Defatted, gas-sterilised cortical bone allograft for posterior lumbar interbody vertebral fusion

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Summary. In posterior lumbar interbody vertebral fusion operations, variously sized, rectangular shaped, defatted, freeze-dried, gas-sterilised cortical bone allografts were used in combination with cancellous bone autografts from excised posterior elements. Single-level fusion, with or without internal fixation, was undertaken in 38 patients aged 50 years or less with disc herniation or a failed discectomy (the younger group) and in 33 women aged 60 years or more with degenerative spondylolisthesis (the older group). Of the various observable indicators of union, changes in the allograft-host interface alone proved to be of practical use. The incidence of nonunion in patients managed with pedicle screws, with a hook and rod system or without internal fixation was 0 of 8 patients; 1 of 14 patients; and 3 of 16 patients, respectively, in the younger group, and 0 of 11 patients; 0 of 8 patients; and 2 of 14 patients, respectively, in the older group. Of the six patients with nonunion, three had persistent low back pain and only two had mobility of the fused segment which was evident on lateral radiographs during flexion and extension. No patient had graft collapse. The decrease in the height of the intervertebral space, chiefly due to settlement of the allograft into the vertebral bodies, in the younger and older groups averaged 1.1 and 1.6 mm, respectively. We concluded that this simplified technique is mechanically sound and ef-

fective in maintaining the height of the intervertebral space. Even when the graft failed to unite, fibrous union could be obtained without graft collapse. Combination with a simple internal fixator, such as a compression rod, facilitates bone union.

Résumé. Pour arthrodèse inter-somatique lombaire par voie postérieure, des allogreffes d'os corticaux stérilisées au gaz, lyophilisées et dégraissées, de configuration rectangulaire et de dimensions diverses, furent utilisées en combinaison avec des autogreffes d'os spongieux provenant des éléments postérieurs excisés. La fusion à un seul niveau avec ou sans fixation interne a été étudiée chez 38 patients âgés de 50 ans ou moins et souffrant d'une hernie discale ou d'une post-discectomie avec stase veineuse en amont (chez les plus jeunes) et chez 33 femmes âgées de 60 ans ou plus souffrant d'un spondylolisthésis dégénératif (chez les plus âgés). Les groupes les plus jeunes et les plus âgés étaient respectivement composés de 8 et 11 patients avec vissage pédiculaire, de 14 et 8 patients avec crochet et tige et de 16 et 14 patients sans fixation interne. Parmi les divers paramètres du processus de fusion, seuls les changements dans l'interface allogreffe hôte, ont prouvé être utiles en pratique. L'incidence d'une non-fusion chez les patients avec vissage pédiculaire, avec crochet et tige et sans fixation interne était respectivement de 0%, 7% et 19% dans le groupe des plus jeunes et de respectivement 0%, 0% et 14% dans le groupe des plus âgés. Des 6 patients avec une nonfusion 3 avaient des douleurs lombaires persistantes et 2 seulement une mobilité du foyer d'arthrodèse en flexion-exten-

sion. Il n'y a eu aucun collapsus de greffon. La perte de hauteur de l'espace intervertébral dû principalement à l'impaction de l'allogreffe dans le corps vertébral fut en moyenne de 1,1 et de 1,6 mm respectivement dans les groupes les plus jeunes et les plus âgés et s'est poursuivie en moyenne 3,8 et 5 mois respectivement dans chaque groupe après l'opération. Nous concluons que cette méthode est mécaniquement satisfaisante avec une technique simplifiée et qu'elle est efficace dans le maintien en hauteur de l'espace intervertébral. Même si la fusion osseuse n'est pas réalisée, une union fibreuse peut être obtenue sans collapsus de la greffe.

Fig. 1. Cutting of the diaphysis of the tibia. The bone is to be placed within the intervertebral space with the axis of the tibia in a vertical direction as in Fig. 2

Introduction

There is a high incidence of graft collapse or nonunion in posterior lumbar interbody fusion (PLIF) using iliac bone autograft [9, 10] because this material is not always strong enough [1], even if tri-cortical bone is used. Cortical bone from the diaphysis of the tibia or femur, whether it is an autograft or an allograft, is mechanically strong enough to serve as a strut to support the interbody fusion [7]. As this cortical bone is thinner than iliac bone of fullthickness, it can be inserted into the intervertebral space without excessive retraction of the nerve roots. Difficulty in harvesting cortical bone autografts of the required dimensions and in cutting hard cortical bone into the desired shape during surgery can be overcome by the use of defatted, freeze-dried, gas-sterilised bone allografts [2, 3, 4]. These grafts have been used in PLIF with or without internal fixation. The purpose of this study was to examine the efficacy of the cortical bone allograft and to determine the most effective and efficient way of establishing solid bone union in PLIF.

Materials and methods

Preparation of the allograft

The cortical bone was obtained from the tibial diaphysis of limbs which had been amputated following trauma or acute ischaemia and stored at -80°C until they were ready to be prepared. The cortical bone was cut with an electric fretsaw into rectangular shapes of 10 to 15 mm in height at intervals of 1 mm and about 25 mm in length (Fig. 1). This bone was then treated sequentially under clean but not sterile conditions [2, 3, 4]:

1. It was washed with deionized water at 4°C , and centrifuged at 1,000 rpm in a hydroextractor to reduce the content of fat and water.
2. It was then defatted in a continuously agitated mixture (1:1 v/v) of chloroform and methanol at room temperature for 48 h, and then centrifuged as above.
3. The chloroform and methanol were allowed to evaporate in an air flow at room temperature.
4. The bone was washed in distilled water by stirring at 4°C for 24 h.
5. It was then frozen at -80°C , and dehydrated by freeze-drying for 7 days in a vacuum with the temperature of the condenser at -40°C and the shelf at about 25°C .
6. It was wrapped doubly in sterilising packs (Steriking See-Through Peel-Packs, Wipak Medical, Nastola, Finland), in which one side was paper and the other transparent plastic film.
7. Finally, the bone in the pack was exposed to ethylene oxide gas at 30°C for 12 h, and aerated to remove residual ethylene oxide and its toxic by-products.

The packs containing the bone were enclosed in transparent waterproof wrapping and stored at room temperature until they were ready to be used.

Fig. 2. Position of cortical bone allograft and cancellous bone autograft. *Autograft*: Cancellous bone autograft from excised posterior elements. *Allograft*: Cortical bone allograft

Table 1. Background of the patients

	Disc herniation or post-discectomy failed back in men or women aged 50 years or less (the younger group)			Degenerative spondylolisthesis in women aged 60 years or more (the older group)		
	with pedicle screws	with hook and rod	without internal fixation	with pedicle screws	with hook and rod	without internal fixation
Number of patients (men/women)	8 (7/1)	14 (10/4)	16 (13/3)	11 (0/11)	8 (0/8)	14 (0/14)
Age ^a (years)	39 ± 11 (23~49)	38 ± 8 (22~49)	41 ± 11 (25~50)	64 ± 3 (61~70)	65 ± 3 (60~68)	66 ± 7 (60~79)
Fused segment						
L3/4	0	2	1	2	0	1
L4/5	4	6	7	8	8	13
L5/S	4	6	8	1	0	0
Follow-up period ^b (months)	35 (26~53)	51 (28~91)	36 (28~45)	36 (24~72)	58 (27~99)	35 (25~44)

^a Values are means and standard deviations with ranges in parentheses ^b Values are means with ranges in parentheses

Technique of operation

At operation, the medial two-thirds of the facets and the caudal two-thirds or more of the adjoining cephalad lamina were excised. The cartilaginous end-plates and disc material were totally removed. The central portion of the posterior longitudinal ligament and the underlying annulus fibrosus was retained. The posterior rims of the vertebral bodies were cut with a chisel. The peripheral portions of the cortical end-plates, which were to be in contact with the cancellous bone autograft, were partially decorticated. Their central portions were preserved without decortication to prevent settlement of the cortical bone allograft into the vertebral bodies. Four or five pieces of rectangular thick cortical bone allografts were placed as struts, and small pieces of cancellous bone autograft were packed anterior and lateral to the cortical bone allografts (Fig. 2). The autograft was obtained from excised portions of the facets and lamina. The cortical bone allograft was driven into a vertical position with a bone impactor in an intervertebral space which had been expanded using a Cloward vertebral spreader.

Between October 1985 and December 1987, a compression hook and rod system, using a Kaneda posterior device [6], was fixed between the two adjoining laminae as an additional procedure. We then changed to a pedicle screw and rod system using a Kaneda anterior device [5] and this was used from January 1988 to September 1991. The patients were confined to bed during the first week after operation and thereafter a hard corset was worn for two months.

The subjects in this study had single-level PLIF using the pedicle screw system, the hook and rod system, or without any internal fixation, which was undertaken at the level of L3/4, L4/5, or L5/S1 for disc herniation or after failed discectomy in patients aged 50 years or less (the younger group), and for degenerative spondylolisthesis with a slip of less than 50% in women aged 60 years or more (the older group). We excluded patients who had previously undergone fusion or had congenitally fused segments, scoliosis or kyphotic deformity of the lumbar spine. Seventy-three were selected for this study. One died of myocardial infarction 9 months after the operation, and another moved away 2 months after surgery. Thus, 71 patients were available for review (Table 1). Symptoms and signs were recorded by one of the authors (M. K.) and radiographs of the lumbar spine were obtained at least every 2 months during the

first 2 years after the operation. Lateral radiographs of the lumbar spine on maximum flexion and extension were obtained approximately 2 years after operation. The internal fixation was always removed after the radiographs had indicated bone union.

Lateral radiographs of the lumbar spine were evaluated in terms of the decrease or increase in the graft-host interface [8] (Fig. 3), anterior progression of new bone within the intervertebral space [8] (Figs. 3, 4), formation of continuous bone bridges between the posterior rims of the two adjoining vertebral bodies (Fig. 4), decrease in the height of the intervertebral space and fracture of the allograft.

The height of the intervertebral space was defined as the average of the distance between the anterior and posterior vertebral rims. The value of decrease in the intervertebral space height was obtained by subtracting the height of the intervertebral space measured at the final follow-up from that recorded immediately after operation.

Results

Complications

There were no instances of infection, as denoted by wound drainage or erythema. No graft was fractured or displaced and there was no breakage of the internal fixation. One patient treated for a failed discectomy at the level of L5/S1 had a transient neurological deficit in the S1 distribution after operation.

Determination of radiological parameters of bone union

Radiographic evidence of ossification of the remaining disc material, anterior progression of new bone within the intervertebral space and formation

Fig. 3A–D. A 35-year-old man who underwent PLIF with the hook and rod system for pain following discectomy. **A** Two weeks after operation; *arrows* indicate the allograft-host interface. **B** Four months after operation; a decrease in the allograft-host interface is noted. **C** Ten months after operation; loss of the interface is noted. **D** Three years and nine months after operation; an *arrow* indicates anterior progression of new bone within the intervertebral space

Fig. 4A–C. A 62-year-old women who underwent PLIF with the hook and rod system for degenerative spondylolisthesis. **A** Before operation. **B** Two months after operation. **C** Four years and four months after operation; *arrows* indicate continuous posterior bone bridge and anterior progression of new bone

Table 2. Parameters of bone union

Decrease in allograft-host interface	
Time (months after operation) for detecting the decrease	4.1 ± 3.3
Number of patients showing the decrease ^a ;	
until 7.4 months after operation	61
from 7.4 to 10.7 months after operation	0
from 10.7 to 14.0 months after operation	1
from 14.0 to 17.3 months after operation	3
Number of patients not showing the decrease	6
Loss of allograft-host interface	
Time (months after operation) for detecting the loss	7.9 ± 5.1
Number of patients showing the loss ^b ;	
until 13.0 months after operation	61
from 13.0 to 18.1 months after operation	0
from 18.1 to 23.2 months after operation	2
from 23.2 to 28.3 months after operation	2
Number of patients not showing the loss	6
Anterior progression of new bone within the intervertebral space	
Number of patients showing the progression	19
Time (months after operation) for detecting;	
Appearance of the progression	10.4 ± 6.2
Completion of the progression	27.1 ± 13.6
Formation of continuous posterior bone bridge	
Number of patients showing the formation	12
Time (months after operation) for detecting;	
Appearance of the formation	9.2 ± 7.4
Completion of the formation	26.4 ± 23.2

Values given as $X \pm Y$ are means and standard deviations

^a The mean and standard deviation (SD) of the time required for detecting the decrease were 4.1 and 3.3 months, respectively, after operation. The sums of the mean and SD, the mean and two times SD, the mean and three times SD, and the mean and four times SD were 7.4, 10.7, 14.0, and 17.3 months, respectively

^b The mean and SD of the time required for detecting the loss were 7.9 and 5.1 months, respectively, after operation. The sums of the mean and SD, the mean and two times SD, the mean and three times SD, and the mean and four times SD were 13.0, 18.1, 23.2, and 28.3 months, respectively

Table 3. Results with bone union and decrease in the intervertebral space height

	Disc herniation or post-discectomy failed back in men or women aged 50 years or less (the younger group)			Degenerative spondylolisthesis in women aged 60 years or more (the older group)		
	With pedicle screws	With hook and rod	Without internal fixation	With pedicle screws	With hook and rod	Without internal fixation
Number of patients with						
Union of normal process	8	13	13	11	7	9
Delayed union	0	0	0	0	1	3
Non-union without mobility of the segment	0	0	2	0	0	2
Non-union with mobility of the segment	0	1	1	0	0	0
Number of patients with decrease in the intervertebral space height by;						
less than 2.0 mm	8	12	11	10	6	9
2.0 to 4.0 mm	0	2	5	1	1	3
more than 4.0 mm	0	0	0	0	1	2
Duration of progress of the decrease ^a (months)	N/A	2.8 ± 1.2	4.4 ± 2.4	5	4.6 ± 1.9	5.5 ± 2.1
		(2~5)	(2~9)		(2~6)	(2~9)

^a Values are periods until the progression of the decrease ceased in patients with the decrease by 2 mm or more, and are means and standard deviations with ranges in parentheses

of continuous posterior bony bridges between the two adjoining vertebral bodies (Figs. 3, 4), were observed only in patients with normal bone union. These findings were only seen in the late stage of union in a small proportion of patients (Table 2).

When bony union was completed, the autograft had the appearance of a well-incorporated bony mass. In the early stages of union, the interface between the autograft and the vertebral bodies was not clearly visible on lateral radiographs in 52 of the 71 patients because the cancellous bone autografts were almost radiolucent and totally or partially concealed from view by the allograft. Thus, the state of the autograft-host interface was not a practical guide to the progress of union, but the interface between the cortical bone allograft and the vertebral bodies (Fig. 3) was visible in all the 71 patients, and its appearance was helpful in assessing union.

Assessment of union

Of the 71 patients, 65 showed loss of the allograft-host interface. Of these, 61 demonstrated a decrease, or loss of the allograft-host interface at a stage not later than the sum of the mean and standard deviation of the time required for the detection of each finding. In 4 patients loss of the interface became apparent later than the sum of the mean and twice the standard deviation of each period of time (Table 2).

Patients were defined as having normal union when decrease in or loss of the allograft-host interface was detected not later than 7.4 and 13.0 months, respectively, after the operation. The result was defined as delayed union when the findings were first detected later than those periods, and as nonunion when the allograft-host interface was increased at 17.3 months or present at 28.3 months after the operation. The 17.3 and 28.3 month stages were derived from the sum of the mean and 4 times the standard deviation of the time required for detection of decrease in and loss of the interface, respectively (Table 2). The nonunion group was divided into those with and those without mobility of the fused segment on flexion and extension.

Bone union and decrease in the height of the intervertebral spaces

In both the younger and older groups of patients, the incidence of normal bone union was highest in those with the pedicle screw system and lowest in those without internal fixation (Table 3). There was no significant correlation ($P > 0.05$) between the three groups as to internal fixation and the results of bone union, as determined by a contingency table. Nonunion with mobility of the fused segment, i.e. definite pseudo-arthritis, was seen in only two patients in the younger group, one with the hook and rod system and the other without internal fixation.

Decrease in the height of the intervertebral space in the younger group was only 1.1 mm on average, with a standard deviation of 1.1 mm. The decrease in the older group was 1.6 mm on average with a standard deviation of 1.9 mm. More than 4.0 mm of decrease was seen in only 3 patients from the older group (Table 3). In patients with a decrease of 2.0 mm or more, progression of the decrease ceased at 3.8 months on average, with a standard deviation of 2.0 months for the younger group. In the older group, the decrease ceased at 5.0 months on average, with a standard deviation of 2.0 months.

Decrease in the height of the intervertebral space is of equal significance to the settlement of the allograft into vertebral bodies, because most of the progress of the decrease in height is usually observed during the 2 months after operation; the height of the allograft never decreased during this period.

Of the cephalad and caudal aspects of the allograft-host interface, one interface increased and the other disappeared in every patient with nonunion. No patients showed an increased interface in both aspects, which would have indicated sequestration of the allograft.

Persistent postoperative low back pain

Each of the 71 patients had low back pain before operation, and 6 of the 71 patients (3 of the 6 with nonunion and 3 of the 65 with normal or delayed union) had persistent low back pain 2 years after the operation. The 3 patients with nonunion and low back pain were all from the younger group. The pain did not restrict daily activity in any instance.

Of the 3 patients with nonunion and low back pain, lateral radiographs on flexion and extension

revealed mobility of the fused segment. Of the 3 patients with nonunion but without low back pain, none showed mobility of the fused segment.

Discussion

A disadvantage of the use of iliac bone autograft alone in PLIF is graft collapse. This often results in nonunion or malunion, even though better fusion can be obtained if the pedicle screw fixation is added [9, 10]. We believed that graft collapse would be prevented and bone union improved by combining the advantages of a cancellous bone autograft as a source of osteoprogenitor cells with a cortical bone allograft as a bioactive, biodegradable spacer which provided mechanical support. In our graft complex, the cancellous bone autograft is supported by the slowly-resorbed cortical bone allograft, and in the early stage contributes only to bone formation, not to mechanical support. The new bone in the autograft bridges the two adjoining vertebral bodies, growing into a solid bone mass which further stabilises the segment. However, the cortical bone allograft gradually loses mechanical strength.

The long-term presence of a radio-opaque contour of cortical bone allograft indicates slow resorption of the allograft and the mechanical strength of the construct. Patients with delayed union have bone hypertrophy which results in gradual bony union or a rigid fibrous union without mobility of the fused segment.

In PLIF using iliac bone autograft for degenerative spondylolisthesis, nonunion was reported in 2 of 27 of patients without internal fixation and 0 of 7 with Steffee's VSP system [10]. Nonunion occurred in 32 of 200 (16%) patients who underwent PLIF for disc herniation using iliac bone autograft without internal fixation [10]. It was also reported that in PLIF using iliac bone autograft for disc herniation, degenerative spondylolisthesis or spondylolytic spondylolisthesis, the graft collapsed in 38 of 371 (10%) patients without internal fixation, 4 of 44 (9.1%) with Roy-Camille's pedicle screw system, and 1 of 87 (1.1%) with Steffee's VSP system [9]. In our series of Japanese patients, both the pedicle screw system and the hook and rod system decreased the incidence of delayed union or nonunion, although the former system was more effective.

In practical terms, a rectangular-shaped cortical bone autograft cannot be used in PLIF, as precise cutting of cortical bone is very difficult during surgery. Defatting and freeze-drying make bone

more permeable to ethylene oxide gas, with few harmful effects on osteogenic properties. Furthermore, even bone which is contaminated with bacteria can be effectively sterilised with little residual ethylene oxide and toxic by-products [2, 4]. A defatted, freeze-dried, gas-sterilised cortical bone allograft can be easily and precisely cut into desired shapes by using an electric fretsaw under clean but not sterile conditions.

When an iliac bone autograft is used within the intervertebral space, the process of bone union can easily be monitored by routine radiographs. In our PLIF construct, however, a radio-opaque and slowly resorbed cortical bone allograft occupies a large area of the intervertebral space on the lateral radiograph, and the process of union in the combined cancellous bone autograft cannot be clearly seen during the early stages of incorporation. For this reason, detection of the progress of union in the early stages is dependent upon a reaction of the host bone around the allograft, such as a decrease in the allograft-host interface. In the late stages of bone union, ossification of the disc material due to appositional interstitial bone growth is apparent as anterior progression of new bone and formation of a posterior bone bridge. These are seen at an average of about 10 months and are complete in approximately 2 years (Table 2). These changes may represent the process of remodelling of the fusion mass which connects the two vertebral bodies.

Insertion of full-thickness iliac bone into an intervertebral space requires excessive retraction of the nerve roots and dural sac. This procedure has a potential risk of nerve root damage. The cortical bone allograft used in our method was about 5 mm in width, being much thinner than unicortical ilium. Insertion necessitated only slight retraction of the nerve root, as undertaken in discectomy for disc herniation. None of the 73 patients in our series had additional permanent neurological deficit after operation and only one had a transient complication.

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