JOURNAL OF MATERIALS SCIENCE: MATERIALS IN MEDICINE **16** (2005) 325–331

Coralline hydroxyapatite reinforced with polylactide fibres in lumbar interbody implantation

P. YLINEN[1, 2,*], M. RAEKALLIO[3], R. TAURIO[4], K. VIHTONEN[2], S. VAINIONPÄÄ[2], E. K. PARTIO[2], P. TÖRMÄLÄ[4], P. ROKKANEN[2]
[1]*ORTON Orthopaedic Hospital of Invalid Foundation, Helsinki*
E-mail: mia.siitonen@hus.fi
[2]*Department of Orthopaedics and Traumatology, University of Helsinki and Helsinki University Central Hospital, Helsinki*
[3]*Faculty of Veterinary Medicine, University of Helsinki, Helsinki*
[4]*Institute of Biomaterials, Tampere University of Technology, Tampere, Finland*

Porous hydroxyapatite HA blocks reinforced with poly-l/dl-lactide fibres were used to maintain the lumbar disc space and to start to create intercorporeal fusion in 23 growing pigs. In four pigs two emptied non adjacent disc spaces were left open. After 3, 6, 12 and 16 weeks the implanted disc blocks were studied radiologically, histologically, histomorphometrically, microradiographically, and with oxytetracycline fluorescence. In plain films slight to moderate ossification of the implanted disc spaces was detected at 12 and 16 weeks. Resorption of the implants was seen radiologically from 3 weeks and fragmentation from 12 weeks onwards. In microradiographs disintegration of the coralline inner structure started at 3 weeks. Histologically, connective tissue ingrowth was seen inside the porous structure from three weeks onwards. Small amounts of new bone were visible and connective tissue inside the implant increased from a mean of 65.6% at 3 weeks to a mean of 79.4% at 16 weeks histomorphometrically. The bone ingrowth varied from 0.7 to 1.7%. A loss of height in the implanted disc spaces was seen ($p < 0.05$, linear regression analysis). In control pigs the emptied disc spaces lost their height similarly. The implants used were not strong enough to maintain the lumbar disc height.

1. Introduction

Solid lumbar interbody fusion results in long-term stabilization of unstable lumbar segments and correlates with a better outcome as compared to posterior stabilization [1]. Anterior fusion may be performed through anterior approach or extraperitoneally through lumbotomy. Posterior lumbar interbody fusion (PLIF), has been introduced as a safer and less morbid operation method and has presently become widely used. All approaches are technically demanding and highly susceptible to complications. Disadvantages are autogenous bone grafting procedures with donor-site morbidity and a prolonged operation time. An artificial bone graft substitute, to be used both as a spacer and as a bone ingrowth adjusting device in the evacuated disc space, could be a useful solution. By choosing an implant with appropriate measures, the disc height can be preserved, while new bone grows up through the implant fusing the adjacent vertebral bodies.

By virtue of its similarity to the mineral constituent of human bone, hydroxyapatite (HA) has been extensively studied as a bone graft substitute. Hydroxyapatite has no inflammatory, immunological or toxicological effects in human tissues [2]. It bonds to the adjacent bone without fibrous encapsulation [2–4]. HA can be produced as non-porous, dense or porous implants and as granular particles with pores.

The dense structure of HA is mechanically strong enough to be used as a spacer in the disc space [5], but, in lack of porosity, no osteoconduction occurs. In that case there is no gradual bone replacement, either, because pure dense HA does not resorb [2]. In fact, the block form of dense HA spacers has been in clinical use in cervical spine in the treatment of the degenerative disease with radiculopathy and/or myelopathy [5]. The clinical outcome with dense HA fusion has been reported equal to autologous iliac crest interbody fusion, and patients who underwent synthetic HA fusion had even less need for a second operation due the plug slippage or resorption at the same or an adjacent level.

The osteoconductive properties of porous hydroxyapatite (HA) are well documented [2, 3]. The optimal

*Author to whom all correspondence should be addressed.

pore size is dependent on the structure of the host bone and the site of implantation, and also the mechanical factors seem to influence the quantity of bone ingrowth [6]. The optimal pore size for osteoconduction appears to be between 150 and 500 μm. With a porous structure, however, the ceramic implant is very brittle, and when used under mechanical stress or cyclic loading conditions fracture or crushing without bone ingrowth may result. Reinforcement of porous HA blocks has been attempted with absorbable coatings or impregnation, but these methods have proved to delay or worsen bone ingrowth [7]. A previous study was carried out comparing HA blocks reinforced either with polylactide (PLA) or polyglycolide (PGA) threads in filling bone defects in rabbit tibiae [20]. The study showed good bone ingrowth and no difference between the two reinforcing fibres.

In the present study, with poly-l/dl-lactide (PLDLA) threads reinforced porous HA blocks were used in interbody implantation of the lumbar spine in growing pigs. The goals of the present study were to evaluate the strength and resulting osteointegration of the reinforced HA blocks in the experimental lumbar disc replacement.

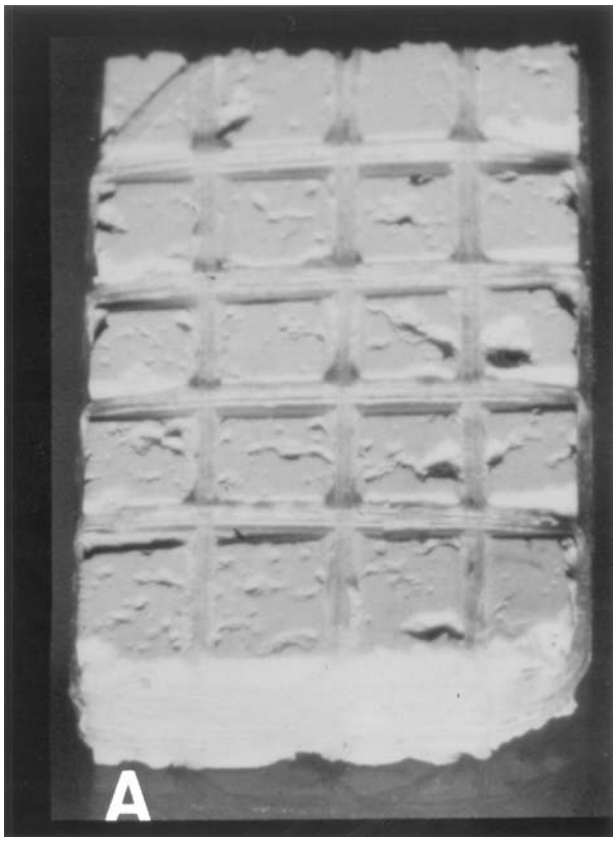


Figure 1 Reinforced porous hydroxyapatite implant sized 2 × 3 × 8 mm used in the study. Reinforcing poly-l/dl-lactide threads were placed in the grooves on sides facing toward the vertebral end-plates making intimate contact of hydroxyapatite and host bone possible.

2. Materials and methods

2.1. Implants

The implants were manufactured in the Institute of Biomaterials, Tampere University of Technology, Tampere, Finland. Blocks of commercially available coralline hydroxyapatite with the mean porosity of 200 micrometers were used as the raw material (Interpore 200^{TM}, Interpore International, Irvine, CA, USA). Interpore 200^{TM} porous HA is derived from the mineral skeleton of specific marine corals. The manufacturing process preserves the porous structure of the coral and closely mimics the microstructure of natural bone. The HA blocks were sawed 3 × 8 × 12 mm in size, and 0.5 mm deep grooves were made lengthwise and crosswise on the largest surfaces 2 mm apart from each other. The measurements of the implant were similar to those of the disc space of a growing pig weighing 15 kg. Poly-l-lactide was melt-spun, and the fibre was drawn through poly-dl-lactide solution to coat the fibre and improve its adhesion to the ceramic. The final coated composite fibre was an average 0.3 mm in diameter and it was wound into the grooves and around the block so that, the ceramic surface was left open (Fig. 1). Three fibres were wound in each groove. The blocks were pressed against a hot surface (135 °C) to melt poly-l-lactide and then fuse the fibres into each other and into the HA block. The implants were sterilized by gamma radiation.

2.2. Operations

Twenty-seven growing pigs were operated on through laparotomy. At the time of operation the pigs were at the same age coming from three different farrows and weighing from 13.5 to 20.5 kg. The pigs fasted for one preoperative day. Atropine 0.1 mg/kg (Atropin®, 1 mg/ml, Orion, Finland) and diazepam 0.2 mg/ml (Diapam®, 5 mg/ml, Orion, Finland) were injected intramuscularly (IM) as premedication about 30 min before the anesthesia was inducted. Ketamine hydrochloride (Ketalar®, 50 mg/ml, Parke-Davis, Barcelone, Spain) was administered 10 mg/kg IM. The induction of the anaesthesia was accomplished by intravenous (IV) administration of thiopental until effect (approximately 8 mg/kg) (Penthotal® Natrium 2.5%, Abbot S.p.A., Campoverde, Italy). After induction topical anaesthetics (Xylocain®) were sprayed into the pharynx. The pig was intubated, and the anaesthesia was maintained by oxygen-1.5% halothane inhalation. The prophylatic antibiotic of one million unit of procaine penicillin (Prokain-Penicillin Novo®, 300,000 IU/ml, Novo Industri AS, Copenhagen, Denmark) was injected IM.

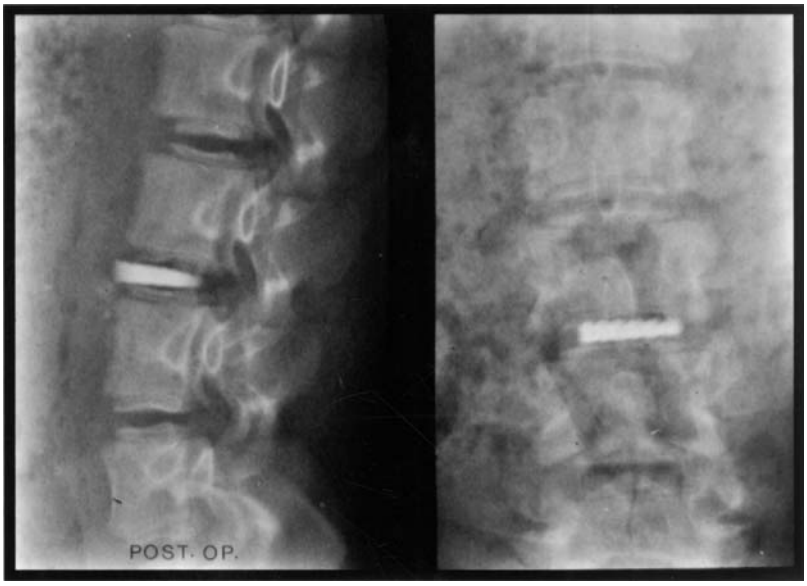
The pig was placed in supine position, and a sand bolster was located under the lumbar vertebrae to accentuate lumbar lordosis. The operation area was scrubbed with betadine solution (Betadine®). The abdomen was opened through a paramedian left-sided rectus muscle-splitting incision. The small intestine, the greater omentum, and the transverse colon were kept in the upper abdomen with the help of a flexible tampon and by keeping the pig in the Trendelenburg position. Using deep wound retractors the retroperitoneum was incised left to the lower lumbar vertebral bodies and to the abdominal aorta. Leaving the aorta and vena cava on the right side of the incision, the finger was smoothly introduced retroperitoneally freeing the attachments of

the peritoneum and exposing the long anterior ligament. The ligament attachments were freed from the vertebrae with a knife at the area of the two to three lower segments. With help of two blunt retractors the freed ligament, along with great vessels, was reflected to the right to get an exposure to the intervertebral disc. The disc space L4/L5 or L3/L4 was exposed. The disc material was removed, and the cartilaginous end plates were exposed down to the bleeding bone. The posterior annulus was kept intact.

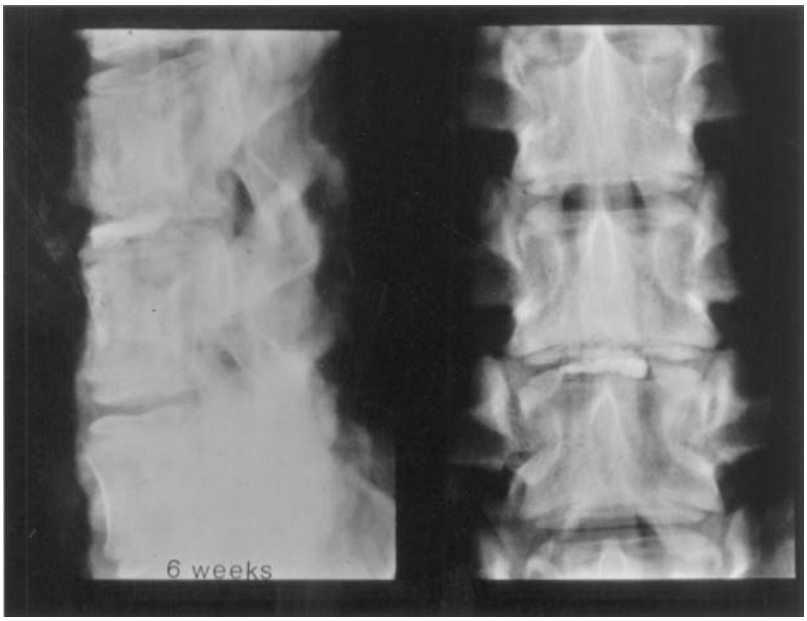
The disc space was irrigated with saline. The reinforced HA block was introduced into the disc space. The anterior ligament was fixed to bone with a few sutures after restoring the normal lordosis. Flunixin meglumine (2 mg/kg, Finadyne®, 50 mg/ml, Orion, Turku, Finland) was used as analgesic. The follow-up times were 3, 6, 12 and, 16 weeks. In 23 pigs the disc space was replaced by the reinforced HA block. In four pigs two non-adjacent disc spaces were identically exposed but they were left open without implantation to serve as a control.

2.3. Examination methods

After operation radiographs in antero-posterior and lateral projections were taken from the lumbar spine. The focus to the object distance was 1.2 m. (Fig. 2(A)). Seven to ten days before sacrifice oxytetracycline 50 mg/kg (Terramycin®, 100 mg/ml, Pfizer, Brussels, Belgium) was given IM. After sacrifice the pigs were weighed, and the lumbar spine was detached with psoas muscles. Radiographs were taken from the preparation. The vertebral block was further prepared, and smaller blocks were sawed: the bone block with the implanted disc in the middle, the upper adjacent block with the non-operated disc respectively, and, blocks of facet



(A)



(B)

Figure 2 (A) Postoperative radiograph of lumbar spine. HA implant is placed in the emptied disc space between the lumbar bodies of L 4 and L 5. (B) radiograph after 6-week follow-up. HA implant has not been fragmented.

joints from the operated and non-operated segments. Six specimens were taken from every HA-implanted lumbar spine. The specimens from non-implanted control spines were taken from evacuated disc segments, from intact disc segments and from facet joints, respectively.

The specimens were fixed in a series of ethanol immersions with rising concentrations (70–99%) and embedded in methylmethacrylate. The blocks with disc spaces were sawn sagittally in the middle of the block. Using a microtome Jung Polycat S, 5 μm thick sagittal sections were cut for histologic and histomorphometric studies. For microradiographic and oxytetracycline (OTC) fluorescence studies 80 μm thick sections were cut with a saw microtome Leitz 1600. In the facet joint specimens the cutting level was determined as transverse in the middle of the joint line.

2.4. Radiological studies

In the native radiographs ossification was evaluated using semiquantitative scoring from gr. 1 (0%) to gr. 4 (76–100%) [7]. The disc height was measured with a VIDAS-based image analyzer (Kontron Videoplan Image Processing System, Kontron, Munich, Germany) by coupling the radiographs from the light board with a video camera to the screen. The disc height was measured both from the lateral and a-p projections, one measurement from each margin of the disc space, after which the mean of the measurements was calculated. The local changes in vertebral posture, kyphosis or lordosis were measured using X-Caliber^{TM} (Eisenlohr Technologies Inc, CA, USA). The angle between the two vertebral bodies were measured using their posterior margin as a reference.

2.5. Histological studies

The 5 μm thick sections were stained with Masson modification of Goldner stain [8]. The timing and type of tissue reactions against HA and reinforcing PLDLA fibres, the type of connective tissue and the findings indicating bone igrowth were evaluated histologically. The histologic analysis was also made from the specimens of the facet joints to evaluate possible changes in the articular cartilage retrieved from the implanted lumbar segment compared to the changes in the cartilage from the adjacent non-operated segment.

2.6. Histomorphometrical studies

Five-micrometer-thick sections stained by the Masson-Goldner method were used. The quantitative histomorphometry of the tissue and HA fractions was done using the Leitz Diaplan lens system coupled with a low-light charge-screen CCTV camera (Panasonic WV-CD1 30, Matsushita Electric Industrial Co., Ltd., Japan) and a VIDAS-based image analyzer (Kontron Electronic GMBH, Eching/Munich, Germany). Special software using colour thresholds was programmed for colours indicating HA, connective tissue, and bone. In each HA-implanted specimen the areas of HA, ingrown connective tissue, and ingrown new bone were measured. The lens used in the microscope was 2.5×, and the magnification in the screen was 38×.

2.7. Microradiographical studies

Eighty-micrometer thick sections were exposed for radiography using the Faxitron cabinet X-ray system (Hewlett-Packard 43855 A) and Kodak Spectroscopic plates type 649–0. The microradiographs were evaluated to see fracture of the HA implant and incorporation of the bone inside the implant. The facet joints were also studied on the microradiographs.

2.8. Oxytetracycline fluorescence studies

Unstained 80 μm thick sections were studied in polarized light to detect oxytetracycline (OTC) uptake. The uptake was evaluated inside the implant as well as in the bone next to the implant. The uptake was also studied in the non-operated discs and in the facet joints.

3. Results

From 27 operated pigs six had postoperative complications, all in the implanted study group. Two pigs died, one because an intraoperative vascular lesion caused a vascular insufficiency of the left hind leg and the pig was sacrificed on the first postoperative day. The other pig was found dead on the first postoperative day, and, according to the autopsy, due to ventricular dilatation and perforation. Two pigs had mild paraparesis but they were able to move and could be followed up, one for three weeks and the other for six weeks. Two pigs had a postoperative incisional hernia without evidence of symptoms related to it.

In all, there were 21 implanted and four control pigs available for follow-up. The mean weight of the pigs at operation was 16.6 kg (13.5–20.5 kg), and there was no difference between the groups with different follow-up. The mean weights at sacrifice were 23.1 kg at three weeks, 44.5 kg at six weeks, 64.4 kg at 12 weeks, and 103.8 kg at 16 weeks. All the implantations were evaluated with radiologic and microradiologic studies, histologically, histomorphometrically, and with OTC labeling techniques. In control specimens radiological and histological studies were performed.

3.1. Radiological findings

The radiological findings are presented in Table I. Local kyphosis was a frequent finding of the implanted disc segment along with anterior bone bridging or ligament ossification (Fig. 2(a) and (b)). Initially, in the postoperative radiographs a small local lordosis was measured varying from mean 0.4° to mean 2° but at follow up, a moderate increase to local kyphosis could be seen in every groups but the means were not statistically different ($p > 0$ 0.05, ANOVA). The disc height was also measured from the radiographs. According to the linear regression analysis the results showed a

TABLE I Radiological findings after lumbar interbody implantation at different follow-up times

Findings[a]	Follow-up time (weeks)			
	3	6	12	16
Implant displacement	0	0	0	1
Implant fragmentation	0	0	2	3
Implant resorption	1	1	2	3
Disc space ossification	0	0	1	2
Anterior ligament ossification	2	2	2	2
Anterior bone bridge	1	1	2	3
Local kyphosis, mean (°)	13.4°	10.7°	15.9°	18.0°
Epiphyseolysis	1	1	1	2
No. of implants	5	4[b]	5	6

[a]The grade of changes is classified as follows: 0 none, 1 slight, 2 moderate, 3 plenty, 4 complete (see Materials and Methods).
[b]The plain radiographs of one pig were missed after slaughter, all the other specimens were available.

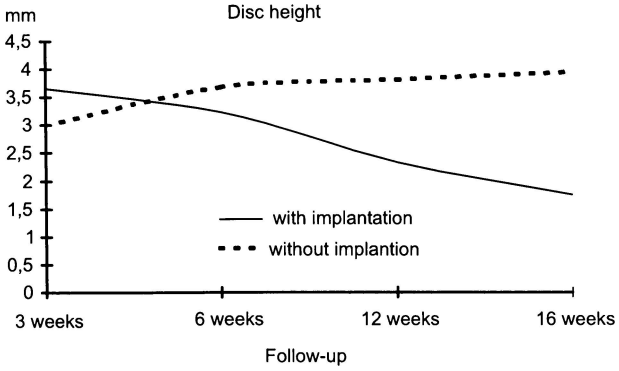


Figure 3 Disc height measured from radiographs of the implanted and adjacent non-operated disc spaces. The implanted disc space seems to collapse during the follow-up contrary to the non-operated disc space which grows in congruence with the growth of the pigs.

gradual loss of height in the implanted disc spaces during the follow-up ($p < 0.05$). Similarly, but contrary to the implantation the non-operated adjacent disc spaces gained their height during the follow up in accordance with pig growth (Fig. 3). In cases of epiphyseolysis the local kyphosis was more marked as well as anterior ligament ossification and formation of the anterior bone bridge.

In control pigs the emptied disc spaces reacted similarly to the HA implanted disc spaces. A slight kyphosis, mean 2.1°, was measured initially postoperatively and the increase during the follow-up ranged from a mean of 7.5° at six weeks to a mean of 13.7° at 12 weeks and the figures were in accordance with those of the implanted discs. The loss of disc height seemed also identical and, radiologically a narrow space from 1 to 2 mm was still seen at 12 and 16 weeks. The formation of anterior bone bridge, at its different states, was seen in all cases but was marked from six weeks onwards.

3.2. Histological findings

Hydroxyapatite was seen as void spaces. *At three weeks* the connective tissue pervaded into the porotic spaces inside the implant. Ingrowing tissue was formed as loose bundles of collagen fibres. The reinforcing lactide fibres were seen in polarized light. *At six weeks* the HA implant was no longer seen as uniform. Inside HA the connective tissue was rich in collagen. Lactide fibres visualized clearly in polarized light but their inner structure was partly fragmented. No foreign-body reactions were seen. *At 12 weeks* the connective tissue inside the HA stained partly more green as a sign of collagen activity, but isles of new bone formation were rare. The HA implant was fragmented. Also the inner structure of lactide fibres was fragmented, but no foreign-body reactions were seen. *In the 16-week* specimens small isles of new bone formation could be seen inside the connective tissue. New bone was formed between HA and connective tissue (Fig. 4). Inside the fractured HA implant there was mainly collagenous connective tissue, and a loose fibrotic spinal union was formed. Areas of destructions of vertebral epiphysis were seen leading to collapse of intervertebral spaces. The anterior bone bridge formation was developed.

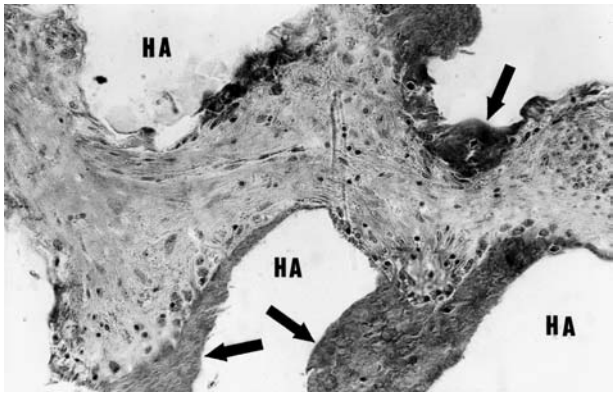


Figure 4 Histology of a 16-week specimen. Small areas of bone ingrowth (arrows) are seen in the interface between HA and connective tissue showing direct apposition of new bone to HA without an intervening fibrous layer. Large void areas visualize HA without tissue ingrowth (original magnification 250, Masson-Goldner stain).

In control specimens the collapsed disc space was mainly filled with unorganized collagen fibres from three weeks onwards. Bone formation anteriorly between adjacent vertebrae was present at three weeks becoming more expansive during the follow-up. In the beginning, some void spaces were seen but later the disc space was filled with more organized and thickly grown collagen fibres. Finally, at 12 weeks and especially at 16 weeks some ossification of the space was seen along with islets of collagen tissue remaining.

3.3. Histomorphometrical findings

The connective tissue reaction inside the implant was marked already at three weeks (Fig. 5). The rate of connective tissue varied from mean 65.6% at three weeks to mean 79.4% at 16 weeks, but statistically the means were different ($p < 0.02$, ANOVA). However, by using Tukey comparison of means the percent rates of connective tissue were equal at 3, 6 and 12 weeks ($p < 0.05$) and, they did not correlate to follow-up time. Respectively, the means of the per cent amount of HA varied from 33.7% at three weeks to 19.2% at 16 weeks and they were both statistically different ($p < 0.03$, ANOVA). Again, by grouping the means with Tukey

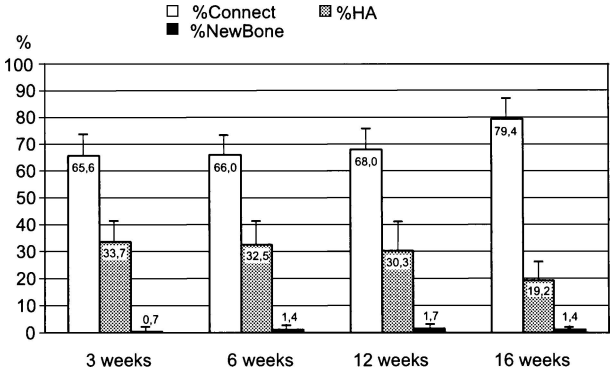


Figure 5 Results of histomorphometric measurements. The areas of HA, ingrown connective tissue, and new bone were measured from the implanted specimens. There was a significant decrease of HA during the 16-week follow-up. Connective tissue pervades the porous material even at three weeks after which its quantity keeps fairly constant. There was no significant new bone ingrowth seen during the 16-week follow-up.

method the mean amounts of HA were identical at 3, 6 and 12 weeks. Finally, the bone ingrowth was minimal at every follow-up period, but rates of only 0.7–1.7% could be measured. Instead, statistically expectations of the new bone rates did not differ from each other at different follow-up times ($p < 0.6$, ANOVA) and, according to regression analysis were not corresponded to follow-up time, either.

3.4. Microradiographical findings

The implant, its coralline structure, and the interface between implant and bone were well demonstrated. Until six weeks the implants remained unbroken, but disintegration of the coralline structure was seen, starting from the implant surface at three weeks and being propagated throughout the implant at six weeks. At its worst the porotic scaffolding inner structure was totally lost (Fig. 6). The implants were seen as uniform at three to six weeks' follow-ups, but at 12 and 16 weeks all the implants were broken, first in pieces through the lines of the reinforcing fibres and later as totally collapsed. In the 16-week specimens even migration of the HA granules into the vertebral bodies specimens was seen. Microradiography demonstrated no bone ingrowth. Even intimate contact between implant and bone was mainly lost, demonstrated by a void zone surrounding the implant. The facet joints were detected as normal in all lumbar segments.

3.5. Oxytetracycline fluorescence findings

Slight OTC uptake was seen in the majority of specimens in every follow-up group. At 3 weeks in three out of five specimens some uptake inside the implant was seen. 3 out of 4, 4 out of 5 and 3 out of 6 specimens showed some uptake at 6, 12, and 16 weeks, respectively. The amount and intensity of the uptake did not increase with the follow-up time. The more the implant was fragmented, the less (or no) uptake was detected.

In facet joints some OTC uptake was seen in subchondral bone but there was no difference between facets joining operated or unoperated discs. Activity was similar throughout the follow-up period.

4. Discussion

Autologous bone grafting can be associated with significant morbidity, and an acceptable substitute material has been a scientific challenge. Calcium phosphate ceramics, especially HA, has been shown to be biologically inert resulting in a chemical bond with the host bone [4, 9, 10]. A porous form of HA is osteoconductive. HA has been used in posterior spinal fusions as filling device in addition to autogenous bone grafting [11].

Flatley *et al.* [10] made attempt to obtain intervertebral body fusion using implants made of porous calcium phosphate ceramic in the rabbit lumbar spine. They used composites of beta-tricalcium phosphate and calcium hydroxyapatite and found histological bone ingrowth from six weeks after implantation. The porosity of implants in their study was 50% with pore sizes of 400–600 μm. Ragni and Lindholm [12] used implants made of the same coralline hydroxyapatite as in the

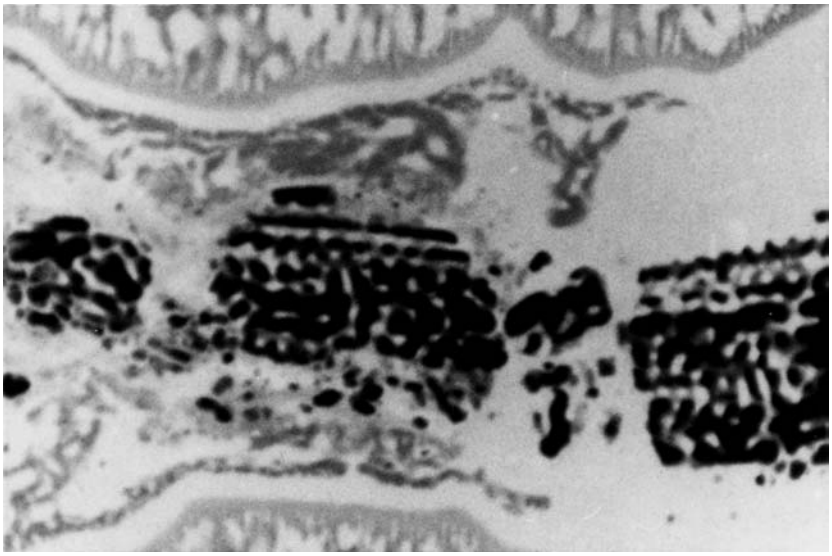


Figure 6 Microradiography of the HA implant in the disc space after 12-week follow-up. The implant has fractured along the lines of reinforcing fibres. Parts of the coralline structure are disintegrated and even migrated (original magnification 40).

present study in the lumbar interbody fusion in rabbits. They found the new bone ingrowth of approximately 15% in porous HA blocks, but it was enhanced by addition of allogenic demineralized bone matrix. Pintar *et al.* [13] used non-porous, dense HA blocks in the lumbar spine of goats, and found the fusion rate of 70% in 24 weeks. Dense HA blocks maintained the disc height better than the autogenous bone. Experimental models of phosphate ceramic implantation in the cervical spine have demonstrated graft cracking and extrusion in 39% (2–3) to 70% [14] which has, in all likelihood, contributed to the higher cervical mobility. Fuller *et al.* [15] studied the effects of internal fixation in the canine thoracic spine model. They found essentially no bone ingrowth in the porous ceramic implants used without internal fixation, whereas in the fusions with internal fixation a mixture of osseus, fibrocartilaginous, and fibrous union was seen in eight weeks. The mean pore size of the implants in their study was 250 μm and the porosity 20%.

The major drawback of using porous implants in orthopaedic applications is their poor mechanical strength. According to Jarcho [4], the compressive strength of porous calcium phosphate ceramics can at its best be only half of that of cortical bone. Attempts have been made to reinforce HA so that it could be accepted in hard tissue prosthetics. Tencer *et al.* [7] coated coralline HA with PMMA to increase compressive strength and Lin and Krebs [16] embedded HA with polysulfone composite. Both of these coatings were non-resorbable and decreased the porous area available for osteoconduction. Tencer and coworkers [17] also coated coralline HA with resorbable polylactid acid (PLA), but the polymer obstructed the pores so that new bone ingrowth was minimal.

The present approach to increase the compressive strength of HA was based on the use of bioabsorbable poly-l/dl-lactide (PLDLA) threads wound around the implant and placed in shallow grooves to allow direct contact to the host bone (Fig. 1). By that method the shear and bending strengths were improved four to fivefold and the impact strengths mean tenfold as compared to non-reinforced implants [18]. The compression strength did not improve.

The data of this study demonstrated a gradual loss of height in the disc spaces implanted and reinforced coralline implants. Although no displacements were seen, the fragmentation and signs of resorption of implants were marked. The loss of the disc heights as compared to the unoperated disc spaces was due to the fragmentation and resorption of the implants. Theoretically, a strong bond and bony ingrowth at the beginning of implantation could hinder the fragmentation and thus maintain the disc height. However, mechanically demanding loading conditions gave rise to a small motion in the bone implant interface, thus hindering stabilization and bone ingrowth. In stable circumstances, as when implanted in the rabbit tibial bone, these implants were filled with new bone irrespective of reinforcing biodegradable fibres [6].

The porosity of implants may be another contributing factor to bone ingrowth. In spinal fusion in rabbits the bone ingrowth has been shown both with implants of a pore size of 400 to 600 μm (4) and with implants of 200 μm [12]. In the rabbits spine the bone ingrowth is more possible, because the mechanical loads in the rabbit spine are lower than those in the spine of growing pigs. Hence, the crucial factors are the implant strength and its stability in the bone implant interface. Otherwise, fusions with internal fixation should be used as shown by Fuller *et al.* [15].

To conclude, coralline HA implants reinforced with PLDLA fibres were not strong enough in demanding interbody implantations in growing pigs. Anterior interbody implantations resulted in instability, loss of disc space and secondary changes like local kyphosis and anterior bone bridging. The future experimental application could be the use of HA implants with internal stabilization as in posterior lumbar interbody fusions.

Acknowledgments

This study has been financially supported by grants from by the Academy of Finland, Finnish Parliament, The Sigfried Juselius Foundation, the Oscar Klingendahl Foundation, and the Research Foundation of Orthopaedics and Traumatology in Finland.

References

1. J. SOINI, P. SLÄTIS, M. KANNISTO and J. SANDELIN, *Clin. Orthop.* **293** (1994) 89.
2. R. HOLMES, *Plast. Reconstr. Surg.* **63** (1979) 626.
3. U. HEISE, J. F. OSBORN and F. DUWE, *Int. Orthop.* **14** (1990) 329.
4. M. JARCHO, *Clin. Orthop.* **157** (1981) 259.
5. H. J. SENTER, R. KORTYNA and W. R. KEMP, *Neurosurgery* **25** (1989) 39.
6. P. YLINEN, *J. Mater. Sci. Mater. Med.* **5** (1994) 522.
7. A. F. TENCER, V. MOONEY, K. L. BROWN and P. M. SILVA, *J. Biomed. Mater. Res.* **19** (1985) 957.
8. J. GOLDNER, *J. Am. Pathol.* **14** (1938) 237.
9. R. W. BUCHOLZ, A. CARLTON and R. E. HOLMES, *Orthop. Clin. North. Amer.* **18** (1987) 323.
10. T. J. FLATLEY, K. L. LYNCH and M. BENSON, *Clin. Orthop.* **179** (1983) 246.
11. R. J. NASCA, J. E. LEMONS and D. A. DEINLEIN, *Orthopedics* **12** (1989) 543.
12. P. RAGNI and T. S. LINDHOLM, *Clin. Orthop.* **272** (1991) 292.
13. F. A. PINTAR, D. J. MAIMAN, J. P. HOLLOWELL, N. YOGANANDAN, K. W. DROESE, J. M. REINARTZ and B. CUDDY, *Spine* **19** (1994) 2524.
14. T. SHIMA, J. T. KELLER, M. M. ALVIRA, F. H. MAYFIELD and S. B. DUNSKER, *J. Neurosurg.* **51** (1979) 533.
15. D. A. FULLER, S. STEVENSON and S. E. EMERY, *Spine* **21** (1996) 2131.
16. T. C. LIN and S. KREBS, Trans Soc Biomat, 12th Ann Meeting 1986, p. 207
17. A. F. TENCER, P. L. WOODARD, J. SWENSON and J. BROWN, *Ann. NY. Acad. Sci.* **523** (1988) 157.
18. P. TÖRMÄLÄ, R. TAURIO, M. PELLINEN, P. YLINEN and S. VAINIONPÄÄ, in Abstract in International New Business and High Tech Research Conference on Development and Applicatons of Advanced Ceramics and P/M Materials 3–5 Sept. 1989, Jyväskylä, Finland.

Received 27 February
and accepted 17 November 2004