	25		Alive, 14 mths	Temporary postoperative radial nerve palsy
16	6	M	Ewing's sarcoma	Prox humerus 5/97	0	0	22		Alive, 12 mths	Temporary postoperative radial nerve palsy
17	10	F	Ewing's sarcoma	Prox humerus 9/97	0	0	24		Alive, 6 mths	
18	10	M	Osteosarcoma	Prox humerus 10/97	0	0	25		Alive, 6 mths	

* not available

† this patient presented to the authors' institute with local recurrence in his humerus

Operative technique. The technique was similar to that described earlier for tumours of the proximal or total humerus.⁷ In all patients an intra-articular resection was carried out, and we routinely 'captured' the humeral head of the prosthesis by suturing a mesh made of Mersilene around it which was then attached to the edges of the resected rotator cuff or the glenoid labrum.⁸

Lengthening procedures. Lengthening of the prosthesis was offered to the patients when the discrepancy between the two upper limbs was more than 10 mm, or was obvious to the patient or the parents. Two patients declined the offer of further lengthening because they were satisfied with the function of their operated limb (functional rating, 80% and 87%), and they did not have any complaints despite the



Fig. 1

A lateral radiograph of the right arm showing the proximal two-thirds of the humerus which had been resected and replaced by an extensible endoprosthesis with a C-collar-type of extension mechanism.

obvious discrepancy in length between their upper limbs (see below). The growth of the limb was monitored clinically and radiologically.

Functional evaluation. After operation, the function of the limb was regularly evaluated using the system advocated by Enneking et al¹⁷ which has been adopted by the Musculoskeletal Tumor Society (MSTS) and the International Symposium on Limb Salvage (ISOLS).

Results

All patients were followed up regularly until death or for a median period of 70 months (4 to 172) for the survivors. There were five deaths, all due to metastases. Four of these five had had their primary diagnosis and endoprosthetic replacement operations at our institute, and the mean time to death was 25.2 months (12 to 35). The fifth patient had been treated primarily by radiotherapy and chemotherapy at the referring centre. Four years later he had a local recurrence which was treated in our hospital by resection and

humeral endoprosthetic replacement. He died from multiple metastases 29 months after the operation and 70 months after the primary diagnosis.

One patient had a local recurrence of osteosarcoma in the operation scar eight months later. This was treated by wide excision followed by local radiotherapy and the patient was free from disease 30 months later. Six patients developed pulmonary metastases, five of whom died from their disease; one is alive 100 months after the initial diagnosis of the tumour and 50 months after the last of three thoracotomies (Table I).

There were few complications related to the operation for resection of the tumour. Three temporary palsies of the radial nerve had full recovery a few months later. One patient showed radiological features of aseptic loosening of the distal intramedullary stem of the proximal humeral endoprosthesis but remained asymptomatic for 75 months and clinical examination showed a stable fixed prosthesis with very good function. Most of the patients had a variable degree of superior subluxation of the head of the prosthesis in relation to the glenoid at different times. In no patient was the prosthesis subluxed above the level of the clavicle, and this is a normal finding in endoprosthetic replacement of the proximal humerus.

One patient had a major complication. She started to complain of persistent pain in her shoulder eight months after the endoprosthetic replacement. Conservative treatment was attempted without success. The pain persisted and a forequarter amputation was eventually carried out. There were no deep infections, and no revision surgery was undertaken for any reason in the remaining patients.

There were few complications related to extension of the prosthesis or subsequent lengthening. There were two superficial wound complications of percutaneous lengthening. One gaping aseptic wound was treated by secondary suture and a wound infection was treated successfully by antibiotics. No prostheses failed, nor did the extension mechanism.

Out of the 18 replacement prostheses, 11 were lengthened at least once. The other seven did not have any lengthening for different reasons. One had a forequarter amputation for persistent pain nine months after the original operation. Three other patients developed metastases after several months and died before commencement of lengthening. The last three patients are alive with their prostheses and have not yet had an extension. For the 11 patients who have had lengthening procedures, the total number of lengthenings was 44 with a mean total extension of 29.9 mm (6 to 49). The mean number of lengthenings was two per year per patient (1 to 6), achieving a mean increase of 14.9 mm per year per patient (6 to 42). In most cases, at each lengthening one ball-bearing (6.25 mm diameter) or one collar (6 mm diameter) was inserted. The maximum number of lengthenings carried out on any single extensible endoprosthesis was seven, which produced an overall extension of 49 mm. Four survivors with their

Table II. Functional evaluation in relation to limb lengthening for 11 patients at final review

Case*	Score†	Rating (%)‡	Duration between operation and last scoring (mth)	% of achieved lengthening§	Estimated length discrepancy (mm)
1	21	70	178	100	<10
2	26	87	74	50	~50
3	27	90	72	88	<10
4	22	73	96	33	<10
5	24	80	96	60	~50
6	25	83	60	68	<10
7	21	70	16	45	<10
8	25	83	10	32	<10
9	22	73	8	0 (not lengthened yet)	<10
10	24	80	6	0 (not lengthened yet)	<10
11	25	83	4	0 (not lengthened yet)	<10

* all patients who had or yet to be lengthened

† total score of the last functional evaluation of the limb according to the Enneking system adopted by MSTs and ISOLS¹⁷

‡ rating percentage obtained by dividing the total score over the possible maximum score¹⁰

§ percentage of achieved lengthening was obtained by dividing the length of extension of the prosthesis achieved, over the maximum length of extension possible designed for that particular prosthesis



Fig. 2

Seventy-four months after resection and replacement of a Ewing's sarcoma with an extensible endoprosthesis when the patient was aged eight years. The upper arm has been lengthened by 36 mm (50% of the maximum lengthening).

prosthesis in situ have completed skeletal growth with a mean of 36.3 mm.

Of 13 survivors in our series, only one patient was lost to follow-up. At the final review measurement of limb length

showed that a discrepancy of 10 mm or less was difficult for the clinician to determine and was not noticed by the patients. Only two survivors had a greater discrepancy of length (Table II). One had the last of six lengthening procedures 39 months after the replacement operation, and 43 months later he had a limb-length discrepancy of 50 mm, but has refused further lengthening because he is satisfied with his function; his last functional rating was 80%. Another patient has had the same experience; 12 months after the last of six lengthening procedures, limb-length discrepancy became obvious. He is not keen to have any further lengthening and his functional score is 87% (Fig. 2).

The functional evaluation of the patient and the arm was measured using the Enneking system which has been adopted by the MSTs and ISOLS.¹⁷ We were able to assess 11 of the total 18 patients by this system. Of the other seven, five had died and one had a forequarter amputation before this evaluation system was implemented. We could not find any records for the other patient. The last functional scoring for each patient was obtained at a variable period ranging from between four and 178 months after the endoprosthetic replacement (Table II). At that time, the mean functional score for all the 11 patients was 23.8 (21 to 27) and the mean rating percentage 79.2% (70 to 90). The major advantage is the high acceptance by the child and the parents, especially from the emotional and functional aspects.

Movements of the shoulder after humeral resection and proximal humeral replacement were typically in the following ranges: abduction 40° to 60°, flexion 30° to 40°, extension 30° to 40°, internal rotation minimum 120° and external rotation minimum 60°, but with difficulty in control. Passive movements were often greater than normal with full abduction, full flexion, full extension, internal rotation of more than 200° and external rotation of more than 120°. There was little variation among the patients. None could actively elevate the arm above shoulder level. Elbow function was normal in all patients with proximal humeral replacement. Patients with total humeral

replacement sometimes had less than full extension of the elbow.

The longest follow-up for any single patient in our series is a girl who had a Ewing's sarcoma of the midshaft of her right humerus. Her tumour was treated by resection of the whole humerus and replacement by a total endoprosthesis in 1983 at the age of ten years. Over the following 15 years, she has shown no evidence of further disease, and has undergone seven lengthening procedures achieving total extension of 49 mm (full lengthening). She became skeletally mature at the age of 16 years. Complete clinical review and functional evaluation were carried out in March 1998, 15 years after operation and showed full function of the ipsilateral elbow and hand. The prosthesis was stable at the elbow with no clinical evidence of loosening (Fig. 3). The functional rating was 70% and she was quite satisfied with the outcome.

Discussion

Endoprosthetic replacement of the proximal humerus is a well-established procedure in salvage of the upper limb. It is technically fairly straightforward and the prostheses are simple and relatively cheap to fabricate. Their main disadvantage is in the loss of controlled movements of the shoulder, especially the significant loss of abduction and flexion. Elevation of the arm above shoulder height is rarely possible unless the length of bone resected is very short so that most of the muscles around the shoulder can be retained. This has generated much discussion about the best method of reconstruction for the proximal humerus. Some favour allograft arthrodesis, claiming improved functional results particularly in manual workers.

We have been using endoprosthetic replacements of the proximal humerus for the past 19 years and have been impressed with the low number of complications. Mechanical loosening and infection, the two main causes of failure in the leg, have not been apparent in the arm.

Lavy and Briggs¹⁵ dismissed extensible replacements of the proximal humerus because they believed that the procedure simply allowed the prosthesis to sublux superiorly

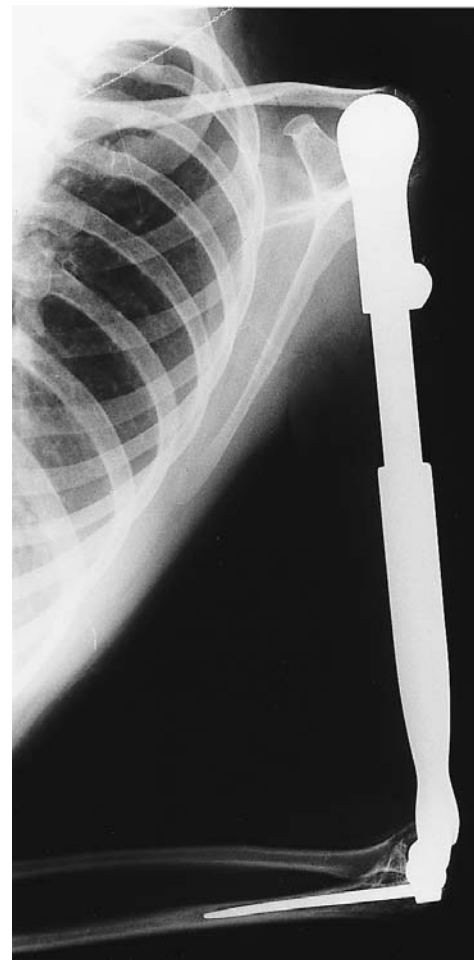


Fig. 3

Radiograph of the left arm of a 24-year-old woman showing a full extension 15 years after insertion of a humeral prosthesis.

ly without giving actual lengthening of the limb. All the patients in our series had a restraining mesh placed around the humeral head to prevent this and this technique seems to have been successful. Some proximal subluxation inevitably occurs because the rotator cuff has been removed, but in all our patients the prosthesis abuts against the superiorly

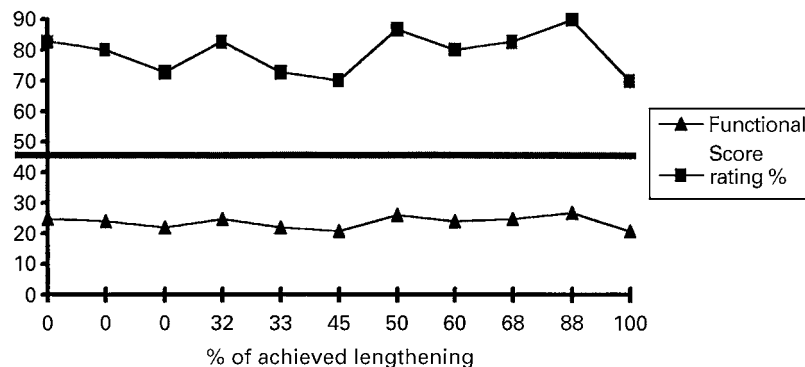


Fig. 4

Graph showing the relationship between function of the limb and progressive lengthening.

placed acromion and the coracoacromial ligament which we try to preserve if possible. Extension of the prostheses resulted in lengthening of the limb with minimal superior subluxation and did not adversely affect the overall functional evaluation and scoring of the limb (Table II). The relationship between these two variables is shown in Figure 4. The functional score of these patients closely matched those scores obtained for patients with cemented proximal humeral endoprostheses.¹⁸

In our patients the arm has grown in length as was intended even after 49 mm of lengthening. Most of our patients did not insist on precise equalisation of limb length accepting a difference of up to 50 mm. The main problem of arm-length discrepancy is cosmetic, but a large difference can cause problems with bimanual tasks.

It is our conclusion that extensible endoprostheses of the humerus are worthwhile and in our hands are virtually free from complications. We recommend their use in any child who may be left with 50 mm of limb-length discrepancy after resection of a tumour. It is not necessary to perform progressive lengthening of the prosthesis as a routine procedure to match the growth of the opposite side, as is the case in extensible endoprosthetic replacement in the lower limbs.

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

1. **Mirra JM**, ed. *Bone tumors: clinical, radiologic and pathologic correlations*. Philadelphia: Lea and Febiger, 1989.
2. **Schajowicz F**. *Tumors and tumorlike lesions of bone and joints*. New York, etc: Springer-Verlag, 1981.
3. **Huvos AG**. *Bone tumors: diagnosis, treatment and prognosis*. Philadelphia, etc: WB Saunders Co, 1979.
4. **Rosen G, Murphy ML, Huvos AG, Gutierrez M, Marcove RC**. Chemotherapy, *en bloc* resection, and prosthetic bone replacement in the treatment of osteogenic sarcoma. *Cancer* 1976;37:1-11.
5. **Burrows HJ, Wilson JN, Scales JT**. Excision of tumours of humerus and femur, with restoration by internal prostheses. *J Bone Joint Surg [Br]* 1975;57-B:148-59.
6. **Simon MA**. Current concepts review: limb salvage for osteosarcoma. *J Bone Joint Surg [Am]* 1988;70-A:307-10.
7. **Ross AC, Wilson JN, Scales JT**. Endoprosthetic replacement of the proximal humerus. *J Bone Joint Surg [Br]* 1987;69-B:656-61.
8. **Ross AC, Wilson JN, Sneath RS, Scale JT**. Humeral replacement. In: Coombs R, Friedlaender G, eds. *Bone tumour management*. London, etc: Butterworths, 1987:151-9.
9. **Finn HA, Simon MA**. Limb-salvage surgery in the treatment of osteosarcoma in skeletally immature individuals. *Clin Orthop* 1991;262:108-18.
10. **Bigard JD, Bigard ME**. Longitudinal growth of long bones. *Arch Surg* 1935;31:568-78.
11. **Digby KH**. The measurement of diaphyseal growth in proximal and distal directions. *J Anat and Physiol* 1916;1:187-8.
12. **Pritchett JW**. Growth plate activity in the upper extremity. *Clin Orthop* 1991;262:235-42.
13. **Pritchett JW**. Growth and predictions of growth in the upper extremity. *J Bone Joint Surg [Am]* 1988;70-A:520-5.
14. **Cool WP, Grimer RJ, Carter SR, Walker PS**. The outcome of extensible endoprosthetic replacement of the proximal tibia and distal femur. In: *Procs 8th International Symposium on Limb Salvage (ISOLS)*, Florence, 1995:126.
15. **Lavy CBD, Briggs TWR**. Failure of growing endoprosthetic replacement of the humerus. *J Bone Joint Surg [Br]* 1992;74-B:626.
16. **Unwin PS, Walker PS**. Extendible endoprostheses for the skeletally immature. *Clin Orthop* 1996;322:179-93.
17. **Enneking WF, Dunham W, Gebhardt MC, Malawar M, Pritchard DJ**. A system for the functional evaluation of reconstructive procedures after surgical treatment of tumours of the musculoskeletal system. *Clin Orthop* 1993;286:241-6.
18. **Damron TA, Rock MG, O'Connor MI, et al**. Distal upper extremity function following proximal humeral resection and reconstruction for tumors: contralateral comparison. *Ann Surg Oncol* 1997;4:237-46.