Distraction and segment transport are accepted treatments for fracture management. This study shows distraction as the more efficient method for osteoinduction.

**Materials and Methods**

This study was performed at the AO/ASIF Research Institute in Davos Platz, Switzerland, and was approved by the Ethics Committee of the Kanton Graubunden. Twenty adult female Swiss mountain sheep (average weight 62 kg) were included in this study, and were divided into two groups (A and B) of 10 animals each.

They were operated under endotracheal anesthesia and strict sterile operating conditions. A modified four ring-hybrid external fixation frame with calibrated vertical rods (8×15 cm) was mounted on the left tibial diaphysis (Figure 1). Each ring was mounted to bone by two 1.6-mm Kirschner wires (Synthes AG From the *Medical Faculty of the Technion, Haifa, Israel; the †AO/ASIF Research Institute, Davos Platz, Switzerland; and the ‡Department of Orthopedic Surgery, Hadassah Medical Center, Ein Kerem, Jerusalem, Israel.

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crossed at right angles for maximum stability (Figure 1). While mounting the frame, care was taken to locate the bone in the center of each ring. Following subperiosteal dissection, a 2.5-cm long segment of bone was resected from the middle third of the tibial diaphysis using a low speed maxillofacial saw (Synthes AG Chur).

In group A, bone ends were brought into contact without compression. The surgical wound was closed by interrupted sutures and bandaged. Following a 72-hour resting period, intermittent manual distractions every 8 hours in 0.3-mm increments were started using the calibrated vertical rods of the fixation frame (Figure 1). On day 28, the length of the left tibia was restored and comparable to the right tibia. Tissues were left to consolidate for 7 additional days.

In group B, a third proximal osteotomy was performed 2 cm proximal to the cranial osteotomy of the removed segment. Thus, a transportable segment was created. It was stabilized by a fifth ring with two cross wires, located between the upper and lower rings. Following the 72-hour resting period, segment transport of the free proximal segment was started at 8 hourly intervals in 0.3-mm increments using the calibrated vertical rods of the fixation frame (Figure 2). Radiographic follow-up was the same for both groups. Radiographs were taken in the anteroposterior (AP) and lateral planes on days 14, 28, and 35 at 55 Kv, 200 mA, and an exposure time of 0.25 seconds. On day 35, all sheep were euthanized by an overdose of pentobarbital. The hind limbs were explanted through the knee.

Developing calluses were evaluated and followed by the callus index method as described by Kenwright and Gardner.18 This mathematical ratio represents a quantitative measure of the developing callus.

The explanted tibiae were frozen at −70°C. The right tibia was the control in each experimental animal. Total contact macroradiographs were obtained of all tibiae in a faxitron system (Faxitron 804; Field Emission Corp, McMinnville, Ore; Schweizer AG, Rontgentechnik, Zurich) with a 5-minute exposure time. Using a band saw, the tibia was cut into two equal halves in the sagittal plane. One half was further cut into 350-µm thick slices from which microradiographs were obtained (Figure 3). By using this processing sequence, a clear and detailed topographical anatomy became available for evaluation of all experimental bone defects (Figure 3). The other half of the tibia was processed for histology, and slices were stained with toluidine blue to demonstrate new bone formation (Figure 4).

**RESULTS**

All sheep made an uneventful recovery from surgery. They were kept in individual enclosures, and were full weight bearing on the operated limb within 36 hours postoperatively. Two sheep developed superficial soft-tissue infections around pinholes, both in the second ring from the top. They were treated by local debridement and antiseptic wet dressings, and healed. None received systemic antibiotic treatment, and no deep infections occurred.

Periosteal callus was identified in distraction and segment transport, but was more prominent in the distraction group. In the sagittal plane, it developed first at the muscle/bone interface, next to the muscle bed. Radiographs taken on days 28 and 35 showed that medullary and periosteal calluses became confluent and steadily developed in a posteroanterior direction. In the segment transport group, the distraction callus was far less prominent. At the docking site, callus first appeared on day 28 and was sparse. Callus indices on AP radiographs showed no significant statistical difference.
between distraction and segment transport at any measured time interval, whereas the differences in callus indices measured on lateral radiographs between the two groups showed statistical significance at all time intervals (Table).

These results demonstrate a much more efficient and proliferative osteogenetic process in distraction, originating at the muscle–bone interface. Microradiographs demonstrated medullary and periosteal callus formation in distraction, whereas in segment transport only medullary callus was present.

On microscopic examination, cortical bone in group A demonstrated Howship’s lacunae and direct penetration of newly formed membranous bone into the cortical bone ends at the “fracture” margin. In group B, Howship’s lacunae were not detected in the cortical bone of the transported segment or in the cortical bone of the “fracture” margin.

**DISCUSSION**

Bone has an active metabolic turnover, which is closely interrelated to patterns of loading for new bone formation. Its structure and shape is the morphometric expression of function. Every long-term change in weight bearing patterns, loading, or both is followed by definite changes in the architecture of the cancellous bone, reshaping its form. Gravity induces static loading whereas active loading is the result of muscle motor activities. Cyclic axial loading increases bone turnover and its muscle bed is essential for the induction of new bone formation and fracture healing. This interrelationship has been proven to have practical applications in the reconstruction of femoral heads affected with avascular necrosis and in the treatment of fractures.

Most recently, Sakata et al described the ability of unloading to block the function of insulin growth factor-I in new bone formation. During muscle contraction, muscle tendons at insertion sites create distraction, which is an osteoinductive stimulus thus forming tubercles and tuberosities. The building blocks of skeletal muscles are myofibers with connective tissue septae tissue between them. In the latter, osteoprogenitor cells have been identified and new blood vessels proliferate and penetrate into the fracture gap. The osteoprogenitor cells are pericytes, paravascular cells located in these septae. Distraction in small increments causes no lasting muscle damage thereby not impairing their reported osteogenic potential. Results of this study support the possibility that intimate contact between fractured bone and its muscle bed is essential for the induction of new bone formation and fracture healing. Once started, this osteogenesis cannot be halted by the interposition of membranes with varying pore sizes. In the segment transport group, intimate contact was not preserved in the transported segment, thus explaining why only sparse callus formed at its distracted end and docking site. In the distraction group, metabolic bone activity was preserved as demonstrated by the abundance of Howship’s lacunae in its cortical bone. It is reasonable to assume that this is due to the fact that the transported segment of bone was dissected free of its soft-tissue envelope. It was continuously shifted in the axial plane away from its muscle bed, preventing the effective formation and penetration of new blood vessels from the muscle bed into the fracture gap filling the bone defect. Under these circumstances, the osteoinduction and angiogenesis originating from the muscle bed could not ensue and develop.

Stable fracture fixation applied with minimally invasive surgical techniques, which allow intersegmental axial loading of fractured bone and preserve a viable muscle envelope, appears to be the optimal mechanical condition for the biological process of fracture healing. The new bone is formed by membranous ossification.

**REFERENCES**


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