Mechanical properties of normal avascular and revascularizing cancellous bone: an animal experiment

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Several researchers have attempted to evaluate the material properties of cancellous bone (stiffness, strength) (Behrens et al. 1974, Carter & Hayes 1977, Galante et al. 1970, McElhaney et al. 1970, Townsend et al. 1975). Of considerable interest in clinical practice is the question of how the material properties are affected in avascular and revascularizing trabecular bone when compared with normal trabecular bone.

Material and methods. Using a sterile surgical procedure, the anterosuperior segments of the left femoral heads of African Pygmy Goats were devascularized and isolated, but kept in situ, using acrylic cement. Forty-four goats were used and divided into six groups. The control group was not operated on. Three avascular groups were killed 6, 12, and 24 weeks after the operation. The fifth group was operated on twice: first, to devascularize and isolate the segment and, secondly, to revascularize the same segment by drilling a hole through the acrylic cement barrier. The last group was also operated on twice, similar to the fifth group, but in addition an arteriovenous bundle was transplanted into the segment through the drill hole (Hori 1981). Eleven goats in this group were killed after 12 weeks and 5 goats after 24 weeks.

Specimens for mechanical tests were obtained from all the material of the first five groups. All the test specimens were cylindrical, 5 mm in diameter and 4 mm thick and cored from the anterosuperior segments in the principal trabecular direction. Each specimen was subjected to unconfined compression to failure on a Zwick testing machine at a cross-head speed of 1 mm/min. Yield strength and Young's modulus were determined. The apparent density of each sample was assessed (Carter & Hayes 1977). Histologic examinations were carried out to check avascularity and revascularization using normal and UV light microscopy. No specimens were obtained from the last group, which was subjected to loading in vivo and evaluated only histologically.

Three human postmortem femoral heads were used, and a total of 45 specimens were obtained for testing to assess the validity of the testing methods and as a means of comparison.

Results. The results confirm that the mechanical properties of cancellous bone, both human and goat, are principally functions of apparent density (Carter & Hayes 1977, Galante et al. 1970, McElhaney et al. 1970) (App. dens. goat 0.59-1.48 g/cm³). No differences in strength were observed between normal, 6-, 12-, and 24-week avascular cancellous bone in goats (Figure 1) (yield strength: 4.7-54.6 MPa). This was also true for the stiffness, Young's modulus (E: 84-1,434 MPa). The strength and stiffness obtained in the human specimens were generally in agreement with those published earlier (Behrens et al. 1974, Carter & Hayes 1977, Galante et al. 1970 McElhaney et al. 1970). Decreasing strength and stiffness with increasing age were also observed (Weaver & Chalmers 1966). Very different results were obtained for the revascularizing specimens of group 5. The average yield strength was found to be significantly less than in the normal and avascular specimens (Figure 2). The corresponding apparent density was essentially equal, on an average.

In the last group, 16 goats with an arteriovenous bundle transplantation, the anterosuperior segments were loaded in vivo during a period of 13 weeks (11 goats) and 24 weeks (5 goats). Of the first 11 goats (1 infected excluded), eight segments showed no signs of collapse and two displayed a small partial collapse. In the 24-week group (3 infected excluded), the remaining two segments showed no signs of collapse.

Conclusions
1. The quality of the cancellous bone matrix if isolated in vivo under normal loading conditions remains unchanged.
2. Collapse of the femoral head during avascular necrosis is due to the revascularizing process.
3. Transplantation of an arteriovenous bundle may prevent collapse.

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References

YIELD STRENGTH OF AVASCULAR BONE

Figure 1. Yield strength of avascular trabecular bone as a function of time.

YIELD STRENGTH OF CANCELLOUS BONE

Figure 2. Comparison of yield strength in normal, avascular and revascularized trabecular bone.