Bisegmental cervical interbody fusion using hydroxyapatite implants: surgical results and long-term observation in 70 cases

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Since 1991 we have used synthetic hydroxyapatite (HA) as a substitute for autologous bone grafting in cervical interbody fusions. Hydroxyapatite is a hydroxyl compound of calcium phosphate \([\text{Ca}_10(\text{PO}_4)_6(\text{OH})_2]\) and is the main constituent (65%) of the naturally occurring bone matrix.\(^2\text{,}^{16,19,20}\) Synthetic HA is chemically identical and crystallographically similar to natural HA in bone. The biocompatibility of this material is well established: it does not provoke a foreign body reaction in vivo and its rate of absorption in situ is very slow.\(^16\) Experimental studies have reproducibly demonstrated bioactive properties of HA; formation of direct bonding with the bone has been confirmed by electron microscopy, and growth of bone on the surface of HA implants (osteoconduction) has been observed.\(^23\) Theoretically, these properties make the use of HA advantageous as a construct material in cervical interbody fusion. Unlike autogeneic or allogeneic bone, HA undergoes little absorption and maintains its initial compressive strength. With progression of osteoconduction, the implant becomes surrounded by autologous bridging bone, which eventually fuses with adjacent vertebral. The uniform quality and composition of HA allow for its optimal biomechanical configuration, producing structural stability and alignment.
In an experiment in which HA material with 30% porosity was implanted in canine cervical vertebrae, bone ingrowth into the pores as well as bone formation on the surface of the material (osteoconduction) was observed 4 weeks after implantation. Hydroxyapatite has been used effectively as a bone substitute in oral, plastic, otological, and orthopedic surgery in the past 20 years and the biocompatibility and safety of the material have been unanimously accepted.

The purpose of this report is to describe our design of HA implants for cervical bisegmental interbody fusion, the surgical techniques involved in their placement, and the results of long-term observations in 70 patients in whom the implants were used to achieve fusion during the past 6 years.

Clinical Material and Methods

Hydroxyapatite Implant

The HA ceramic implants were prepared to our specifications by a Japanese manufacturer (Figs. 1 and 2). Briefly, the implants are manufactured according to the following method. Synthesized HA powder is mixed with foaming liquid, poured into a mold, and then dried in an oven. The dried material is processed into the desired configurations by using computer-guided control and then sintered at a temperature higher than 1000°C. The purity of the material is greater than 99%. The HA implants were made to be 30% porous, which was determined to achieve the best balance between compressive strength and bone infiltration. The goals of our design are: 1) to promote bony ingrowth and better fusion, while allowing for adjustability of the graft configuration during surgery; 2) to make the contact area as large as possible to prevent collapse of the cancellous bone and kyphosis; and 3) to make the preparation of the bone cavity and fitting procedure technically less demanding.

In an experimental study of cervical anterior fusion, an HA implant with 30% porosity yielded superior results of fusion in comparison to dense HA material. Although active osteogenesis in the pores as well as on the surface of 30%-porosity material was observed 4 to 24 weeks after surgery, very limited osteogenesis took place on the surface of dense HA material and fusion was inadequate.

Our material has a double pore structure, with smaller pores measuring between 2 and 5 μm and larger pores between 200 and 500 μm. The smaller pores are interconnected; thus, fluid can permeate the material. The larger pores allow ingrowth of the cellular component and deposit of bone material into the graft. The compressive strength of our implant is 55 MPa (539 kg/cm²) and the bending strength is 23 MPa (225 kg/cm²).

A practical advantage of porous HA over nonporous dense material is that the former is amenable to cutting with a conventional high-speed drill. The height and depth of the implant can be adjusted to the bone cavity in which it is placed during surgery. Our implants (Figs. 1 and 2) were designed to provide stability once in place and to prevent collapse of adjacent cancellous bone. Maintenance of the height of the fusion mass is important for preservation of physiological alignment. The top and bottom surfaces of the implant are convex (“lens shaped”), with a wide area of contact, to prevent dislodgement and to withstand compressive force. The convex surface also prevents concentration of stress that occurs with flexion–extension movement of the vertebrae. The large area of contact helps prevent collapse of adjacent cancellous bone.

To maintain the physiological lordotic curve of the cervical spine, the thickest portion of the implant is located forward, with the apex of maximum thickness ventral to the center of the anteroposterior length. The dorsolateral corners are rounded to avoid contact with the nerve roots. The implant is prepared in three different heights: 10, 13, and 15 mm (Figs. 1 and 2).

Surgical Procedure

A conventional anterior cervical approach is used. Bleeding from the attachment of the musculus longus colli to the vertebral body is coagulated. A retractor of our design is inserted underneath the edges of the longus muscle. After incision into the annulus and removal of disc material with curettage, the cartilaginous endplate is entirely removed to expose the cortical endplates. We prefer to complete the partial vertebrectomy, which matches the configuration of the implant, at this stage.
rather than advancing to decompression of the spinal cord or the nerve roots. The cancellous bone above and below the vertebral body is given a concave shape with an air drill to accommodate the implant. Stainless steel instruments made in the exact configuration of the implants (Fig. 3) are used to prepare the bone cavity and ensure precise fitting of the implant. Special attention is paid to the position of the deepest point of the cavity, which holds the apex of the implant. A round 6- to 7-mm-diameter indentation is made at a point ventral to the center of the vertebral body by using a diamond burr drill. This “crater” serves as a socket to secure the apex of the implant in position. After preparation of the bone cavity, the dorsal margin of the vertebral bodies is resected, including the osteophytes and other offending structures such as a hypertrophied or ossified posterior longitudinal ligament (PLL) or extruded disc material. The PLL is usually resected following corpectomy. It is safe to leave the ligament to protect the dura and the neural structures until bone resection is completed with the air drill. The HA implant is inserted using manual traction of the neck with the apex of the convexity of the implant engaged in the “socket” of the bone cavity. Secure placement is confirmed by rigidity in the anteroposterior and lateral directions, with some allowance in rotation. The position of the implant is routinely checked by fluoroscopy before conclusion of the procedure. The position of the implant can also be reliably checked by intraoperative measurement. The anteroposterior diameter of the implant is 13 mm (Fig. 2). The anteroposterior depth of the vertebral body is usually in the range of 17 to 21 mm. Positioning of the socket on the second ventral quadrant of the vertebral body allows placement of the implant in an appropriate position. The stainless steel instruments (Fig. 3) made to determine the proper size of the implants are extremely useful in this situation as well.

Postoperatively, the patients are fitted with a Philadelphia cervical collar, which they are advised to wear for 8 weeks. They are kept in bed for 1 day and are instructed to walk on the 2nd day.

Patient Groups

Patients’ ages ranged from 22 to 83 years with a mean of 50.6 ± 1.3 years. Two patients were in their 20s, seven in their 30s, 26 in their 40s, 19 in their 50s, 13 in their 60s, and two in their 70s; the remaining patient was 83 years old. Twenty-four of the patients were women and 46 were men. The underlying primary pathological conditions included: disc extrusion in 26 cases, hypertrophied PLL in five, ossified PLL in seven, spondylosis in 31, and trauma/subluxation in one case.

Single interbody fusion was performed in 67 cases and fusion of two interspaces in three cases. Three-body or four-body fusions in which long implants (40–57 mm) were used with or without an anterior locking plate were performed in 24 cases, but these are not included in the present report. Cases in which follow-up periods lasted less than 1 year are also not included in this study.

Follow-Up Radiological Studies

The follow-up period ranged from 12 months to 6 years with a mean of 37.1 ± 2.4 months. The patients underwent plain cervical x-ray film examinations with flexion–extension views at 8 weeks. Six months after surgery, plain cervical x-ray films, tomography, computerized tomography (CT), and magnetic resonance imaging studies were performed. The studies were repeated 12 months after surgery.
after surgery and every 12 months thereafter. The patients’ charts were reviewed for the findings of the dynamic studies, which were recorded in all cases.

Analysis of alignment change was performed by direct comparison of radiographs, namely by laying the postoperative radiograph over the preoperative radiographs. Changes in kyphosis or lordosis in the fused segments were accurately assessed using this simple method. Adequate films for this purpose were available in 55 cases.

Results

Surgical Results and Complications

In 67 patients, surgery was performed uneventfully with successful achievement of decompression and construction of the fusion mass (Figs. 4 and 5). No neurological deterioration related to the surgical procedure or to the HA implant was encountered.

In two patients, the implant became dislocated in the early postoperative period (Fig. 6). Both patients were women of short stature. Ventral dislocation was observed on the patients’ radiographs within a few days after surgery. Neither patient developed dysphagia or airway obstruction. The implants were disproportionately large for the small size of the vertebral bodies in these patients. In both cases the construct was revised with readjustment of the implant and enlargement of the bone cavity in which the implant was placed.

In another patient, who was treated with partial vertebrectomy and a bisegmental construct for C4–6 spondylosis, the implant placed in the C5–6 interspace became dislocated dorsally. During a salvage operation, total vertebrectomy of C-5 and fusion of the C4–6 vertebral bod-
ies with a long implant and an anterior locking plate were performed. Neurological disturbances did not develop during the observation period.

These three patients were treated in the early portion of the series. After these incidents, we adjusted the size of the implant by using an air drill during surgery in cases of shorter patients. There has been no incidence of graft dislocation in the more recent 64 consecutive cases.

Postoperative Radiological and Neurological Course

Postoperative x-ray films with flexion–extension views obtained 8 weeks after surgery (Fig. 4F) confirmed stability of the graft in all 70 cases. All patients were allowed to remove the Philadelphia collar after this examination. Tomograms and CT scans obtained 6 months and 12 months after surgery revealed formation of bridging bone; bone growth from adjacent vertebral bodies was seen on the surface of the implant (Fig. 4G and H). One or 2 years after surgery, the entire implant was encased by bone (Fig. 7). Eventually, the fusion appeared as a continuous bone mass surrounding the implant.

In the present series, collapse of the vertebral body or “sinking” was not observed, even in elderly women who suffered from osteoporosis. Normal cervical lordosis present at the time of surgery remained preserved in most cases throughout the follow-up period. Among 55 patients in whom radiological follow up was adequate for analysis, lordosis was present preoperatively in 23. In 22 of them (96%), lordotic alignment was preserved postoperatively throughout the follow-up period (Table 1). Improvement in the alignment of the vertebrae (Fig. 8) was observed in 16 cases (29%), including restoration of lordosis in seven cases with preoperative findings of neutral curve, correction of kyphosis to neutral in six cases, and partial correction of kyphosis in three cases (Table 1).

Neurological deterioration related to the fusion segments was not observed. Neurological status was assessed using the Neurosurgical Cervical Spine Scale, an official scoring system defined by the Japanese Society of Spinal Surgery (Table 2). Adequate follow-up evaluation was available in 63 patients. The mean preoperative score for this group was 10.6 ± 0.17 (mean ± standard error of the mean [SEM]), and the postoperative score was 13.6 ± 0.1 (mean ± SEM, p < 0.0001, analysis of variance). The average improvement rate of the neurological score was 90.3 ± 2.2% (based on the following equation: improvement rate = [postoperative score – preoperative score]/[100 – preoperative score]). The postoperative perfor-
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The present clinical series demonstrates that solid fu-
lation patients. The porous material, like the implants used in our series, allows bone ingrowth into the pores and promotes union with adjacent bones. Osteoconduction is another unique property of the material. Formation of bridging bone on the surface of the implants was observed in postoperative radiographic studies (including tomograms and CT scans) within 6 months after surgery. The process progressed over time and, finally, the implanted HA became entirely encased. Because our implants are smaller than the vertebral bodies, in width and in depth, the encasing bone eventually fuses two adjacent vertebral bodies. It appears that bone formation and integration of adjacent vertebral bodies are more important in bearing stress than direct union between the HA and the bone.

Zdeblick, et al., used coral-based HA to provide ante-
rior cervical fusion with and without internal fixation by an anterior plate system in a goat model. They found 48% of the implants were incorporated histologically by 12 weeks after surgery. The rate increased to 71% of the implants when internal fixation was used. However, collapse of the implant was observed in 24 (with plates) to 29% (without plates). Akino used both porous and dense HA material to provide anterior fusion in a dog model and found formation of new bone on the surface of the porous HA implant and in its pores 4 weeks after surgery. The amount of bone formation increased up to 8 weeks and then became stable. With dense HA, the process progressed only at an inadequate rate over 24 weeks.

Clinical application of HA to anterior cervical fusion was pioneered by Koyama and Handa in Japan. Their implants are made with nonporous dense material in the form of a trapezoid (lateral view) for maintenance of lordosis. The two surfaces adjoining the vertebral bodies have ridges that must be precisely fitted in the gutters drilled in the bone cavity. The processes protrude into the cancellous bones and secure the implant in place. These implants have been used in a large number of cases and have achieved reliable results.

In the present series with follow-up observation periods lasting longer than 12 months (maximum 72 months), malunion in the latent phase was not observed. In the three cases with implant dislocation, migration became evident within a few days after surgery. In the rest of the series, flexion–extension studies performed 8 weeks after surgery invariably demonstrated a stable graft construct. After the incidences of dislocation in the early portion of our series, we made the implant smaller in patients of small stature. Since then there has been no incidence of graft dislocation. In fact we have not experienced that complication in the last 64 consecutive cases.

Disintegration of HA implants in cervical fusion has been reported. We believe appropriate biomechanical design of the implant is crucial. Our implants have a large area of contact with the vertebral bodies, with convex surfaces to avoid concentration of mechanical stress. If the surface of the implant inserted in the interspace is flat, the compression load will be concentrated on a certain point, or “fulcrum,” on the surface, especially with flexion–extension movement. There has been no incidence of breakage in the present series with up to 72 months of follow-up.

In the process of fusion in which an autograft is placed,
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the graft bone has to be absorbed first and replaced by the host bone after invasion of microvessels and osteoprogenitor cells, the precursors of osteoblasts (creeping substitution).\(^\text{20}\) Mobilization of undifferentiated mesenchymal cells (oste induction) takes place in response to the bone morphogenic protein, which is present in the graft matrix or secreted by the osteoblasts. Growth of microvessels and perivascular tissue containing osteoblasts occurs and bone substance is deposited (oste conduction). In cases of allograft implants obtained from human cadaver or implants of synthetic porous HA, osteoinduction takes place on the surface and inside the framework. During fusion in which autologous bone has been used, osteoinduction is observed from 1 to 4 weeks and osteoconduction continues for several months to years.\(^\text{25}\) Remodeling, the process of absorption and bone deposition in response to mechanical stress, continues for years.

Unlike autografts or allogeneic grafts, HA is not amenable to absorption by the host cells. Resorption of HA is very limited in both cell-mediated processes and solution-mediated processes.\(^\text{16}\) Collapse of the graft implant and subsequent loss of alignment in the construct did not occur in our experience with HA, which we believe is a significant advantage over natural bone grafts, either autogeneic or allogeneic.

The technique can be applied in cases of spondylitis and hypertrophy or ossification of the PLL in which substantial portions of the vertebral bodies have to be removed. As increasing amounts of vertebral body have to be resected, implants with greater height—13 or 15 mm—can be used. The implants and the technique have been used effectively in combination with an anterior locking plate in cases with spinal instability.

Conclusions

Based on the long-term postoperative results, we believe our technique of bisegmental fusion using HA is safe and effective. The material and technique eliminate the need for graft harvest and induce reliable fusion of adjacent vertebrae with preservation of the initial alignment. The implant functions not only as filling for the defect, but also as the core for formation of the bone mass required to endure mechanical loads.

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Disclosure

The authors have no financial interest in the HA implants. Patents pending: S.N 08/268,103 (United States), P4423826.6 (German), and U05-037185 (Japan); design patent No. 925351 by Asahi Optical Co. Ltd., Tokyo, Japan.

References


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