Polymeric debris from absorbable polyglycolide screws and pins

Intraosseous migration studied in rabbits

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The migration of polymeric particles during degradation of absorbable implants made of polyglycolide was investigated in the cancellous bone of distal rabbit femur by using a transverse osteotomy model. The osteotomy was fixed either with a 4.5 x 25 mm screw or with two 1.5 x 30 mm pins. The histologic sections obtained at 3, 6, 12, and 36 weeks were morphometrically analyzed using polarized-light microscopy. The migration of the polymeric debris into the host-tissues showed two different patterns. On the one hand, particles were in all specimens seen lying intracellularly in phagocytic cells in a regular front close to the original tissue-implant boundary. In addition, in several specimens there occurred expansions filled with largely extracellular polymeric particles that bulged into the hematopoietic bone marrow up to 2.8 mm from the original implant cavity. This kind of particle migration over long distances could not be explained by cellular transport, but may have been caused by an increased osmotic pressure that developed within the implant cavity during depolymerization of polyglycolide.

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Submitted 91-12-29. Accepted 92-04-17

The general biodegradability of pieces made of polyglycolide and other absorbable polyesters of alpha-hydroxy carboxylic acids in bone has been demonstrated in several studies (Christel et al. 1982, Hollinger and Battistone 1986, Vainionpää et al. 1986), but little has been published on the details of the degradation and absorption of these polymers within bone tissue. A better knowledge of these processes is important as several of the clinical series published on the use of polyglycolide implants in fracture fixation have been burdened with the occurrence of late spontaneous sinuses yielding remnants of the degrading implant, the incidence of this complication being on average 8 percent (Böstman et al. 1987, Hirvensalo 1989, Hoffmann et al. 1989, Poigenfürst et al. 1990, Böstman 1991a, Rokkanen 1991, Böstman et al. 1992). Also implants made of polylactide, another biodegradable alpha-hydroxy polyester for orthopedic applications, have been associated with late inflammatory reactions (Eitenmüller et al. 1990, Rozema et al. 1991). No experimental model of such a polymeric debris-expelling tissue response has so far been presented.

We studied in rabbits the morphometric characteristics of the degradation of screws and pins made of polyglycolide within cancellous bone with special attention being paid to migration of the resultant polymeric debris.

Material and methods

Implants

Colorless screws and pins, composed of polyglycolide and constructed from Dexon sutures as raw material (Davis & Geck, Gosport, UK), were used. The implants were manufactured (Bioscience Ltd, Tampere, Finland) by creating, under heat and pressure, a polyglycolide matrix that was reinforced with longitudinal suture fibers of the same polymer (Törmälä et al. 1991). The average molecular weight of the polyglycolide was 6×10^5, and the density of the implants was 1.6 g/cm^3. The screws measured 4.5 mm in major thread diameter, 3.3 mm in core diameter and 25 mm in length. The cylindrical pins measured 1.5 mm in transverse diameter and 30 mm in length. The volume of a screw was approximately 280 mm^3 and that of a pin 53 mm^3. The implants were sterilized in ethylene oxide.

Surgical procedure

The implants were inserted into the right distal femur of mature New Zealand rabbits. Through a medial parapatellar approach, a transverse osteotomy was done 10–12 mm proximal to the knee joint and fixed either with one screw or with two pins. The implants were placed in holes drilled through the intraarticular inter-

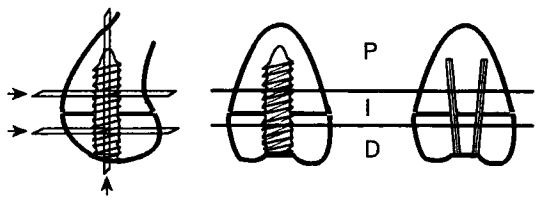

Figure 1. Lateral and anteroposterior diagrams of the distal rabbit femur showing the transverse osteotomy and the placing of the fixation devices, either one screw or two pins, made of polyglycolide. The planes of the longitudinal and the transverse histological sections cut for microscopic examination are indicated (arrows). For morphometric analysis the distal femur was divided into three zones; P proximal, I intermediate and D distal.

condylar portion of the femur axially towards the intramedullary canal (Figure 1). For the screw the drill-hole was first tapped. No postoperative splinting was used. The follow-up times were 3, 6, 12, and 36 weeks. Each screw-fixed follow-up group originally comprised 5–6 animals. The decision to include pin fixation, too, into this study was made after preliminary analysis of the screw-fixed specimens. Since the groups with follow-up times of 6 and 12 weeks turned out to be the crucial ones, 4 animals with pin fixation were added to these groups to allow a comparison of the degradation behavior between the two kinds of implants. 2 rabbits of the 36-week screw-fixed group were lost due to causes unrelated to the operation, leaving in all 24 animals for histomorphometry.

Morphometry

After dissecting the distal femur free of soft tissues, it was fixed in ethanol solutions and then embedded in methyl methacrylate (Schenk 1965, Baron et al. 1983). Longitudinal and transverse 5-µm sections were cut parallel and perpendicular to the long axis of the implants, respectively (Figure 1), and stained using the Masson-Goldner trichrome method. In addition, 80-µm-thick longitudinal sections were made in the coronal plane and left unstained to permit assessment of larger polymeric particles that could possibly have been displaced during the processing of the 5-µm sections.

The sections were viewed in polarized-light microscopy (Ernst Leitz, Wetzlar, Germany). Polyglycolide being an optically anisotropic compound, all polymeric material originating from the implant could be identified due to its bright yellowish-white birefringence under polarized light.

The distal femur was divided into three zones, equal in size, in relation to the length of the implants (Figure 1). A semiautomatic computerized analysis system MOP Videoplan (Kontron, Munich, Germany) linked by a video camera to the microscope was used. The patterns of migration of the polymeric particles into the tissues and the relation of the particulate polymeric debris to cellular spaces and individual cells were assessed. The maximum distance of the polymeric particles from the nearest point of the original tissue-implant boundary, and size of the migrated particles were measured. The original tissue-implant boundary was determined with the aid of graticules placed over the microscopic fields. The Mann-Whitney two-sample rank sum test was used.

Results

In the 3-week animals, signs of degradation of polyglycolide were diminutive, with small erosions only along the outermost brim of the screw thread. Polymeric material could not be seen in the host-tissues at a distance greater than 0.15 mm from the original tissue-implant boundary. In the 6-week animals, commencing degradation and invasion of vascular connective tissue into the screws and pins had disfigured the implant surface. From 6 weeks on, the osteotomies showed bony union, and the intraarticular orifices of the implant channels were filled with tough fibro-connective tissue. In the 12-week animals, degradation had proceeded, and connective tissue infiltration had reached the core of the implants.

In the 6- and 12-week specimens, polymeric debris was seen to have migrated into the hematopoietic bone marrow, with the maximum distance from the original boundary of the implant cavity varying greatly (Figure 2). Two distinct patterns of particle migration emerged. One showed an even dispersion of the debris not more than 0.85 mm from the original tissue-implant boundary (Figure 3), this basic pattern being present in all specimens, on all sections, and in all zones. The other pattern, seen in 5 screw-fixed and in one pin-fixed animal in addition to the basic one, comprised sacklike bulging accumulations of polymeric debris at distances of up to 2.8 mm from the implant cavity (Figure 4). The diameter of these expansions that were lined with a fibrous capsule (Figure 5) varied from 0.8–2.1 mm. The expansions occurred only in the proximal and intermediate zones.

Most of the particles that formed the regular polymeric front located 0.85 mm or less from the original tissue-implant boundary lay intracellularly within

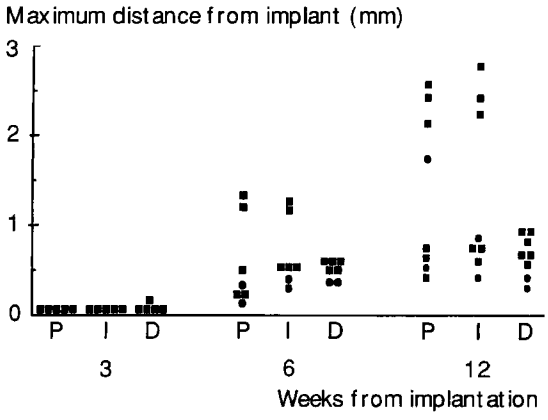

Figure 2. Maximum migratory distance of the polymeric particles in the three zones of the specimens. In the 36-week specimens no polymeric material could be seen in the sections.

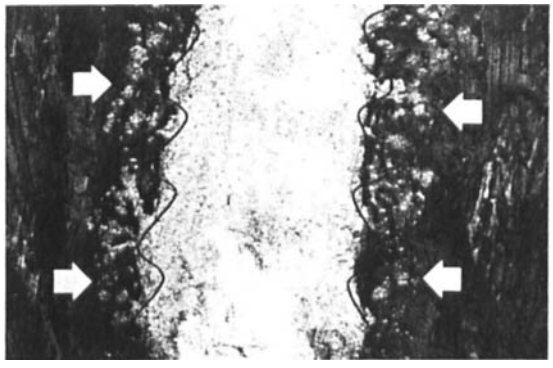

Figure 3. Longitudinal, coronal-plane section of the intermediate zone of a 12-week screw-fixed specimen under polarized light showing migration of the polymeric debris into the host-tissues in a regular front (arrows) close to the original tissue-implant boundaries which have been marked out. Unstained 80-µm-thick section, ×16.

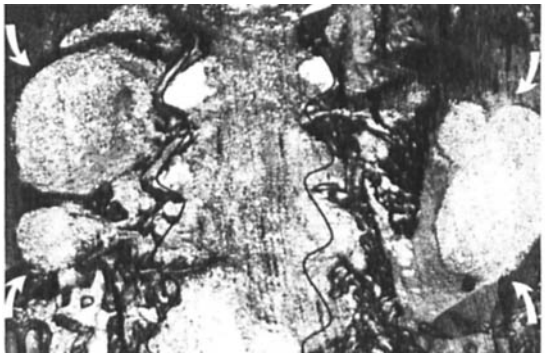

Figure 4. Longitudinal, coronal-plane section of a 12-week screw-fixed specimen showing several sacklike bulging expansions (arrows) filled with expelled polymeric debris at considerable distances from the original tissue-implant boundaries which have been marked out. Unstained 80-µm-thick section, ×12.

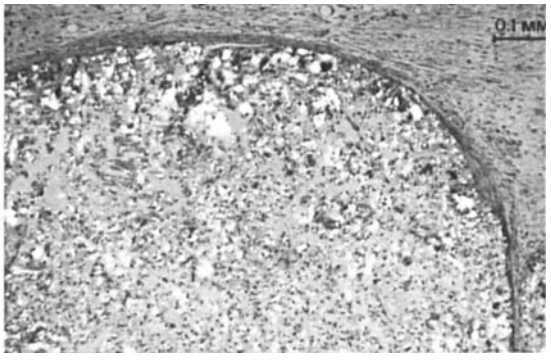

Figure 5. Histologic section under polarized light of one of the sacklike accumulations of polymeric debris depicted in Figure 4. An expansion of blown-up appearance filled with dispersed extracellular polymeric particles and lined with a fibrous capsule bulging into the bone marrow is seen. Masson-Goldner trichrome, ×150

mononuclear phagocytes or giant cells of foreign-body type, whereas the polymeric debris seen in the bulging expansions at a greater distance seemed to be located largely extracellularly (Figure 5).

The average size of the migrated particles was 15 × 25 µm. It turned out to be impossible to determine the particle density within the host-tissues as the particles were ragged, very variable in size, and often overlapping one another. There were no differences in the morphometric variables between the screw and the pin-fixed specimens. At 36 weeks after insertion, no traces of the implants could be seen in the specimens. No sinuses discharging through the skin occurred.

Discussion

The biodegradation of polyglycolide occurs principally through a random hydrolytic cleavage of the ester bonds of the polymer in the tissue fluids, nonspecific enzymatic action playing only a minor role (Kopecek and Ulbrich 1983, Hollinger and Battistone 1986). Recently, it has been suggested that autocatalytic activity by carboxyl groups inside rather than at the surface of an implant makes rapid hydrolysis possible also in the center of large implants (Vert et al. 1991). When decomposition of the implant has resulted in particles of a suitable size, the polymeric debris is ingested by phagocytic cells. This process is accompanied by a transient, nonspecific foreign-body

reaction (Vert et al. 1984, Howard et al. 1985, Hollinger and Battistone 1986, Böstman et al. 1990).

The main result of our study was that at 6 and 12 weeks after implantation when disintegration of the implants had advanced, accumulations of extracellular, polymeric debris in bulging expansions could occasionally be found at remarkable distances from the original tissue-implant boundary giving the impression that they had been forced into the surrounding tissues. No displacements at the osteotomy indicating instability of the fixation and subsequent moving of the implants were seen. Consequently, since polyglycolide is a hydrophilic compound (Christel et al. 1982, Törmälä et al. 1991) and the orifices of the drill-holes made for the screws and pins had become filled up with connective tissue already at 6 weeks after implantation, an increased intracavital osmotic pressure expelling the debris into the bone marrow of the distal rabbit femur would seem a plausible explanation. The depolymerization process of polyglycolide results in an increasing number of low-molecular-weight degradation products, and polar groups in these molecules increase the osmotic effect more than neutral compounds would do.

In our study, the bulging expansions were not encountered in the distal zone, where the network of cancellous bone trabeculae was considerably denser than in the intermediate and proximal zones which were largely composed of loose hematopoietic bone marrow. Under these circumstances no external sinuses discharging the debris through the skin were formed, as might have been the case in more compact cancellous bone and with a less tightly sealed orifice in the implant cavity. Radiographically discernible expansions of the implant tract have been detected in patients with ankle fractures operated on with polyglycolide rods (Böstman 1991b), and such radiolucencies were associated with sinuses.

The evidence of an increased osmotic intracavital pressure associated with degradation of polyglycolide implants is so far only indirect. But if this hypothesis is true, it would be the pressure in relation to the resistance of the surrounding tissues that determines the possible formation of an external sinus. Such local factors could explain the variation in the incidence of sinuses between different anatomical regions.

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