The alteration in mechanical properties of bone graft after the addition of hydroxyapatite bone graft substitutes

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The problems of supply, cost, increasing demand and infection risk that are associated with the use of allograft are well known. The addition of bone graft substitutes, such as hydroxyapatite (HA) to allograft has various advantages in terms of extending supply and also providing more reliable mechanical properties. In this way HA can be used for both trauma and elective joint replacement surgery.

The mixing of bone and HA to form an aggregate will result in mechanical properties different from those of the individual parts. However, at present the changes in material properties of such a mix have fully investigated and the optimum mixing ratio has not been characterized.

The acetabulum is subjected to mainly compressive forces during impaction grafting and subsequent walking. Therefore a compressive model of a uniaxial compression chamber was used to investigate the change in mechanical properties that occurs with the addition of HA in varying proportions to morcellised bone graft (MBG).

Materials and methods

Bone graft was prepared using femoral heads donated from patients undergoing total hip replacement surgery. The femoral heads prepared by removing all of the soft tissue before being morcellised using a Noviomagnus mill before being prepared with washing and hydrogen peroxide in the manner used commercially.

Non porous HA (npHA) was prepared using a precipitation method of Jarcho et al, with a reaction between Calcium Carbonate and Orthophosphoric acid before being dried and then sintered at 1200 °C for 120 minutes. (Jarcho 1992) It was then sieved to give a particles size range of 2-5mm, which is in keeping with the usual range in clinical practice.

The porous HA, pHA was Apapor60, a 60% macroporosity ceramic, (Aparate Ltd, U.K.) and sold commercially in 2-5mm sizes for use in revision surgery.

Chamber The uniaxial compression chamber was a 30mm diameter, steel chamber. Holes were drilled in the bottom to allow fluid drainage. Loads were applied using a 10 kN load cell.

Specimens were prepared in the volumetric proportions used clinically, pure ceramic, pure bone graft, and then a 2:1, 1:1, 1:2 ratio of MBG to HA.

The samples were subjected to compressive forces of incrementally increasing loads of up to 2 KN for 60 cycles. The sample was unloaded for 5 minutes to simulate the implantation of a cup before being reloaded to 2 KN, for 3 minutes to allow the specimen to creep.

The mechanical parameters that were examined were the stiffness of the sample at the 60th cycle, Ec60 (the unloading gradient of the stress-strain curve), the compaction at 60th cycle, C60 (percentage of specimen starting height) and creep (gradient of change in specimen height against time).

Statistical analysis

The different bone:HA mixes were compared by Mann Whitney U tests. The parameters analyzed were the Ec60, C60 for the different mixes. Median values and interquartile ranges are given, with statistical significance taken as p<0.05.

Results

Apparent stiffness The apparent stiffness of the different proportions of bone and both npHA and pHA lie between the values of the bone and HA individually. The apparent stiffness of all of the mixes lie closer to the apparent stiffness of the pure bone graft than the pure HA. All of the mixes are significantly different from one another (p<0.05).

All of the bone:npHA were significantly stiffer than the comparative mixes of bone:pHA. (p=0.05)

The apparent stiffness of the different mixes for the bone:npHA fall between the upper and lower bounds of the stiffness of the composite as predicted by the rule of mixtures. By comparison experimental values for bone:pHA mixes fall on the lower bound.

Compaction Increasing the proportion of non porous HA significantly decreased the compaction of the sample (p<0.001). The compaction developed for the mixes was well spaced between those of the pure components with neither bone nor ceramic having a dominant influence.

This was not true for the porous HA with no difference being observed between the mixes. (p=0.56)

The pure components and all of the mixes of the npHA were significantly different from one another (p<0.05). The different volumetric mixes of bone and npHA lie equally spaced between the compaction measured for the pure bone and pure npHA and in between the upper and lower bounds of the rule of mixtures.

By comparison, the pure pHA and the pure bone were the least compacted specimens and were not significantly different from one another. (p=0.20) All of the composites were significantly more compacted than the pure components with no significant differences being found between the different mixes. (p=0.011)

Creep rate The creep rate of all of the mixes was closer to that of the pure HA than pure bone. Pure npHA and all of the mixes of bone:np HA demonstrated significantly less creep than the comparable mixes of bone:porous HA (p=0.01).

Discussion

The apparent stiffness of the sample was greater with the bone exhibiting a dominant effect upon the behaviour. The viscoelastic behaviour is a characteristic of the MBG and due to its organic component. The addition of small amount of bone dampens the particles of HA, leads to a reduction in the number of fractures seen within the HA and also allows a greater increase in the strain.

The total compaction behaved differently for npHA and pHA, npHA decreased compaction in a linear manner whereas pHA became more crushed and had no effect upon total compaction. Inasmuch as the development of the stiffness is most influenced by the addition of the bone, it is the properties of the ceramic that majorly influence the resistance to compaction.

The addition of HA significantly decreased the creep. The creep for both the npHA and pHA with bone mixes is influenced most by the HA. The stiffer npHA particles resist subsidence much than the less stiff, more fragmented pHA particles.

Conclusion In conclusion, bone graft substitutes are becoming increasingly important in their role in trauma and revision surgery. A thorough understanding of their mechanical properties and the effect following their addition to bone graft is essential if we are to utilize them to their full clinical advantage.