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Preparation of morselised bone for impaction grafting using a blender method

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A R T I C L E I N F O

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A B S T R A C T

Impaction bone grafting is a method of restoring bone stock to patients suffering significant bone loss due to revision total hip surgery. The procedure requires morselised bone (MB) to be impacted into the site of bone loss in order to stabilise the prosthesis with the aim of the long term resorption and reintegration of the impacted bone graft. Currently, the method for producing MB requires the use of expensive surgical bone mills or manually-intensive rongeurs that can produce a limited variety of particle sizes and may have a low throughput. This study examines the potential to produce suitable MB using a domestic blender. The method produces a wide range of particle sizes without the need for an adjustment of the system. It was found through packing modelling that this particle distribution resulted in reduced initial graft porosity and thus a theoretical potential to increase the graft stiffness and ability of the graft to stabilise a prosthesis in comparison to a manually prepared roughly cut morselised bone samples. Mechanical testing confirmed the increased mechanical performance of the graft through both impaction testing and subsidence testing. The blended MB was found to exhibit greater graft stiffness under the same impaction conditions. The graft was also found to have subsided less in comparison to the rough cut, less well graded MB. Scanning electron imaging also confirmed the retention of the trabecular structure necessary for revascularisation and host bone ingrowth. In conclusion, the blender method offers a rapid and cheap way of obtaining morselised bone with favourable particle size distribution, particle morphology and mechanical properties with preservation of the bone trabecular structure.

1. Introduction

With the widespread success of total hip replacements (THR), the need for revision surgeries has also grown. Studies have shown that hip replacements wear slowly, but the problem progresses with time; after 10 years, there is a 90% probability that the implant will be functioning well (Learmonth et al., 2007), after 20 years the probability is about 80% (Berry et al., 2002). The growing trend of younger patients undergoing joint replacement surgeries, coupled with the chances of failure increasing over the lifetime of the prosthesis, has led to an increase in the number of implant revisions. The percentage level of revisions was found to be 19% in the US from 1997 to 2003 (Ong et al., 2006) and 15%, for 2005, in the United Kingdom (Dixon et al., 2004); the demand for hip revision procedures is projected to double by the year 2026 (Kurtz et al., 2007).

In order to ensure that there is osteointegration of the replacement implant, the surrounding cement mantle and any unsuitable bone needs to be removed. This process can lead to significant loss of bone and several studies have shown that the outcome of revision surgery can be dependent on the scale of this bone stock loss (Kavanagh et al., 1985; Callaghan et al., 1985). As a result, the restoration of bone stock at the implant site is desirable. The current method of achieving this is impaction grafting where morselised bone is impacted into the bone cavity, providing a stable graft bed for the new prosthesis (Slooff et al., 1984).

Surgical rongeurs (Walschot et al., 2010; Bolder et al., 2002) and manually (Brennan et al., 2011; Voor et al., 2004; Verdonschot et al., 2001; Gos and Nilsson, 1999) and electrically (Kligman et al., 2003) operated surgical bone mills are used to produce morselised bone (MB). In the case of bone mills, a selection of cutting surfaces (rasps) and sieves are required to produce a range of particle sizes. After morselisation, the standard surgical practice is for the MB to be washed in warm saline solution to remove excess fat content (Brennan et al., 2011; Voor et al., 2004; Gos and Nilsson, 1999).

The size of the particles used for impaction grafting can influence the mechanical properties of an impacted graft. Due to the physical nature of MB, the discipline of soil mechanics offers a good insight to the mechanical behaviour during impaction grafting. It is widely

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accepted in soil mechanics that a well graded, wide range of particle sizes offers better mechanical stability (Voor et al., 2004; Brewster et al., 1999; Craig, 2004). However, current morselisation techniques result in MB which is considered to be poorly graded. In order to produce MB that has better grading characteristics, the use of a variety of different bone mill attachments would be required.

A number of studies have stated that implant stability is highly dependent on the stiffness of the impacted graft (Karrholm et al., 1999). The correlation between the impaction force applied and increasing stiffness has been documented by a number of studies. Verdonschot et al. (2001) applied 98 compression cycles of 840 N to determine a MB stiffness of 84.5 MPa. This compares favourably with the impact method used by Bavadekar et al. and Xu et al. who found mean maximum stiffnesses of 48 MPa (Bavadekar et al., 2001) and 68.06 MPa (Xu et al., 2011) respectively.

The long term dimensional stability is a major factor in evaluating the success of an impacted graft; it is this characteristic that determines whether a patient can return to an active lifestyle. This dimensional stability is generally characterised as subsidence of the impacted graft or prosthesis and has been evaluated by the application of cyclical loads similar to those experienced during gait. The subsidence values in the literature vary due to differing test conditions and materials used; however, values of 1.28–2.31 mm for pure allograft samples have been reported (Van Haaren et al., 2005; Blom et al., 2002).

The present study seeks to prove the hypothesis that bone allograft material prepared using a blender-based bone morselisation method can achieve comparable mechanical properties to that prepared by established means. Use of this method would have the additional advantages of fast processing time and lower capital costs. The blender method presented here could offer the potential to develop surgical grade blenders for use in the clinical setting and could be based on widely-available base motor units with the use of disposable blades and containers. This would reduce the need to sterilise the cutting surfaces between procedures and reduce the potential for disease transfer. A widely available domestic blender with an operating design common to the sector was used as a proof of concept here.

2. Materials and methods

Bovine bone femoral heads were obtained from an abattoir and stored at − 18 °C until required. Prior to undergoing the morselisation process, the femoral heads were thawed at room temperature for two hours. The average temperature of samples during morselisation was measured as 18 °C.

The femoral heads were initially sectioned into pieces approximately 2 × 2 × 2 cm using a reciprocating saw. During the sectioning of the bovine femoral heads, care was taken to remove the denser cortical bone. This was not always completely effective and as a result, the morselised bone was visually inspected. Any cortical bone fragments that were found in the morselised batch were then removed manually. The sectioned bone was weighed prior to morselisation. These sections were then morselised using a high RPM domestic blender with a power rating of 1000 W (Nutri Ninja Auto IQ, SharkNinja, USA). Approximately 30 g of sectioned bone was placed in the blender per processing batch and the sample was blended for 5 s. The recovered ‘blended’ MB particles (bMB) were weighed to examine any mass loss occurring during the process. In order to determine whether the bMB produced by this method had the mechanical properties required to stabilise a prosthesis, a comparative ‘rough’ cut MB sample (rMB) was produced using a handheld oscillating saw and a rongeur. The rMB samples were washed in warm saline solution to remove excess fat content as per the standard procedure (Brennan et al., 2011; Voor et al., 2004; Gos and Nilsson, 1999).

Samples of 10 g of bMB and rMB were imaged using an Inspex HD 1080p Vesa camera (Ash Technologies Ltd., Ireland). The resulting image was analysed using ImageJ software to calculate the particle size of the samples via binary image thresholding (Abramoff et al., 2004). The resulting MB granule distribution was used to calculate the theoretical optimum granule distribution using a modified Andreassen model (Funk and Dinger, 2013):

$$Vc = \left(\frac{d - d_0}{D - d_0}\right)^q \times 100$$

where; V_c is the cumulative (volume) percent finer than, d is the particle size, d_0 is the minimum particle size, D is the maximum particle size and, q is the distribution coefficient or exponent.

Using a distribution coefficient of 0.37, the modified Andreassen model can calculate a particle distribution resulting in 100% packing or 0 voids within a granular mix (Funk and Dinger, 1992). Limits of 1–10 mm were placed on the model to prevent the assumption of infinitesimally small particles being available within the graft; this also constrained the model to granules representative of those in the literature. Regression analysis was then used to assess the fit of bMB and rMB samples to the optimum model.

Scanning electron microscopy (SEM) of the bMB was carried out with a Hitachi TM-1000 SEM (Hitachi High Technologies Europe, Krefeld, Germany). In order to prevent damage to the SEM as a result of outgassing, the marrow within the MB particles was removed by soaking in acetone for 24 h at 37 °C followed by a further 24 h drying at 37 °C. To present the overall structure of an individual particle of bMB, forty sequential SEM images were taken and used to create a mosaic image.

The impaction process used was based on similar studies presented in the literature (Walschot et al., 2010; Voor et al., 2004; Bavadekar et al., 2001). 5 g of bMB and rMB were individually placed in a constraining tube (diameter 20 mm) and subjected to an impaction force of 3.1 kN applied by a drop weight striking a stainless steel rod telescoping inside the constraining tube (n = 5) (Fig. 1). The impacted graft was then placed in a compression testing machine equipped with a 1 kN load cell (Tinius Olsen, UK) to measure the stiffness, or Young's modulus. The stiffness was calculated as the slope of the stress-strain curve between 68% and 98% of the maximum stress recorded. A limit of 80 N or 0.3 mm of displacement was placed on the stiffness test to prevent additional compression than provided by the impact force. The cross-head displacement velocity was 0.5 mm/min. Each graft sample was

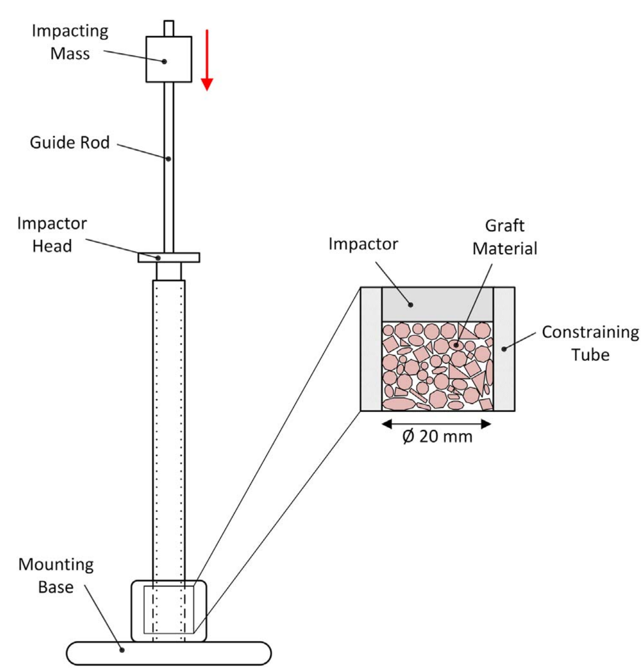

Fig. 1. Schema of the graft impactor apparatus.