

Case report

Bone transport over an intramedullary nail A case report with histologic examination of the regenerated segment

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1. Introduction

Bone transport is useful for the treatment of segmental defects, non-union and osteomyelitis. Bone transport has been compared to conventional techniques for the treatment of segmental defects and infection and found to provide better restoration of leg length, to need less cancellous grafting, to have fewer graft fractures and to require less operating time and hospital stay and to have a lower disability [1–3]. When comparing bone transport with cancellous grafting rates of union and infection have been found to be similar [1–3]. Bone transport over an intramedullary nail has been reported in animal studies [4,5] and in small clinical trials [6–9]. There are clear advantages to intramedullary fixation during bone transport, including improved rigidity of the fixation construct [8,10]. This has been suggested to be an important mechanical factor for optimal regeneration; other advantages include maintenance of anatomic length and alignment and early removal of the external fixation system, permitting improved patient mobilisation and muscle function [11].

However, bone transport over an intramedullary nail undermines two of Ilizarov's principles for opti-

mising osteogenesis: preservation of blood supply and preservation of medullary osteogenic tissue, thereby possibly compromising the viability of the regenerating segment [12]. Yet, studies using sheep and goat models of distraction osteogenesis over an intramedullary nail do not demonstrate compromise of the regenerating segment [4,10].

Important questions remain regarding viability of the transport segment, the healing pattern of the regenerating segment in humans, the capacity of the endosteum to contribute to primary healing [6] and the observed asymmetry in healing between posterolateral and anteromedial regions of the tibia [4,10]. In this paper a case of intercalary segment bone transport performed over an intramedullary nail for the treatment of a tibial non-union with large segmental bone loss is reported. The radiographic and histologic features of the regenerating segment in a human are described and the influence of an intramedullary device on distraction osteogenesis during bone transport is discussed.

2. Patient and methods

2.1. Case report

A 45-year-old Caucasian female fell from a horse and sustained a closed short oblique fracture of the middle third of her left tibia (A0/ASIF A2 pattern). Attempted internal fixation with an intramedullary nail was complicated by inability to pass the nail across the fracture. The fracture site was then opened

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and plate osteosynthesis was performed using a six hole, 3.5 mm DCP plate (Synthes).

Delayed union followed and was treated with open grafting and replacement of the internal fixation with an eight hole DCP plate (Synthes). Three months later deep infection developed. The infected non-union was treated with removal of the metal and external fixation and she was referred to us. Excision of dead and infected bone resulted in a 16-cm diaphyseal defect. This was stabilised with a two-ring Ilizarov fixator with a tranfixion wire immediately adjacent to the tibial articular surface. Intravenous antibiotic therapy was initiated and one month after debridement of the infected diaphysis, infection appeared to be eradicated, although a large segmental defect remained. The external fixation was revised to an unilateral orthofix limb reconstruction system (Orthofix Instrument, UK) and an intramedullary nail was inserted using a limited exposure to bridge the defect and maintain length. A submetaphyseal corticotomy was performed separating a 3.5-cm bone transport segment from the proximal tibial metaphysis. Care was taken to preserve the periosteal blood supply. After five days, distraction was commenced at a rate of 1 mm/day in four increments. New bone formed well with radiographic evidence of good consolidation of the regenerating segment. Nine months after initiation of distraction osteogenesis the transport segment reached the docking site. The docking site was explored, scar tissue was removed from between the bone ends, subsequently the nail was removed. During the following month the patient was well and the fracture united. Unfortunately, at this stage a refracture occurred and sign of infection (erythema and malaise) reappeared. The transport fragment appeared sclerotic on X-ray and the patient could not tolerate any further treatment and, therefore, elected to undergo below knee amputation 37 months after the initial injury.

2.2. Materials and methods

The amputated lower extremity was taken directly to the laboratory for fixation and analysis. The tibia was separated from its soft tissue attachments by sharp dissection. The proximal level of resection was in the proximal third of the diaphysis through regenerated bone. The distal extent was through the fracture site. The bone was sectioned circumferentially into five segments; anteromedial, anterolateral, posteromedial, posterior and posterolateral. Each circumferential region was then sectioned into 1–2 cm lengths. The bone was fixed in 10% neutral buffered formaldehyde and then decalcified in 15% EDTA buffered (pH 8.0) for 2–4 weeks. Specimens were radiographed to confirm complete decalcification. After decalcification, sections were embedded in paraffin wax for histological

analysis. Transverse and longitudinal sections were cut at 10 μ m thickness and stained with haematoxylin and eosin. Gram staining was also performed.

3. Results

3.1. Gross description of the specimen

The length of the specimen was 18 cm with 16 cm of regenerated bone and 2 cm of the transported segment. There was no purulent exudate or evidence of gross infection at the non-union site or within the medullary canal. The residual transport segment appeared avascular, dense and necrotic. There was clear delineation between the dense cortical bone of the transport segment and the trabecular bone of the regenerated segment. The new trabecular bone had a vertical alignment. The regenerated segment appeared well-vascularised especially on the periosteal surface. The endosteal surface appeared irregular, with patchy avascular areas with small areas of grossly necrotic bone near the endosteum of the anteromedial portion of the tibia.

3.2. Radiographic appearance

Throughout the 9-month period of bone transport, the radiographic appearance of the regenerating segment demonstrated normal maturation and consolidation. The original defect measured 16 cm. Early regenerating bone appeared as parallel vertical calcification. The transport segment appeared sclerotic at 7 months and remained without evidence of remodelling or resorption (Fig. 1a). At the end of transport the regenerating segment showed excellent alignment with the docking site (Fig. 1b). The regenerating segment appeared to be undergoing active remodelling and maturation along its length without radiographic evidence of focal necrosis or devascularisation.

3.3. Histologic examination of the regenerate

Longitudinal and transverse sections were examined from each of the 52 sections along the length and around the circumference of the regenerated and transport segment. These were assessed histologically in terms of bone viability, vascularity, remodelling activity, type of bone structure and organisation (woven or trabecular) and for evidence of inflammation or infection.

Examination of the regenerated and bone transport segments showed clear differences between the organisation and structure of pre-existing bone and bone induced by distraction. In transverse sections, the regenerated segment showed a largely trabecular or-

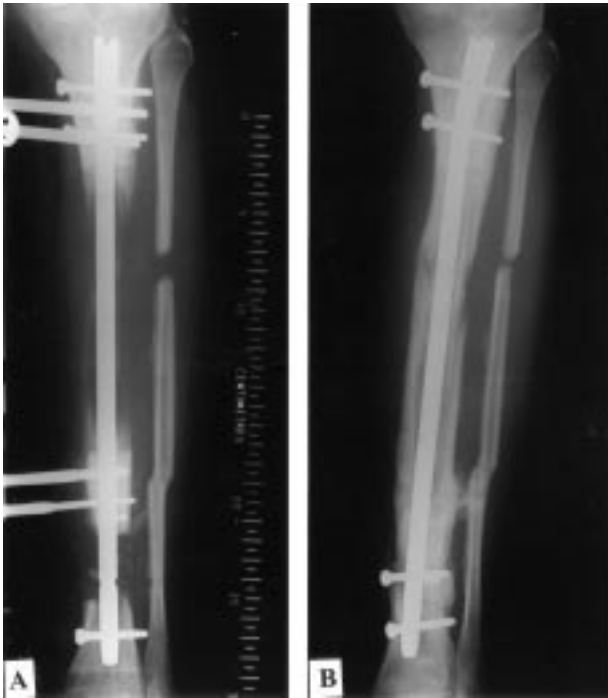


Fig. 1. (a) AP view of the radiographic appearance at 7 months after initiation of bone transport. Transport segment appeared with sclerotic features and there was evidence of early consolidation of the regenerating segment. (b) Radiographic appearance at 9 months, completion of bone transport. There was good alignment of the regenerating segment and evidence of good consolidation of the regenerating segment, but radiographic evidence of non-union at the docking site was obvious.

ganisation without formation of a discrete cortex of compact bone (Fig. 2a). In longitudinal sections it was evident that the trabecular pattern of the regenerated segment was oriented in a columnar fashion, the columns of trabecular bone lying parallel to the direction of distraction (Fig. 2b). In contrast, the bone transport segment retained its dense cortical structure, showing little evidence of remodelling or neovascularisation, both features which were prominent in the regenerating segment (Fig. 2c). The dense sclerotic radiographic appearance of the transport segment correlated with the histological appearance.

This revealed dense lamellar bone with generalised loss of osteocyte nuclei from a number of the lacunae within compact bone, focal fibrosis within Haversian channels and hypermineralisation of the edge of bone surrounding the Haversian channels. The transport segment had multiple empty lacunae indicating that bone necrosis had occurred (Fig. 2c). Under polarised light the transport segment was composed of mature lamellar bone. In contrast, the regenerated segment was composed of a mixture of woven and lamellar bone. The regenerated segment showed evidence of active remodelling with prominent cement lines and osteoblasts and osteoclasts on the trabecular surfaces.

Immature woven bone was seen even in the proximal portion of the regenerating segment 22 months after the initiation of distraction, demonstrating a prolonged phase of remodelling in the regenerated segment (Fig. 2d).

Within the regenerated segment, the bone was largely viable and composed of a mixture of woven and lamellar bone in trabeculae of variable thickness (Fig. 3a). However, along the endosteum, where bone abutted the fibrous membrane within the marrow space, necrotic bone trabeculae were seen (Fig. 3b). Evidence of ischaemic and necrotic changes within the regenerated segment included empty central osteocyte lacunae within the trabecular bone (Fig. 3c). There was also prominent hypermineralisation of the edges of Haversian systems in the vicinity of necrotic bone. This was essentially only in the inner third of the specimen and principally in the anterior specimens. Comparing specimens of bone taken from the posterolateral region with those in the anteromedial region of the regenerated segment, there was clear evidence of asymmetry. Specimens taken from the posterolateral segment showed numerous osteocytes within thickened trabeculae and frequent cement lines indicating that the tissue was metabolically active with rapid bone formation and remodelling (Fig. 4a and b). However, active osteoblastic and osteoclastic activity was essentially confined to the periosteal and endosteal areas. Polarised light revealed a mixture of woven and lamellar bone, with no evidence of endochondral bone formation in the posterolateral region (Fig. 4c). Foci of chronic inflammation were seen in the distal part of the anteromedial region of the regenerated segment (near the non-union site); these contained an infiltrate of lymphocytes, histiocytes and occasional plasma cells (Fig. 4d). There was no evidence of acute inflammation and no organisms were seen on Gram staining of any of the specimens (not shown).

4. Discussion

In this case, bone transport over an intramedullary nail was performed with induction of a long regenerating segment. An amputation was eventually carried out when refracture occurred at the docking site because of the prolonged period of treatment for the fracture and not because of any insufficiency of the regenerated segment. This supports the view that distraction osteogenesis can occur successfully over an intramedullary nail during bone transport. However, the histological analysis of the regenerated segment indicated that there were asymmetries within the regenerated segment of (1) endochondral bone formation; (2) trabecular structure; (3) indices of metabolic activation and (4) cell viability. These histologic asymme-

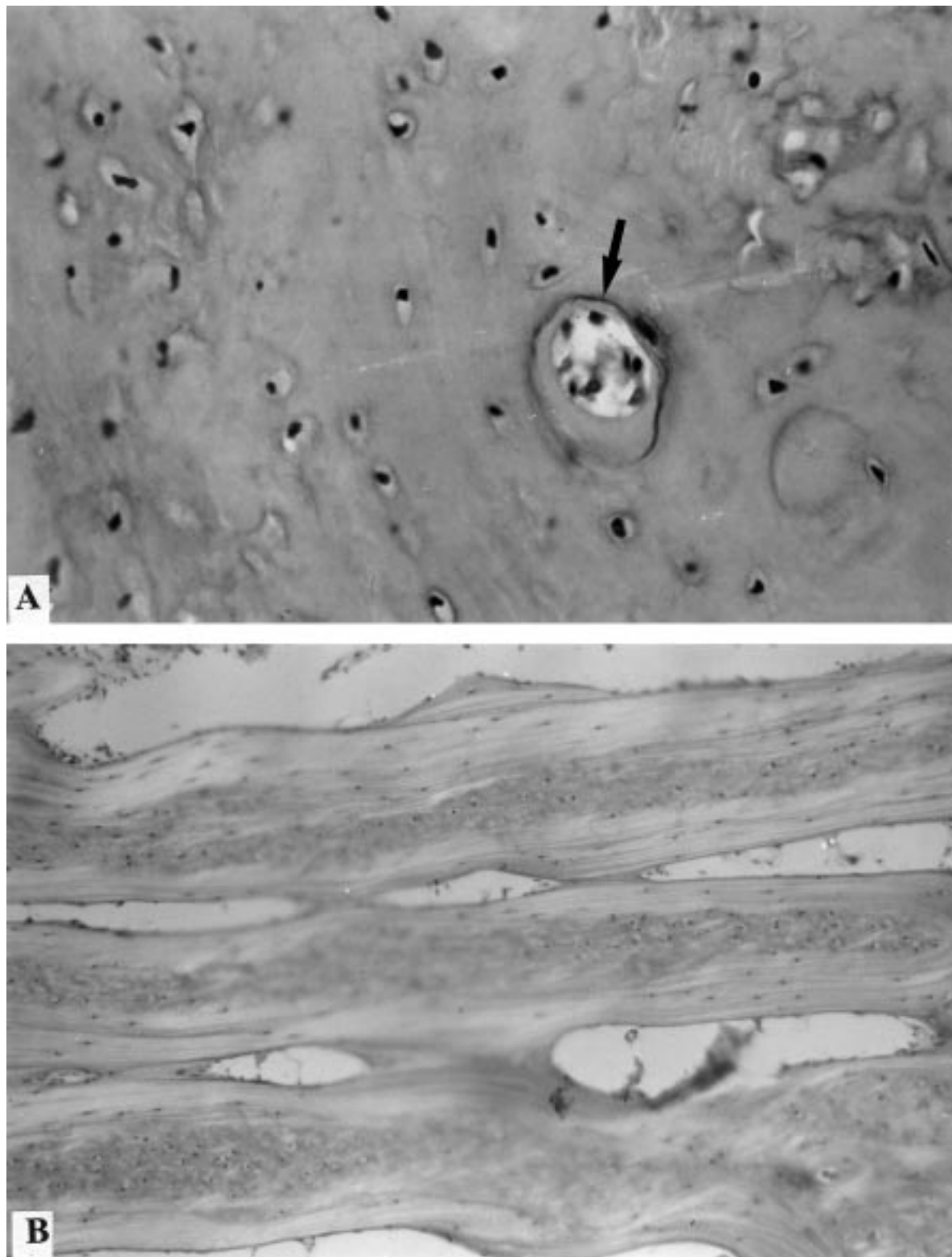


Fig. 2. (a) Transverse section of the regenerated segment showed trabecular appearance with Haversian channels (arrow). (b) Longitudinal section of the regenerated segment under polarised light. The new bone formed parallel to the direction of distraction with trabecular pattern. (c) Dense cortical bone of the transport segment showing numerous scattered empty lacunae (arrows). Absence of osteoblast or osteoclast activity confirms no remodelling within the segment. (d) Woven and lamellar bone with prominent cement lines in trabeculae of the regenerated segment. There was active remodelling by numerous osteoclasts (arrows). (a–d) Haematoxylin and eosin staining, $\times 100$.

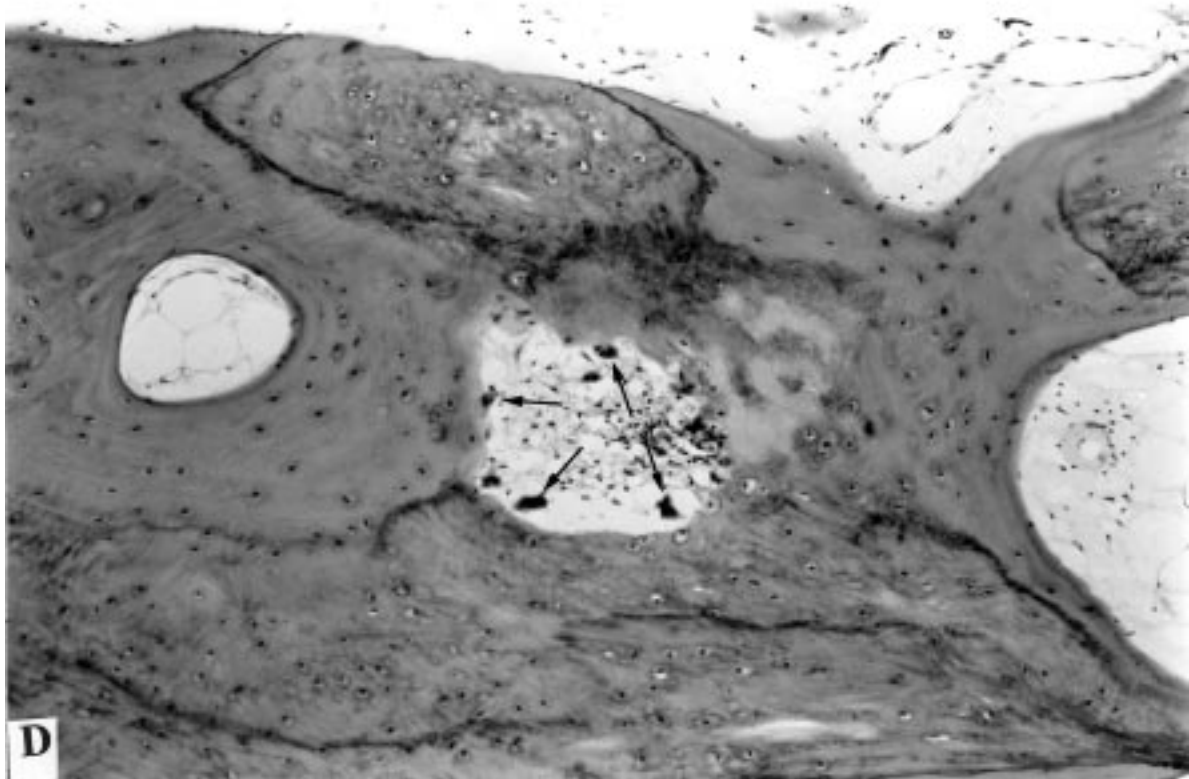
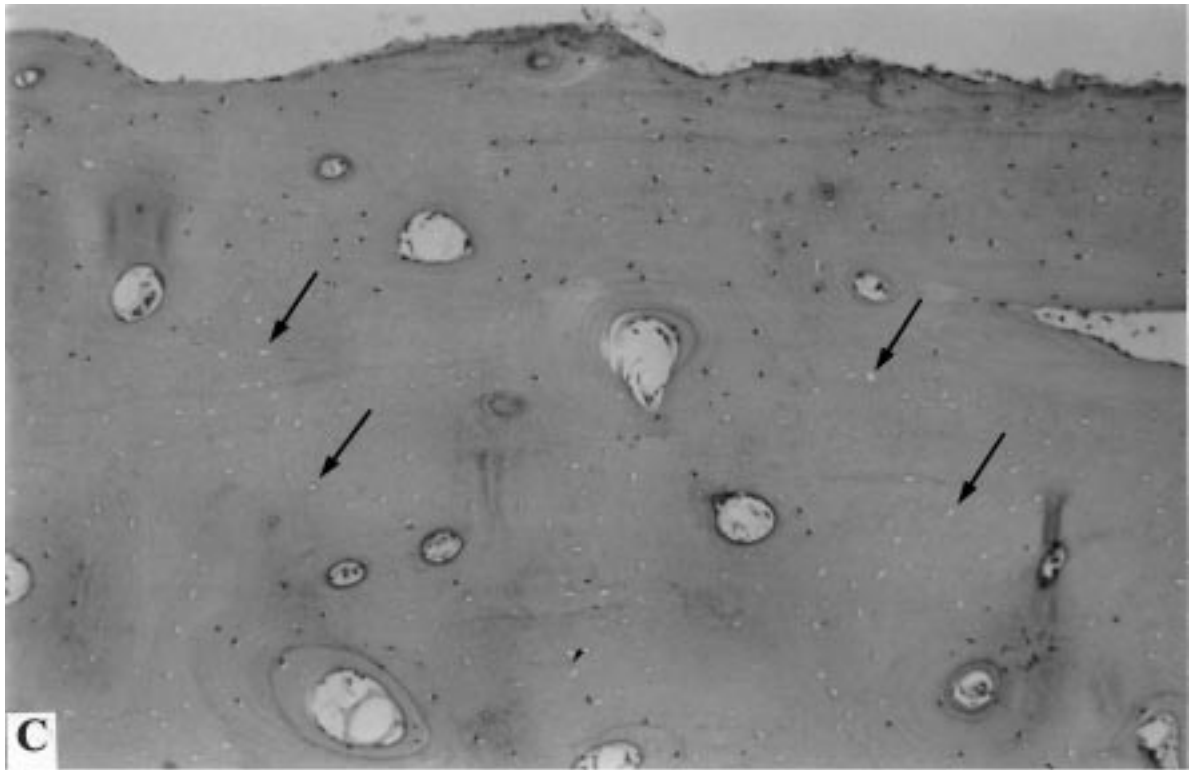


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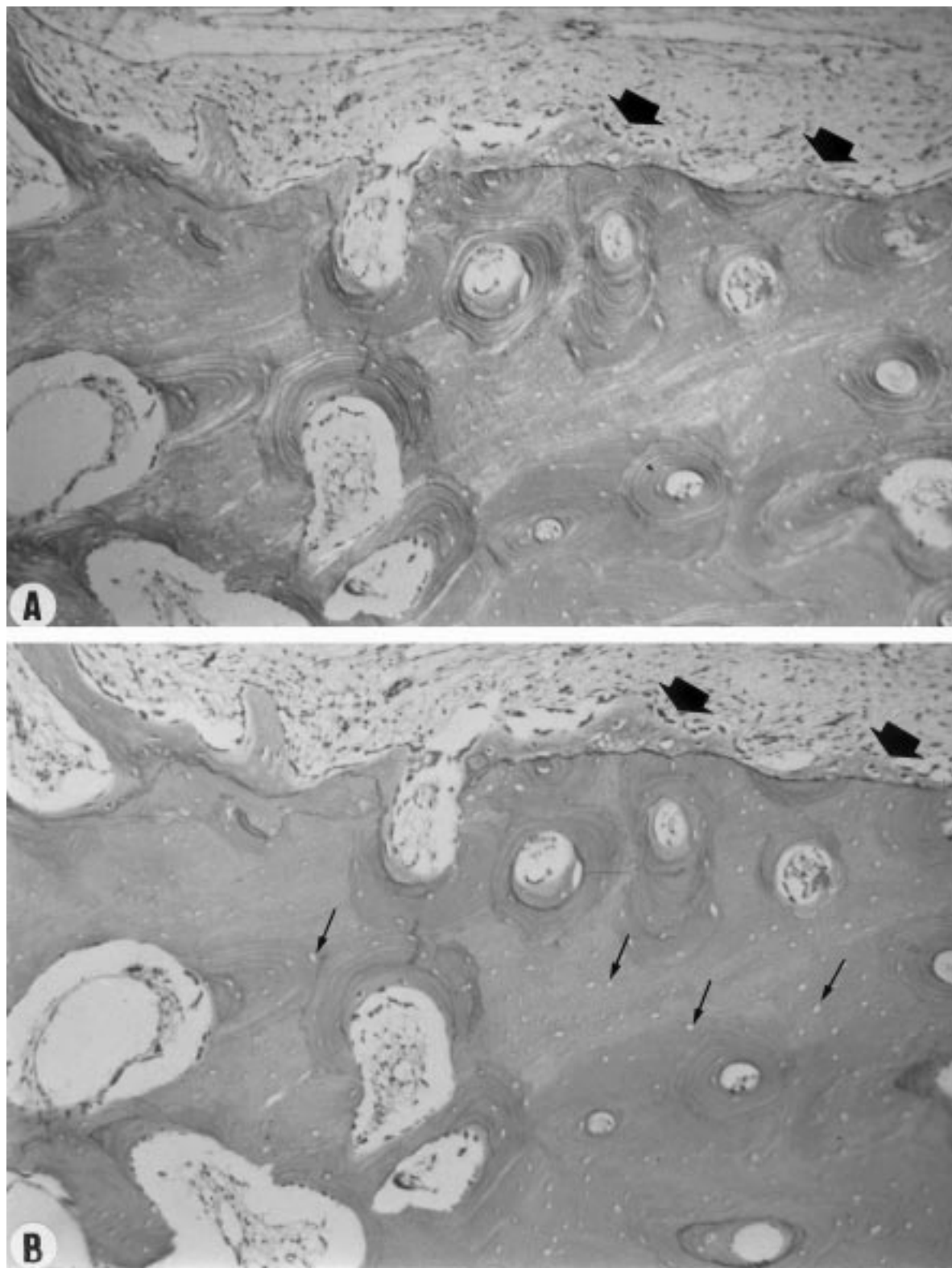


Fig. 3. (a) View of anteromedial endosteal region under polarised light. Lamellar bone was predominant within the regenerated segment, there was appositional new woven bone formation at the surface (arrows). (b) Endosteal region of the anteromedial aspect of the regenerated segment. There was appositional bone formation on the endosteal surface (big solid arrows). There were numerous empty osteocyte lacunae (small arrows) in underlying bone. (c) High power view appositional bone formation on necrotic endosteal bone surface (arrow) from anteromedial region of the regenerated segment. (a–c) Haematoxylin and eosin staining, (a) and (b), $\times 100$; (c) $\times 400$.

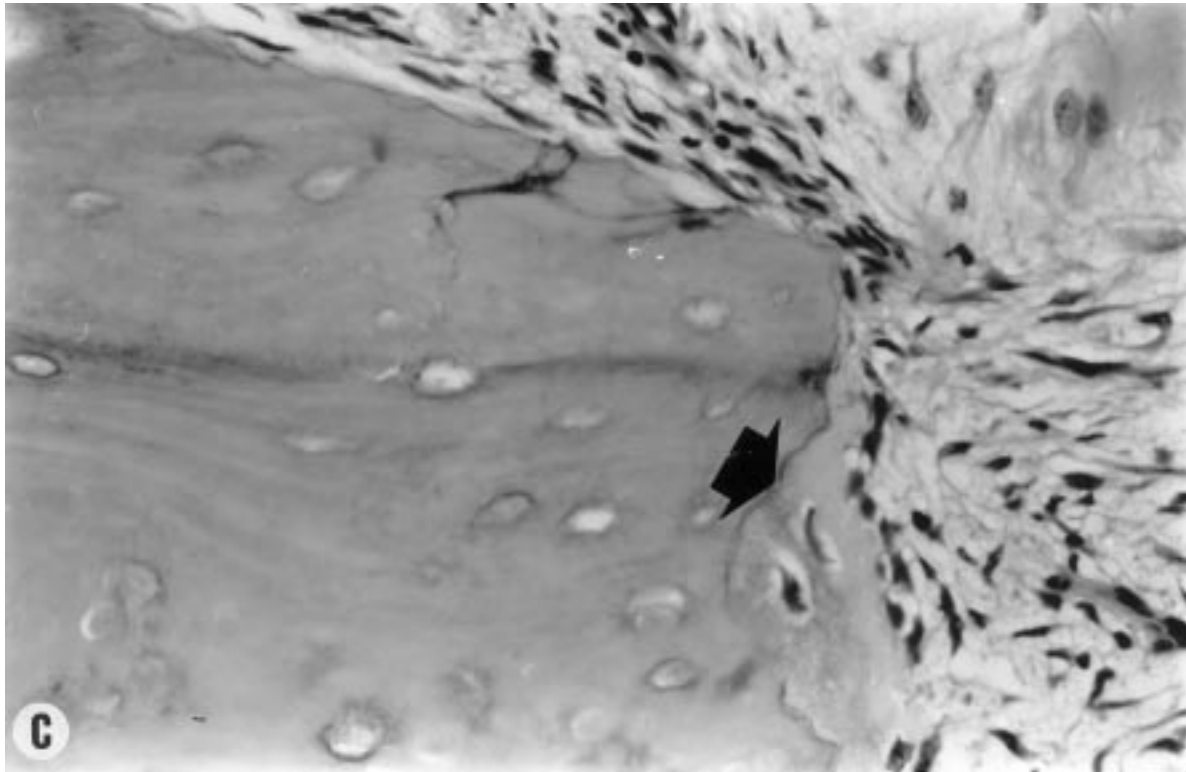


Fig. 3 (continued)

tries were not apparent clinically. Specimens from the anteromedial regions of the tibia showed evidence of ischaemia along the length of the distraction callus. Primitive callus formation was seen with a cartilaginous morphology. Evidence of ischaemia to the anteromedial region of the tibia was also suggested by the organisation of the callus, with thinner and less cellular trabeculae, fatty replacement of the marrow cavity and fewer parallel cement lines than in the specimens from the posterolateral tibia. Intramedullary nailing poses a risk of infection and creates a pathway for infection to spread along the length of the diaphysis. We identified no evidence of extension of infection along the length of the regenerated segment. The absence of identifiable organisms or acute inflammation along the regenerated segment suggest that the histologic observations of compromised bone viability and regenerative capacity were primarily due to compromised vascularity rather than dissemination of infection.

In previous reports on the histology of lengthened tibiae using external unilateral lengthening frames rather than intramedullary nails necrotic bone fragments were observed, but the pattern of endosteal and anteromedial ischaemia was not identified [7,13,14]. We have identified histological evidence of ischaemic changes to the anteromedial region of the regenerated

segment and compromised viability relative to the posteromedial region of the tibia. We conclude that the histological asymmetries within the regenerating bone were due to compromise of the endosteal circulation from intramedullary fixation. During short segment bone transport, the transport fragment may be able to maintain some of its original soft tissue attachments. However, during bone transport over a long distance this may not be possible. In this situation the transport segment may have to depend entirely on blood flowing through the longitudinally arranged blood vessels in the regenerating segment for its viability. Intramedullary nailing may compromise the blood flowing to the transport segment through the regenerating segment and result in necrosis of the transport segment. Patients in whom the transport segment becomes avascular will be at risk of non-union or refracture at the docking site and in cases of radical excision for infection, necrosis of the transport segment would predispose these patients to recurrence of infection. Therefore, for long segment bone transport we suggest that bone transport over an intramedullary nail should be carefully considered or avoided especially in patients whose excision has been done for infection.

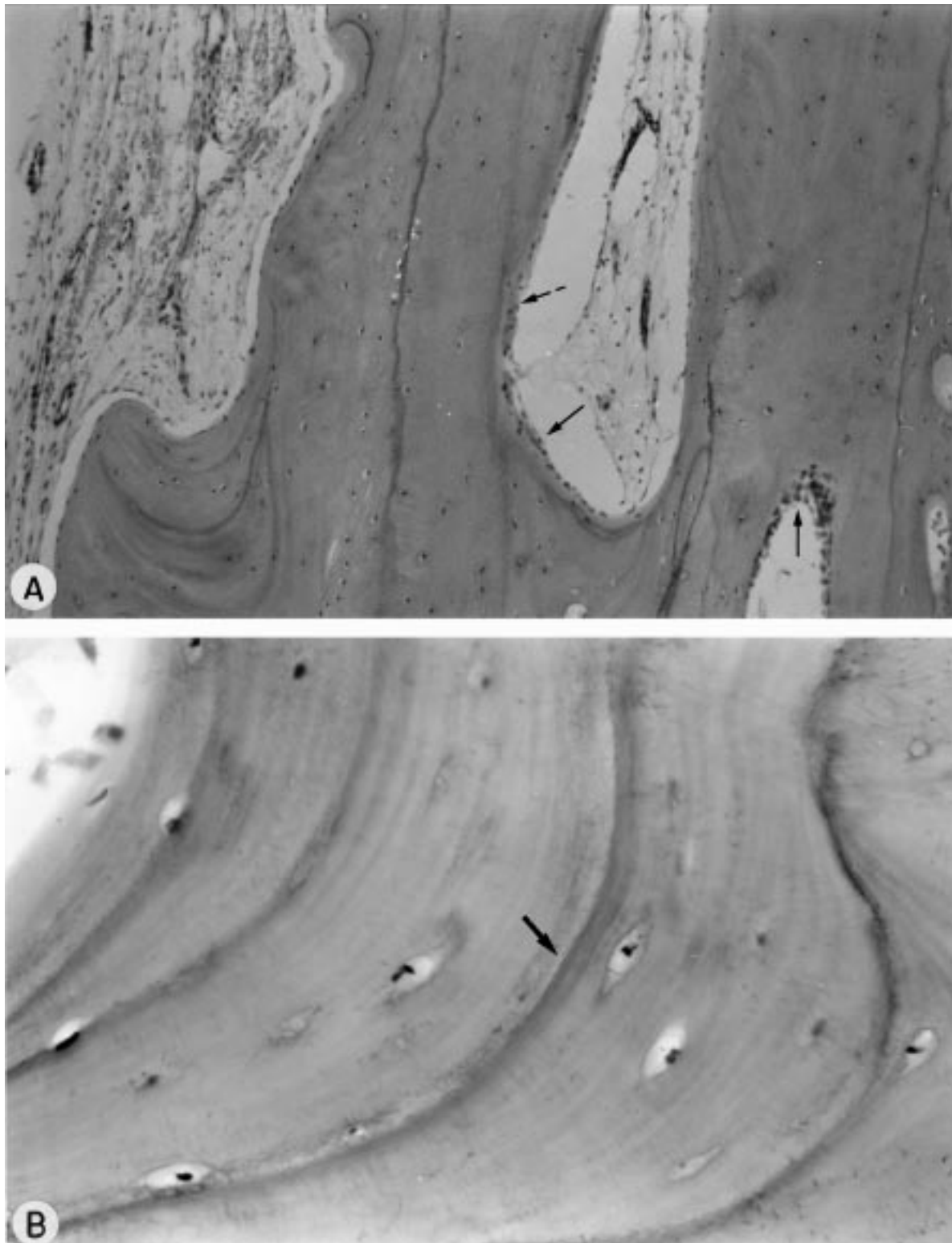


Fig. 4. (a) The regenerating bone near the endosteal surface at the posterolateral aspect. Note the prominent cement lines and plump osteoblasts lining on the bone surfaces (arrow). (b) High power view of the regenerating bone from the posterolateral region. The prominent cement lines (arrow) indicates active bone formation and remodelling. (c) View of anteromedial endosteal region under polarised light. Lamellar bone was predominant within the regenerated bone, there was appositional new woven bone formation at the surface (arrows). (d) Foci of chronic inflammation (arrow) were seen near the non-union site of the distal site of the regenerated segment. (a–d) Haematoxylin and eosin staining, (a, c and d), $\times 100$; (b) $\times 400$.

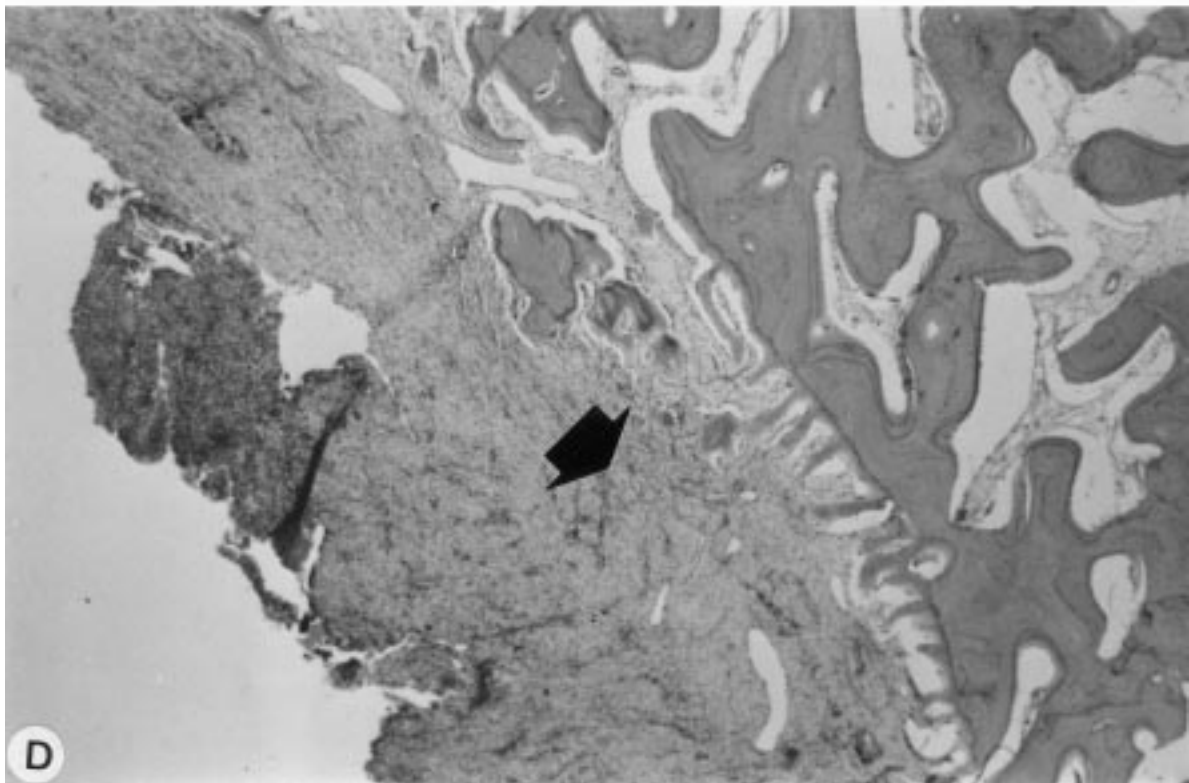
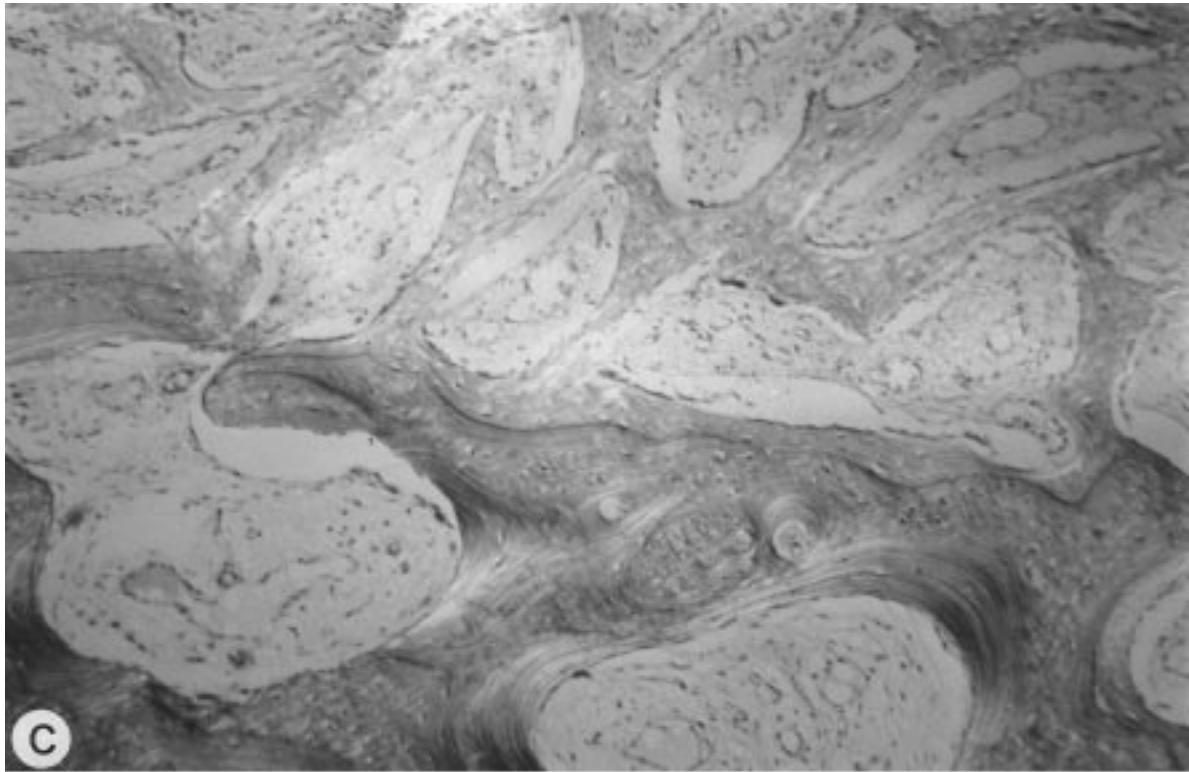


Fig. 4 (continued)

References

- [1] Cierny G, Zorn KE. Segmental tibial defects: comparing conventional and Ilizarov methodologies. *Clin Orthop* 1994;301:118–23.
- [2] Green SA. Skeletal defects: a comparison of bone grafting and bone transport for segmental skeletal defects. *Clin Orthop* 1994;301:111–7.
- [3] Williams MO. Longterm costcomparison of major limb salvage using the Ilizarov method versus amputation. *Clin Orthop* 1994;301:156–8.
- [4] Lin V, Huang S, Lui T, Chapman M. Limb lengthening over an intramedullary nail: an animal study and clinical report. *Clin Orthop* 1996;330:208–16.
- [5] Schemitsch EH, Kowalski MJ, Swionkowski MF, Harrington RM. Comparison of the effect of reamed and unreamed locked intramedullary nailing on blood flow in the callus and strength of union following fracture of the sheep tibia. *J Orthop Res* 1995;13(4):382–9.
- [6] Paley D, Catagni MA, Argnani F, Villa A, Benedetti GB, Cattaneo R. Ilizarov treatment of tibial non-unions with bone loss. *Clin Orthop* 1989;241:146–65.
- [7] Prokuski LJ, Marsh JL. Segmental bone deficiency after acute trauma: the role of bone transport. *Orthop Clin North Am* 1994;25:753–63.
- [8] Tornetta P, Bergman M, Watnik N, Berkowitz G, Steuer J. Treatment of grade IIIB open tibial fractures: a prospective randomized comparison of external fixation and nonreamed locked nailing. *J Bone Joint Surg* 1994;76(4):13–7.
- [9] Watson JT, Anders M, Moed BR. Management strategies for bone loss in tibial shaft fractures. *Clin Orthop* 1995;315:138–52.
- [10] Brunner UH, Cordey J, Kessler S, Rahn BA, Schweiberer L, Perren SM. Bone segment transport in combination with an intramedullary nail. *Injury* 1993;24S:29–44.
- [11] Raschke MJ, Mann JW, Oedekoven G, Claudi BF. Segmental transport after reamed intramedullary nailing: preliminary report of a 'monorail' system. *Clin Orthop* 1992;282:233–40.
- [12] Marsh JL, Prokuski L, Biennann JS. Chronic infected non-unions with bone loss: conventional treatment vs. bone transport. *Clin Orthop* 1994;301:139–46.
- [13] Shearer JR, Roach HI, Parsons SW. Histology of a lengthened human tibia. *J Bone Joint Surg* 1992;74:39–44.
- [14] Windhager R, Tsuboyama T, Siegal H, Groszschmidt K, Seidl G, Schneider B, Plenk Jr. H. Effect of bone cylinder length on distraction osteogenesis in the rabbit tibia. *J Orthop Res* 1995;13(4):620–8.