Neck fracture femoral heads for impaction bone grafting

Evolution of stiffness and compactness during impaction of osteoarthrotic and neck-fracture femoral heads

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Background The need for safe bone allografts is increasing and preservation of femoral heads from patients being operated on with hip arthroplasty should be encouraged. However, should we preserve femoral heads from patients operated on for neck fracture as tissue mechanical quality may not be satisfactory?

Material and methods We compared the evolution of stiffness and compactness of fresh-frozen morselized bone obtained from osteoarthrotic femoral heads and those from neck fractures. Both materials were also compared after freeze-drying and irradiation. We used 6 osteoarthrotic and 6 neck-fracture femoral heads to prepare 4 batches of morselized bone. 18 samples from each batch were impacted in a contained cylinder. Frozen bone grafts were tested after thawing at room temperature for 2 hours and freeze-dried grafts were tested after 30 minutes of rehydration.

Results The stiffness of fresh-frozen neck fracture bone was lower than that of fresh-frozen osteoarthrotic bone at 150 impactions. The stiffness of freeze-dried irradiated bone was higher than that of the fresh-frozen bone and did not differ between osteoarthrotic and neck-fracture bone.

Interpretation Solvent-treated freeze-dried bone from femoral heads procured during arthroplasty for sub-capital hip fractures represents a valuable source of material for allografts, addressing concerns regarding serological testing, medical history and bone quality.

Demand for bone allografts is increasing continuously, and preservation of femoral heads from patients being operated with hip arthroplasty should be encouraged (Michaud and Drabu 1994, Delloye 1995). It is uncertain, however, whether or not this recommendation should include femoral heads procured during hip arthroplasty after femoral neck fractures. The use of femoral heads from neck fractures may cause problems: selection of this donor population will most probably lead to a significant increase in exclusion. Serological screening of the donor 6 months after surgery (the quarantine period) is considered to be impractical, unrealistic and difficult to apply (Muller and Patsalis 1994) and above all, the mechanical quality of tissue may not be satisfactory.

We have studied the evolution of stiffness and compactness of morselised grafts prepared from osteoarthrotic femoral heads and compared the results with those from femoral heads derived from neck fractures. As fresh-frozen femoral heads from neck fractures should be difficult to deliver after the 6 months of quarantine, we have also compared both materials after processing to avoid the quarantine period.

Table 1. Source of the material

Donor				Whole head				Freeze-dried irradiated		Fresh-frozen	
Name	Sex	Age	Origin	Weight (g)	Diameter (mm)	Apparent density (g/cm³)	Weight [a] without c/c (g)	Half head	Weight (g)	Half head	Weight (g)
BL	F	79	Arthrotic	68.4	45	1.91	34.9	Post	17.4	Ant	16.6
BR	M	77	Arthrotic	80.0	50	1.63	44.5	Post	21.3	Ant	22.2
EJ	F	78	Arthrotic	74.1	44	2.22	37.4	Ant	18.0	Post	18.4
GMR	F	78	Arthrotic	64.7	46	1.69	32.2	Post	15.9	Ant	15.6
WA	F	74	Arthrotic	78.3	52	1.42	34.1	Ant	15.0	Post	18.2
LM	M	78	Arthrotic	65.6	47	1.61	32.9	Ant	17.6	Post	14.4
Mean		77.3		71.9	47.3	1.75	36.0		17.5		17.6
AMT	F	71	Fracture	66.3	49	1.44	44.4	Post	19.8	Ant	23.5
BR	M	81	Fracture	73.7	50	1.50	51.0	Post	25.5	Ant	24.5
DT	M	74	Fracture	67.1	48	1.55	47.6	Ant	24.7	Post	21.8
DM	F	92	Fracture	45.7	44	1.37	30.9	Ant	15.8	Post	14.2
SD	F	84	Fracture	38.7	41	1.43	26.6	Post	12.5	Ant	13.2
DA	F	67	Fracture	57.4	46	1.50	40.5	Ant	18.3	Post	21.1
Mean		78.2		58.2	46.3	1.46	40.2		19.4		19.7

[a] Weight without cartilage/cortex

Materials and methods

Preparation of morselized grafts

We isolated the cancellous bone from 6 osteoarthrotic and 6 neck-fracture femoral heads (Table 1). The soft tissues (articular cartilage remnants and synovium) and the cortical neck were shaved off with a band saw. Heads were then cut in the frontal plane into two halves: anterior and posterior. Considering the osteoarthrotic and neck-fracture origin, one half femoral head from each donor was assigned to the fresh-frozen group or to the process group, to make up four series: fresh-frozen osteoarthrotic and fresh-frozen neck fracture morsels, processed osteoarthrotic and processed neck-fracture bone chips. The 4 series of half femoral heads were morsellized once with the small rasps of the Noviomagus bone mill (Spierings, Nijmegen, the Netherlands) (particle size 3.3 mm, SD 1 mm). Within each group, morsellized grafts were then mixed. The fresh-frozen groups containing their original marrow fat were weighed to make up 18 homogeneous samples of 5 g each, and stored frozen at –80°C. Fresh-frozen grafts were neither rinsed nor fat-reduced with tepid saline.

Table 2. Weight lost in preparing the morselized grafts

Batch	Total weight (g)	Weight after treatment (g)	Ratio [a]	Weight of each samples (g)
Fresh-frozen, arthrotic	102	102	1	5
Fresh-frozen, fracture	116	116	1	5
Freeze-dried, arthrotic	105	36.7	0.34	1.7
Freeze-dried, fracture	115	34.2	0.30	1.5

[a] Weight after treatment / total weight

The two “processed” series were treated according to the standard protocol developed by our tissue bank (Delloye et al. 1987). Bone morsels were thoroughly washed under a jet of deionized water to remove bone marrow and blood cells. Lipid extraction and protein denaturation (a prion-inactivating procedure) were achieved by solvent-detergent treatments. Processed morsellized grafts were further freeze-dried for 72 h (temperature condensor –80°C, temperature of the chamber –30°C, working vacuum 1×10^{-4} mm Hg). The residual moisture of the bone was calculated by gravimetry to be 2.0% of dry material (Sartorius MA 30, Goettingen, Germany). Graft samples were immediately packaged under vacuum and preserved at room temperature. Both groups were irradiated at a minimal guaranteed dose of 25 kGy (maximum 30 kGy, $Cobalt_{60}$ source).

In the two processed groups, morsellised grafts loose fat, marrow and water. We found that samples of 5 g fresh-frozen osteoarthrotic and fresh-frozen neck fracture morsellized graft only weigh 1.7 g and 1.5 g, respectively, at the end of the freeze-drying process (Table 2).

Mechanical testing

Mechanical testing was performed according to the experimental design described by Bavadekar et al. (2001). Morselized graft samples were introduced into an aluminium tube and impacted by a mass of 455 g falling from a height of 1 m (frequency 1 blow/5 seconds) on a solid cylinder telescoping freely in the tube over the grafts. The aluminium tube was equipped with microscopic holes to allow for drainage of saline and fat during compaction.

The fresh frozen morselized grafts were thawed at room temperature, 2 h before the mechanical test. The freeze-dried irradiated samples were rehydrated separately with saline (in their plastic vials) for 30 min before being tested. One sample at a time was loaded into the cylinder and put through the testing. The impaction procedure was interrupted regularly (at 1, 3, 10, 50 and 150 impactions) to measure the height of the column of morselized grafts with a digital caliper, and also its stiffness. The compressive stiffness (or Emod, MPa) of the impacted grafts was measured by gently compressing the impacting material at a speed of 0.5 mm/min in a testing machine (Zwick model Z50/TH3A, Zwick GmbH, Ulm, Germany). The load was measured by a 2 kN load cell and the displacement was measured with an extensometer (Multisens, Zwick) positioned across the tube and the impactor. Tests were limited to a range of either 80 N of force (0.5 MPa) or 0.3 mm of displacement, to avoid excessive compression of the grafts during the measurement. The cylinder of grafts was immediately unloaded after reaching one of these limits. Stiffness was calculated as the slope of the linear part of the curve (between 60% and 98% of maximal load). The height and stiffness measurement were standardized and performed over a constant time of 1 min between impactions, to avoid interference with the time-dependent mechanical properties of morsellized grafts (Ullmark and Nilsson 1999). For each type of graft, 18 measurements were performed for up to 3 impactions, 14 for up to 10 impactions, 10 for up to 50 impactions and 6 for up to 150 impactions.

Density measurements

The apparent density of the impacted material was measured using a pQCT (peripheral quantitative computed tomography machine, model XCT Research SA+, Stratec, Pforzheim, Germany) on 4 samples impacted to the third impaction, 4 to the tenth impaction, 4 to the fiftieth impaction and 6 until the final 150th impaction. Density values are expressed in g/cm^3.

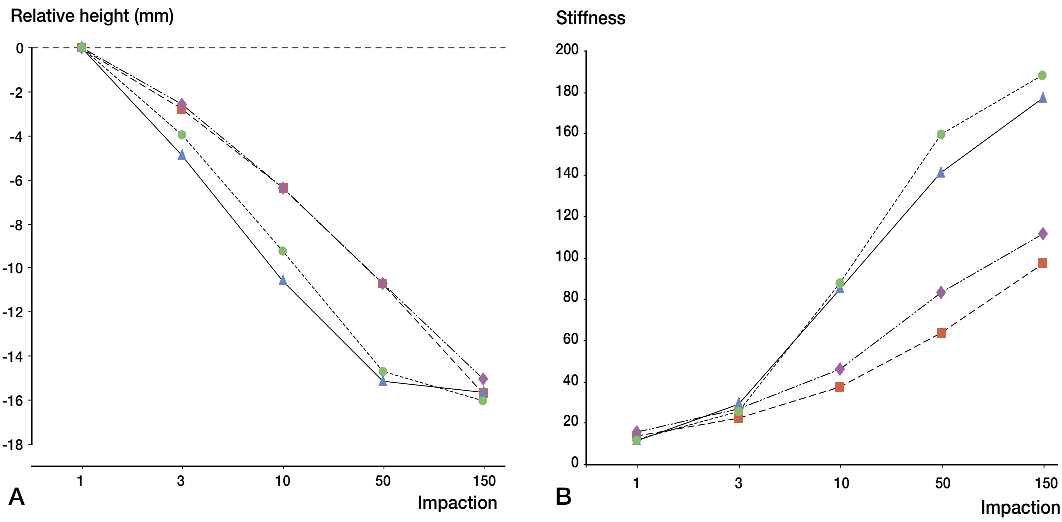
Statistics

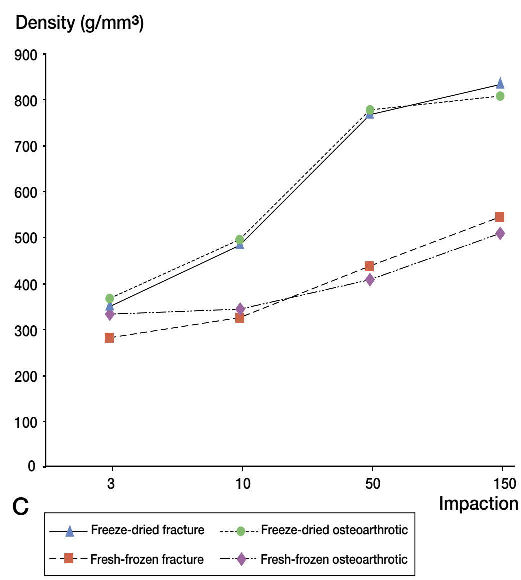
Analysis of variance (ANOVA) with repeated measurements (SPSS 10.0, SPSS Inc., Chicago, IL) was used to compare the results of the different types of graft. The dependent variables were the height and the stiffness. The first within-subject variable was type of graft (freeze-dried or fresh-frozen). The number of impactions was introduced as a second within-subject factor. Such a model estimates whether the overall behavior (the whole curve) is different when using one type of graft or another. This analysis was performed by considering results from 1 to 3, 1 to 10, 1 to 50 and 1 to 150 impactions, to investigate the initial part of the impaction procedure. To compare the density estimations of both types of graft, two-sample t-tests were used.

Results

During impaction, the height of the graft layer in the two processed series decreased quickly from 1 to 50 impactions, and led to a quite steady state up to 150 impactions. Fresh-frozen series became deformed more slowly than the processed series until 50 impactions ($p < 0.001$), but reached the same decrease in height after 150 impactions (Figure 1A).

We observed a constant rise in the stiffness of the four types of graft. Stiffness for the processed series increased more quickly after 3 impactions, up to 150 impactions. Stiffness in the fresh-frozen series increased more slowly after 10 impactions





Freeze-dried irradiated grafts compacted much faster than the fresh-frozen bone, as shown by the greater reduction of height between 1 and 50 impactions. After 50 impactions, freeze-dried irradiated bone reached a steady state while fresh-frozen bone continued to impact. Between 10 and 150 impactions, the stiffness of the freeze-dried irradiated grafts was higher than that of the fresh frozen series. The stiffness of the fresh-frozen osteoarthrotic grafts was higher than that of the fresh-frozen neck-fracture group after 150 impactions. Independently of the bone origin, density increased after 3 impactions in the freeze-dried irradiated series, while a lower increase was observed after 10 impactions in the fresh-frozen series.

and never reached the level of the processed series (Figure 1B). Stiffness in the processed grafts was significantly higher than for the fresh-frozen series, from 10 to 150 impactions ($p < 0.001$). No difference was observed between processed morselized grafts from osteoarthrotic bone or neck fractures. Stiffness for the fresh-frozen osteoarthrotic grafts was higher than for the neck-fracture grafts after 150 impactions ($p < 0.05$). The maximal stiffness value obtained with the fresh-frozen osteoarthrotic group after 150 impactions (111 Mpa) had already been reached after little more than 10 impactions with the processed series, demonstrating the faster rise in stiffness with freeze-dried irradiated grafts.

The density increased during impactions in all of the groups (Figure 1C). The mean density rose quickly from a value of 0.35 g/cm^3 at 3 impactions to 0.84 g/cm^3 at 150 impactions in the two processed series. In contrast, the fresh-frozen grafts showed a slow rise in density from 0.28 g/cm^3 at 3 impactions to a final value of 0.54 g/cm^3 at 150 impactions. At 10, 50 and 150 impactions, the density was significantly higher for the freeze-dried irradiated series ($p < 0.001$). No difference was observed between processed osteoarthrotic and neck-fracture grafts, nor between both fresh-frozen series.

Discussion

We have previously shown that freeze-dried irradiated bone becomes impacted much faster than fresh-frozen bone (Cornu et al., Acta Orthop Scand, accepted) and that the brittleness of freeze-dried irradiated bone increases compactness and stiffness when used as morselized grafts (Cornu et al. 2000, Cornu et al., Acta Orthop Scand, submitted MS 03/059). Differences in the mechanical behavior and final density previously observed by us were thought to be related to the bone quality of the individual donor (Brown and Ferguson 1980, Goldstein 1987, Ciarelli et al. 1991). While the origins of the bones were clearly different in this study, donors were selected to reduce the age and gender differences. Nevertheless, we expected to observe differences between the osteoarthrotic and neck-fracture series. This was not the case for freeze-dried and irradiated bone. When fresh-frozen femoral heads obtained during arthroplasty for neck fracture have to be used for impaction bone grafting, more hammer blows are required to obtain a modulus equivalent to fresh-frozen osteoarthrotic bone. Our data indicate that the use of the processed freeze-dried irradiated bone could improve surgical practice by saving surgical time and reducing the number of impactions required (de Roeck and Drabu 2001, Mazhar et al. 2001, Thien et al. 2001). Less impactions should in theory prevent the risk of cortical femoral fractures, which is a frequent complication during impaction allografting (Leopold et al. 2000, Pekkarinen et al. 2000, Slooff et al. 1996).

Considering the bone quality, femoral heads from sub-capital hip fractures are considered to be osteoporotic, containing less bone and more fatty and cellular marrow (Brewster et al. 1999). When surgeons have to fill a defect and request femoral heads from a tissue bank, they may make the assumption that all femoral heads are the same. This is not true; femoral heads from subcapital fractures yield a smaller bone quantity. Issuing bone allograft by weight, which predicts volume after impaction, is recommended (Henman and Finlayson 2000). Dispensed in a standard bone volume, ready to use and stored at room temperature, the morselized freeze-dried grafts would save time and make the procedure more reproducible.

Harvesting femoral heads from elderly patients with sub-capital hip fractures is associated with the problem of obtaining an accurate medical history, and also informed consent. The possibility of occult pathology, such as tumors and pathological fractures, must be considered (Palmer et al. 1999, Sugihara et al. 1999). Patients may also not survive long enough to perform serological screening after the 6-month quarantine. These problems might be solved, at least partially, by bone processing. As there is no quarantine period for the processed grafts (European Association of Musculo-Skeletal Transplantation (EAMST) and European Association of Tissue Banks (EATB 1997), such grafts could be made more readily available than fresh frozen femoral heads. Solvent-detergents and irradiation allow a significant reduction in the risk of disease transmission, thanks to the multiple-stage inactivation treatments (Feinstone et al. 1983, Spire et al. 1984, 1985). The observation that an HIV-infected tissue that had been freeze-dried did not transmit the virus suggests that this physical treatment may be effective against viral transmission (Simonds et al. 1992). Nevertheless, we recommend careful donor selection.

We conclude that femoral heads procured during arthroplasty for sub-capital hip fractures represent a valuable source of bone when a validated process is applied, thus alleviating the concerns regarding serological testing, medical history and bone quality. Solvent-detergent treated, freeze-dried irradiated bone is mechanically superior to fresh-frozen bone for impaction bone grafting.

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