Akihito Minamide
Tetsuya Tamaki
Munehito Yoshida
Hiroshi Hashizume
Yukihiro Nakagawa

The use of sintered bone in spinal surgery

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A. Minamide (✉) · T. Tamaki
M. Yoshida · H. Hashizume · Y. Nakagawa
Department of Orthopaedic Surgery,
Wakayama Medical College,
811-1 Kimiidera, Wakayama City,
Wakayama 641-8157, Japan
e-mail: aminami@emory.edu,
Tel.: +81-73-441-0645,
Fax: +81-73-448-3008

Abstract The sintered bovine bone True Bone Ceramics (TBC) is one of the biomaterials based on calcium phosphate, an organized crystal of bone mineral and a biomaterial possessing a natural trabecular structure. We examined whether the sintered bovine bone can integrate with recipient bone and adjust to the strength of recipient bone for anterior spinal fusion in an animal model. Based on radiographic evaluation, manual palpation, biomechanical testing, and histological examination, spinal fusion with TBC resulted in a composition and structure similar to that of

autograft (and to no implantation). TBC, with its moderate strength, tended to adjust to the bone stiffness of the host bone in the respective specimens as new bone growth developed. Our observations warrant further clinical investigation of the use of sintered bone as an effective spinal arthrodesis, especially in patients who have fragile vertebrae, as in osteoporosis.

Keywords Animal model · Biomaterials · Biomechanics · Sintered bone · Spinal fusion

Introduction

Vertebral body destruction sometimes results in spinal instability or neural compression. Such conditions include osteoporosis, traumatic spinal injury, spinal tumors, and infectious diseases of the spine. Several reports of neurological compromise caused by delayed vertebral collapse after osteoporotic compression fracture have been recently published [11]. Anterior decompression of the vertebral body or vertebral corpectomy is indicated to relieve stress on the neural tissues, and to permit reconstruction of the destabilized spine. In reconstruction, autologous bone grafting has been the standard way to obtain bone fusion. However, the use of autografting is subject to limitations on suitable location and volume, and the harvesting of autologous bone grafts is responsible for significant morbid complications in as many as 30% of patients [5]. To avoid the disadvantages of autologous bone graft, considerable attention has been directed toward development of suitable biosynthetic bone graft substitutes. Synthetic

biomaterials provide attractive alternatives for use in spinal fusion. However, such biomaterials have proved problematic, and reliable methods have not been established to apply these relatively stiff materials to patients who have fragile vertebrae, as in the case of osteoporosis. Implanted biomaterials have been reported to sink into the vertebra above or below the implantation site because of comparative differences in strength between recipient bone and the biomaterial [1]. As artificial substitutes designed to repair lost bone tissue morphologically, these materials must be fully biocompatible. They must also be able to provide for the rapid penetration of osteogenesis from the host bone bed to the center of the implant. The optimal substitute is one with a composition and a structure similar to that of human bone tissue, and one that has the biological ability to adjust to the unique bone stiffness of each recipient. For the biomaterial that can integrate with recipient bone and adjust to the stiffness of the recipient bone, the sintered bone, which is one of the natural biomaterials based on the calcium phosphate system, may be thought to be a candidate. The moderate mechanical strength and struc-

Fig. 1 **A** Micrograph of a True Bone Ceramics (TBC) block reveals a structure of both monocortical (*arrow*) and cancellous bone. **B** A higher magnification view of the TBC block. Scanning electron microscopy shows preservation of the microstructural structure and interconnecting pores of cancellous TBC

ture of sintered bone may permit it to be used for spinal fusion in ageing patients.

We selected sintered bovine bone, True Bone Ceramics (TBC: Koken, Tokyo, Japan), developed by Ueno et al. [12, 13] in 1983, for the implanted biomaterial in spinal fusion. TBC is made by sintering bovine bone at high temperatures (initially 600°C, secondly 1450°C), and is one of the natural biomaterials, consisting mainly of calcium phosphate and an organized crystal of bone mineral that possesses moderate mechanical strength (mean compressive strength: 9.2 ± 1.9 MPa). TBC is a biomaterial that possesses a natural trabecular structure with interstices connecting to the porous structure of natural bone (Fig. 1). It is thought that the natural bony structure of TBC facilitates the growth of vessels into the material and provides an ideal environment for bone formation [2, 4, 8, 12, 13]. TBC accelerates in vitro adhesion and calcification by osteoblasts more actively than does artificial hydroxyapatite [7].

Materials and methods

The purpose of the present study was to identify whether sintered bovine bone could integrate with recipient bone and adjust to the strength of recipient bone for anterior spinal fusion in an animal model. Seventeen mature pigs were used. A lumbar spinal body fusion was performed through an anterior retroperitoneal approach. The vertebral bodies of L2 and L3 were exposed and the single-level interbody fusion was performed. Either autologous iliac bone (autologous bone group) or sintered bovine bone (TBC group) was implanted for a spinal fusion. Some pigs underwent exposure of the spinal bodies without implantation (control group). The pigs

were sacrificed 3 or 6 months after surgery. The lumbar spines were harvested en masse.

Results

Spinal fusion was confirmed by radiographic analysis, biomechanical testing, and histological examination. Fusion was successful in all pigs that received the sintered bovine bone or the autologous bone. Spinal fusion with TBC resulted in a composition and structure similar to that of the autograft (and of no implantation). The TBC, with its moderate strength, tended to adjust to the bone stiffness of the host bone in the specimens as new bone grew (Fig. 2). In the histological findings, trabeculae of regenerated bone were apposed directly to the TBC and there was no sign of intervening soft tissue between the bone and the implant. The new bony matrix was growing into pores located in the deeper regions of the TBC, so that all pores of TBC gradually filled up.

Augmentation to clinical study using sintered bone

Bioactive materials that possess excellent strength in themselves, such as titanium cage and Apatite and Wollastonite coating glass ceramics (A-W glass ceramics), have been applied clinically to reconstructive spinal stabilization [1, 3, 6, 10]. However, there are doubts about whether spinal reconstruction requires biomaterials that

Fig. 2 Graphs showing the axial compressive (A) and torsional (B) stiffness of each construct. There were no significant differences in the stiffness of each loading method among samples from each group. The unfused L2-L3 motion segments in the control group were separated at the level of the L2-L3 disk. The L2 or L3 segments were tested biomechanically in an identical manner to obtain an internal control and to determine the strength of vertebra itself to minimize the effect of biological variation among different animals

(A)

(B)

are much harder than the recipient bone. In some studies, implanted biomaterials affected the adjacent vertebrae because of relative differences in strength between recipient bone and the implanted material [1, 6]. One phenomenon is that the implanted material may sink into the vertebra superior or inferior to the implant in patients who have fragile vertebrae, such as those with osteoporosis. Vertebrae in the ageing spine fail because they cannot support the internal stresses and strains that result from loads applied to the spine. With ageing and osteoporosis, the

strength of the trabecular bone and the structural capacity of the vertebrae are compromised. Reductions in the apparent density and the bone mineral density of trabecular bone typify ageing and osteoporosis. In many experimental studies, the maximum force during compression of vertebral specimens has been assessed, and the failure force has been related to the apparent density and geometric properties of the vertebrae [9]. Measurements have shown that much lower failure force accompanies ageing and severe osteoporosis.

Therefore, the moderate mechanical strength of sintered bone may permit it to be used for spinal fusion in ageing patients with osteoporosis. The basis for this claim is that the optimal substitute material would be one that has a composition and structure similar to that of human bone tissue and one that would biologically adjust to the bone stiffness of a particular patient while allowing the substitute material to serve as a site for new bone formation. In biomechanical and histological testing, our experimental results were similar to those of the autograft and to the group with no implanted vertebrae. Because the implanted TBC integrated so well with the recipient bone and permitted the progressive growth of new bone into its pores, the stiffness of the TBC, with its moderate mechanical strength, appears to have adjusted biologically to match that of the respective host bone at the implantation site. Therefore, TBC appears to be a bioactive material, which forms a permanent integration and adjusts to the recipient bone in a similar manner to an autologous bone graft.

Conclusion

TBC, which is one of the natural biomaterials based on the calcium phosphate system, attained biomechanical and histological equivalency with the autograft (and with no implantation). Most importantly, sintered bone, with its moderate strength, tended to adjust to the stiffness of the bone in the host bed. Although it may be necessary to perform more detailed experimental studies on these improvements to sintered bone and on the use of instrumentation as an adjunct, our observations warrant further clinical investigation of the use of sintered bone as an effective spinal arthrodesis, especially in patients who have fragile vertebrae, as in osteoporosis.

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References

1. Abumi K, Kaneda K, Satoh E, Takeda N, Taneichi H, Ito M (1998) Anterior reconstruction of the thoracic and lumbar spine using Kaneda anterior spinal system: indication and results in destructive spinal disorders (in Japanese). *Rinsho Seikeigeka* 33:495-503
2. Hashizume H, Tamaki T, Oura H, Minamide A (1998) Changes in the extracellular matrix on the surface of sintered bovine bone implanted in the femur of a rabbit: an immunohistochemical study. *J Orthop Sci* 3:42-53
3. Kaneda K, Asano S, Hashimoto T, Satoh S, Fujiya M (1992) The treatment of osteoporotic posttraumatic vertebral collapse using the Kaneda device and bioactive ceramic vertebral prosthesis. *Spine* 17:S295-303
4. Katoh T, Sato K, Kawamura M, Iwata H, Miura T (1993) Osteogenesis in sintered bone combined with bovine bone morphogenetic protein. *Clin Orthop* 287:266-275
5. Kurz L, Grafin SR, Booth RE (1989) Harvesting autogenous iliac bone graft. A review of complications and techniques. *Spine* 14:1324-1331
6. Leong JCY, Chow SP, Yau ACMC (1994) Titanium-mesh block replacement of the intervertebral disk. *Clin Orthop* 300:52-63
7. Matsumoto T, Kawakami M, Kuribayashi K, Takenaka T, Minamide A, Tamaki T (1999) Effects of sintered bovine bone on cell proliferation, collagen synthesis and osteoblastic expression in MC3T3-E1 osteoblast-like cells. *J Orthop Res* 17:586-592
8. Minamide A, Tamaki T, Yoshida M, Hashizume H, Nakagawa Y (2000) An experimental approach to spinal fusion using sintered bovine bone in a pig model. *J Spinal Disord* 13:156-164
9. Myers ER, Wilson SE (1997) Biomechanics of osteoporosis and vertebral fracture. *Spine* 22:S25-31
10. Nibu K, Panjabi MM, Oxland T, Cholewicki J (1997) Multidirectional stabilizing potential of BAK interbody spinal fusion system for anterior surgery. *J Spinal Disord* 10:357-362
11. Shikata J, Yamamuro T, Iida H, Shimizu K, Yoshikawa J (1990) Surgical treatment for paraplegia resulting from vertebral fractures in senile osteoporosis. *Spine* 15:485-489
12. Tamaki T, Sakurai K, Kasamatsu N (1994) Results of basic and clinical studies of true bone ceramics. In: Urist MR, O'Connor BT, Burwell RG (eds) *Bone grafts, derivatives and substitutes*. Butterworth-Heinemann, Oxford, pp 235-244
13. Ueno Y, Shima Y, Ueyoshi A, Harada M, Sakata Y, Maeda T, Akiyama T (1985) Experimental studies of sintered bone implantation (in Japanese). *Bessatsu Seikeigeka [Orthopedic Surgery, Suppl]* 8:85-88