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Stiffness measurements to assess healing in bone transport: a preliminary report

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Abstract Little is known about the pattern of healing in patients undergoing bone transport for limb reconstruction. We evaluated the possibility of using bone stiffness for assessing healing in 8 consecutive patients treated with the Orthofix limb reconstruction system for non-union or bone loss. Six procedures were successful in achieving restoration of leg length and healing at both the docking site and the callotasis segment. Two procedures were unsuccessful, resulting in below-knee amputation. Of the six successful procedures, five were followed with bending stiffness measurements, while one patient was temporarily lost to follow-up. In all cases, the docking site took longer to heal than the callotasis segment. Patterns of healing of the callotasis segment were similar to that found in limb lengthening, and the docking site healed with a rate similar to that found in severe tibial fractures. The stiffness value proved to be a clinically useful, objective measure of healing in bone transport. A level of 15 Newton metres/degree (nm/d) allowed safe fixator removal in these cases.

Key words Bone transport • Stiffness measurements • Fracture healing

Introduction

Bone transport is a technique for limb reconstruction which is based on the generation of new bone at the callotasis site and consolidation of the docking site [1]. Little is known about the pattern of healing in patients in either the callotasis segment or at the docking site [2]. One study reported more frequent delayed union at the docking site than in the callotasis segment [3]. Assessment of healing currently relies on plain radiographs and clinical examination. Bending stiffness has been used as an objective measure to define healing in knee arthrodesis, tibial fractures, and limb lengthening [4–6]. The purpose of the present study was to determine the normal pattern of increasing stiffness during bone transport, and to compare the relative rates of healing of the callotasis segment with the docking site in the same individual.

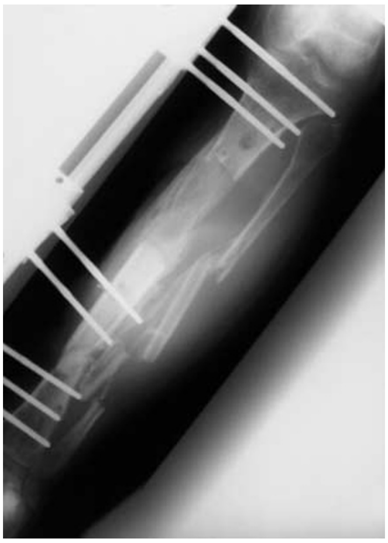

Fig. 1 The Orthofix Limb Reconstruction System. Docking was achieved as early as possible

Materials and methods

Over a four-year period, all patients undergoing tibial bone transport were studied. All patients had given their consent prior to inclusion in the study. A modified de Bastiani periosteal-preserving, low-energy osteotomy was performed [7]. The docking site was prepared either by excision of non-union or by trimming the bone ends in cases of a segmental defect. The Orthofix Limb Reconstruction System was used in all cases (Fig. 1). Docking was achieved as early as possible.

Routine stiffness measurements were made at regular outpatient clinics, when it was felt safe to temporarily remove the fixator, approximately 10 weeks from the end of lengthening or docking. Stiffness assessment was made in the anteroposterior plane with slight internal rotation to minimise the contribution of the fibula to the bending stiffness. This method has been described previously [8]. An average of 5 readings was recorded at regular outpatient follow-up visits. When the stiffness reached 15 Nm/d, the fixator was modified to leave the relevant site unprotected; this defined the healing time [6].

Results

Eight patients underwent tibial bone transport for either traumatic bone loss or nonunion. In 5 patients we were able to make bending stiffness measurements (Table 1). In only two cases, bone graft was used. In patient D, a fibula graft was applied at the time of docking as the bone ends needed further trimming to allow good apposition. In patient E, a delayed bone graft was applied posteriorly, for delayed union.

The stiffness began to rise from the starting point of docking for the distal site and at the end of lengthening for the callotasis segment. The time in weeks to achieve a stiffness of 15 Nm/d, the 'healing time', is shown in Table 2. The median healing time for the callotasis segment was 17 weeks and for the docking site 26 weeks. There were no refractures following fixator removal at either the callotasis or docking sites. One patient who had the fixator removed successfully went on to fracture through a pin site, with

Table 1 Characteristics of patients who underwent bending stiffness measurements during bone transport

Patient	Diagnosis	Age at operation, years	Sex	Regenerated length, mm	Bone graft to docking site
A	Traumatic bone loss	23	F	59	No
B	Infected nonunion	30	M	37	No
C	Infected nonunion	36	M	61	No
D	Infected nonunion	35	M	22	Yes (at 12 weeks)
E	Traumatic bone loss	32	M	90	Yes (immediately)

Table 2 Time to healing in 5 patients who underwent bone transport

	Patient					Median
	A	B	C	D	E	
Callotasis healing time (weeks from end of lengthening)	17	21	17	17	19	17
Docking healing time (weeks from docking)	28	24	26	60	20	26

Table 3 Patients excluded from stiffness measurements

Patient	Diagnosis	Reason for failure to complete study
F	Traumatic bone loss	Poor consolidation and failure to maintain skin cover. Continued to smoke. Leg amputation below knee
G	Infected nonunion	Poor attendance. Presented 17 months following fixator locking for removal. Successful
H	Infected nonunion	Transport over existing intra-medullary nail, persistent infected nonunion. Leg amputation below knee

minimal trauma, one week following fixator removal. In this case the surrounding bone had become very porotic.

Of the three other bone transports performed in our unit (Table 3), two cases failed to reach a healing end point. With one patient, we were unable to make stiffness measurements due to poor outpatient attendance during the critical time period; this patient has since been reviewed and the fixator successfully removed.

Discussion

The rise of stiffness in the callotasis segment and docking site resembled the rise in stiffness recorded in studies of leg lengthening [6] and fracture healing [4], respectively. As in those studies [4, 6], the stiffness rise in our study was approximately exponential. Moreover, the median healing time was 17 weeks for the callotasis segment, similar to the 20 weeks for tibial lengthening reported previously [6]. The median healing time for the docking site was 26 weeks, similar to the 22 weeks observed in the tibial fracture healing study [4]. Although the sample size here is too small for formal statistical analysis, we observed a tendency towards slower healing at the docking site. Even though other Authors have reported problems with re-fracture [9, 10], we did not and 15 Nm/d stiffness provided a safe level for fixator removal. The studies of tibial lengthening [6] and fracture healing [4] also found a value of 15 Nm/d as a safe level of bone stiffness at which to remove the fixator. Therefore, our small series of bone transports confirms the suggestion that it would be acceptable to use a figure of 15 Nm/d as a safe level of bone healing for fixator removal.

Our observation that the docking site healed more slowly than the calloatsis segment can be explained by findings from other centres. Paley et al. [3] reported a series of 25 bone transports, where 8 had delayed consolidation at the docking site while only 1 had delayed consolidation at the callotasis site. Green et al. [11] described a series of 17 patients in which grafting was needed in 5 docking sites for delayed union and in only one callotasis site. Another series of 13 patients identified 3 failed unions at the docking site, even though 6 patients underwent bone grafting or marrow injection [12]. The implication is that this may well be due to inferior conditions at the docking site. Paley et al. [3] identified 3 cases of interposing dead bone and 1 case of interposing infected necrotic bone at the docking site. Green et al. [11] biopsied the forward end of the moving segment in two cases of docking site nonunion, finding features of non-viability including empty lacunae.

It is interesting that the fastest healing docking site in our study was cleaned and grafted at the time of docking (patient E). In this case, the regenerated bone healed in almost the same time as the docking site (at 19 and 20 weeks, respectively). Although we do not advocate bone grafting for all docking sites, since many go on to union without intervention, it would be an advantage to identify early those sites which will need grafting. We believe that with stiffness measurements and reference to the normal charts that have been developed for leg lengthening and fracture healing [4, 6], it is possible to identify this subset early and so predict delayed union.

We found the technique challenging, with two patients going on to amputation, a complication reported by several other centres [3, 10, 11, 13]. Patients should be fully aware of the risks involved before embarking on such a treatment course. Amputation, one of the alternatives to bone transport, should be considered seriously for two reasons. First, the functional result may be better. Second, the procedure may jeopardise an otherwise healthy proximal tibia, thus affecting the chances of a satisfactory below-knee amputation. This was fortunately not the case in our series. With one fracture through a pin site in porotic bone following fixator removal, we now consider the use of a protective splint following fixator removal in cases where bone may have become very porotic following a prolonged treatment course.

Therefore, we believe that in addition to the clinical situations of leg lengthening and fracture healing, bending stiffness is also useful measure of healing in bone transport. It can be an objective method for identifying a level of healing sufficient for safe fixator removal and also, by predicting delayed union, allows for early bone grafting in those patients who need it.

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