Intermittent micromotion inhibits bone ingrowth.

Titanium implants in rabbits

Per Aspenberg[1], Stuart Goodman[1], Søren Toksvig-Larsen[1], Leif Ryd[1] and Tomas Albrektsson[2]

We studied the effects of micromotion on bone ingrowth into a 1-mm canal through a titanium chamber implanted in the proximal tibia of rabbits. The implant surface became "osseointegrated," but an interior core was movable, allowing the central portion of the canal to be moved in relation to the ends. Thus, the ingrowing bone in the canal had to pass an area of *ad latus* motion. When implanted in rabbit tibiae, the canal became filled with ingrown cancellous bone. Bone ingrowth was inhibited by 20 cycles of 0.5-mm movement applied during a 30-second period once daily. With this regimen, the canal was usually filled with vascularized fibrous tissue and significantly less bone. The micromotion chamber may enable detailed studies of the effects of different motion variables on ingrowth of bone.

Department of [1]Orthopedics, University Hospital, Lund, and [2]Institution for Handicap Research, Gothenburg, Sweden
Tel +46-46 151000. Fax +46-46 130732
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Motion between implant and bone inhibits bone ingrowth into a porous implant surface (Duchyene et al. 1977, Pilliar et al. 1986). It is unclear how much motion is compatible with bone ingrowth, with respect to amplitude, number of cycles, and time between strain episodes. Daily, short episodes of strain are sufficient to maintain the structure of long bones (Rubin and Lanyon 1987), and a bone tissue "memory" for strain has been suggested (Skerry et al. 1988). What is the effect of daily, short episodes of strain on the tissue between a metallic implant and bone?

We have developed a model for bone ingrowth into a pore in which motion of a predetermined amplitude and frequency can be manually imposed.

Materials and methods

The chamber

The Micromotion Chamber is a development of the Bone Harvest Chamber (Albrektsson et al. 1984). It is a cylindric titanium implant with a transverse 1-mm-wide canal for tissue ingrowth (Figures 1 and 2). The cylinder is closed at one end and open at the other to receive a removable titanium core. When implanted in the bone, the open end of the cylinder sticks out in the surrounding tissue, allowing the core to be removed when necessary, without disturbing the outer cylinder or the surrounding bone. The cylinder is pierced by two 1-mm-diameter holes coinciding with a transverse groove across the inside end of the core. Thus, when implanted in bone, a continuous canal through the implant provides a channel for tissue ingrowth. The core inside the cylinder is connected to a cover containing two subcutaneous "horns"; this enables the core to be rotated by external manipulation to create an *ad latus* motion in the canal at the interface between the core and the cylinder. The amplitude of movement is predetermined by the size of a stop-screw. The core can be removed at any time to allow repeated harvesting of the contents of the canal, without disturbing the outer cylinder or the surrounding bone.

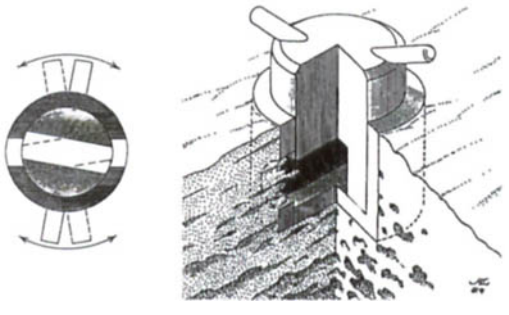
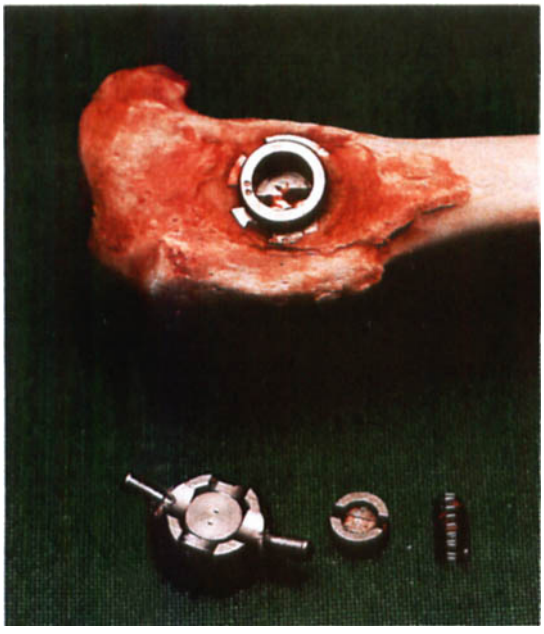


Figure 1. The micromotion chamber (schematic).



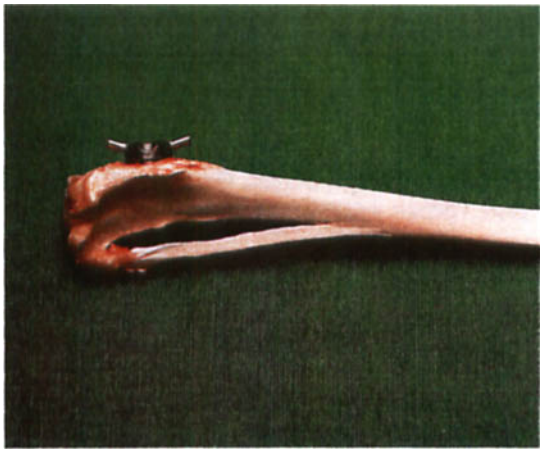


Figure 2. The micromotion chamber disassembled and assembled in the rabbit tibia. To the left the cylinder is osseointegrated and the cover and the core have been removed. A blood clot that has formed in the bone ingrowth canal can be seen at the bottom of the cylinder.

Animals and operations

The chambers were inserted into the proximal tibial metaphysis of 6 adult, lop-eared rabbits (aged > 9 months, weight 4.5–4.9 kg). After 6 weeks, the chambers were considered "osseointegrated," and the contents of the canal were harvested. From the 3rd day after harvest, the chambers were then randomly assigned to either daily manipulations for 30 seconds once daily, to produce 20 movement cycles of 0.5 mm, or no movement. After 3 weeks, the chambers were harvested, then randomly reassigned again for 3 weeks and harvested again. This regimen was followed repeatedly. The animal was killed if an infection became evident.

Evaluation

The harvested tissue was fixed in formalin, decalcified, embedded in paraffin, and cut into sections. Early in the series, transverse sections close to the ends of the canal and sections from the middle (at equal distance from both ends) were sliced with a microtome and stained with hematoxylin and eosin, and methylene blue. Later in the series, longitudinal sections were studied, thus enabling the entire length of the specimen to be visualized on one slide.

Results

Moved chambers

13 specimens were harvested from moved chambers (Tables 1 and 2). 7 contained vascularized fibrous tissue without any visible cartilage or bone. The fibrous tissue was more dense and well organized in the center of the canal than in the periphery, and generally oriented parallel to the canal (Figure 3). The other six specimens showed some bone ingrowth as follows: four specimens contained small amounts of woven bone at one or both ends; one specimen showed more organized bone at both ends, but not in the middle; and one specimen had scanty amounts of woven bone both at the ends and in the middle.

Control chambers

15 specimens were harvested from chambers that had not been moved. All the specimens contained some new woven bone (Figure 4). 11 of the 15 specimens contained lamellar bone at the ends and in the middle of the specimen.

Altogether four specimens were discarded—three because the implant cover came off during the experiment period and one because of an infection.

Table 1. Histologic grading for bone ingrowth

Rabbit no.	Run (cycles/day)	Any bone present	Bone present in the middle
1	20	0	0
	0	1	1
	20	1	0
	0	1	0
	20	1	0
	20	1	0
	0	1	1
	0	1	1
	0	1	1
2	20	0	0
	0	1	1
	20	1	0
3	20	0	0
	0	1	1
	20	0	0
	0	1	1
	0	1	0
4	20	1	1
	0	1	1
	20	0	0
5	0	1	0
	20	1	0
6	0	1	1
	20	0	0
	0	1	0
	20	0	0
	0	1	1
	0	1	1

Runs are listed in temporal sequence for each rabbit.
Bone present: 0 no, 1 yes.

Table 2. Proportion of runs for each animal with bone present in the section

	Animal						
Run (cycles/day)	1	2	3	4	5	6	Sum
Any bone							
20	3/4	1/2	0/2	1/2	1/1	0/2	6/13
0	5/5	1/1	3/3	1/1	1/1	4/4	15/15
Bone in the middle							
20	0/4	0/2	0/2	1/2	0/1	0/2	1/13
0	4/5	1/1	2/3	1/1	0/1	3/4	11/15

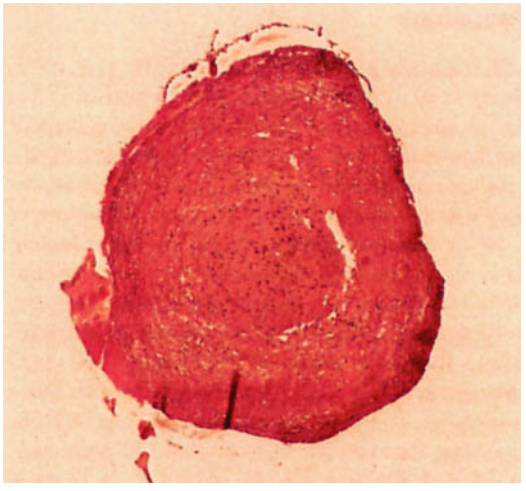


Figure 3. Transverse section of the contents of a manipulated chamber. No bone is seen in the canal. The fibrous tissue is dense in the center and more loose in the periphery. The tissue contains a few distinct blood vessels.

Figure 4. Transverse section of the contents of a non-manipulated chamber. There is abundant trabecular bone present; the quadratic shape of the canal is preserved.

Statistics

If each harvest is considered to be an independent event and the result is expressed as "no bone" versus "any bone" within the canal, the probability of a random occurrence of our result is 0.001 using Fisher's exact test. When only the findings in the middle of the canal are considered, the probability is also 0.001. If the assumption that each harvest is an independent event is not accepted, then ratios can be calculated for each animal that express the presence or absence of bone for each treatment. When this calculation is performed (Table 2), the probability of a random occurrence of our results is less than 0.05 using the Wilcoxon signed-rank test.

Discussion

Despite success in animal studies (Galante et al. 1971, Hedley et al. 1982), porous-coated prostheses in the knee do not consistently achieve the desired amount of bone ingrowth (Cook et al. 1988, Sumner et al. 1989). In the one successful system of bone-implant attachment, namely, titanium dental fixtures (Brånemark et al. 1977), absolute stability during an initial healing phase is considered indispensable for "osseointegration" (Albrektsson and Albrektsson 1987). Although bone ingrowth may not be as demanding as osseointegration, the same prerequisites, perhaps less stringently applied, may be relevant. Motion has also been shown to prevent bone ingrowth. In a dog model, 28-μm motion allowed bone ingrowth, but 150-μm motion prevented it, although only the motion of the matured interface after the healing period was measured (Pilliar et al. 1986).

Bone ingrowth is regular and reproducible in nonmovable titanium chambers, similar to the micromotion chamber (Kälebo 1987). Our data suggest that in titanium chambers one daily episode of motion of relatively short duration is adequate to inhibit bone ingrowth. The presence of blood vessels in the specimens from moved chambers indicates that this inhibition of bone ingrowth is not exclusively due to mechanical disruption of the tissue. Bone ingrowth into endoprosthetic implant pores includes proliferation and differentiation (Hedley and Kozinn 1984). The motion of our chamber generates shear strain, which induced fibrous tissue formation. It seems that, through unknown mechanisms, micromotion has either inhibited preosteoblast proliferation or influenced the choice of a differential pathway for a proliferated pluripotent cell population, favoring fibrous tissue. In this respect, the chamber is also a form of pseudoarthrosis model.

In this study, 6 of the 13 specimens that had been exposed to 20 cycles/day contained small amounts of bone in addition to the fibrous tissue, which may be due to the size of the channel, the number and magnitude of the daily cycles, or other factors.

Søballe et al. (1990) have developed a dynamically loaded device that produces 500-μm axial translation of the implant during each gait cycle in dogs. Our model differs from that of Søballe et al., as we can control the number and time sequence of motion.

Most porous-coated implants have a pore size that is one quarter to one half the size of the channel in this titanium chamber. Therefore, correlation of this model with the clinical situation is speculative. Further studies with smaller diameter pores may enable a closer correlation with the clinical situation.

The motion in our model was 0.5 mm, or 50 percent of the pore diameter. This magnitude of motion is easily achieved across implant interfaces, as has been shown experimentally (Volz et al. 1988, Branson et al. 1989, Dempsey et al. 1989), as well as in-vivo (Ryd et al. 1990). If our results could be extrapolated to human joint prostheses, they would imply that only a few daily episodes of motion during the postoperative period may be adequate to inhibit bony incorporation of the prosthesis.

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