Variations in the amount of calcified tissue at the attachments of the quadriceps tendon and patellar ligament in man

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INTRODUCTION

It is well established that epiphyseal ligaments and tendons attach to bone via four zones of tissue – pure ligament or tendon, uncalcified fibrocartilage, calcified fibrocartilage and bone (Cooper & Misol, 1970; Benjamin, Evans & Copp, 1986; Woo et al. 1988). However, little attention has been paid to differences in the amounts and distribution of these tissues at different attachment sites (Woo et al. 1988).

In a previous paper, differences in the quantities of uncalcified fibrocartilage at the insertion of the quadriceps tendon and the ‘origin’ and ‘insertion’ of the patellar ligament (patellar and tibial attachments respectively) were related to differences in change in angle between the long axis of the tendon or ligament and the long axis of the bone during joint movements (Evans, Benjamin & Pemberton, 1990). In the present paper, we are concerned with differences in the amount of calcified tissue at these attachments. Although bony avulsion of the patellar ligament or quadriceps tendon is rare, ligament failure elsewhere frequently involves avulsion of a flake of bone at the attachment site (Noyes & Grood, 1976; Noyes, DeLucas & Torvik, 1974). Comparisons of the amount of bone at different attachment sites are thus of interest.

There are striking mechanical differences between the quadriceps tendon and the patellar ligament of man (Ellis, Seedhom, Wright & Dowson, 1980; Huberti, Hayes, Stone & Shybut, 1984). According to Eijden, Kouwenhoven, Verburg & Weijs (1986) and Eijden, Weijs, Kouwenhoven & Verburg (1987), the maximum force developed in the tendon exceeds that in the ligament by a ratio of about 8:5, because of the reaction of the patella against the femur. Thus, the insertion of the tendon is subject to a greater maximum force than is either the ‘origin’ or ‘insertion’ of the ligament. The greater cross-sectional area of the tendon reflects the greater force it transmits. However, we do not know whether the amount of calcified tissue at the insertion of the quadriceps tendon is also increased in order to resist the greater force, or whether the greater cross-sectional area of the tendon is alone sufficient to provide the attachment with its necessary strength.

To investigate this issue, we have measured the proportion of total calcified tissue to marrow and the thickness of the calcified fibrocartilage and cortical lamellar bone, in the region immediately deep to the attachments of the quadriceps tendon and patellar ligament.
Strips of tissue, approximately 5 mm wide, were taken from the central portion of the attachment zone of the insertion of the quadriceps tendon and the 'origin' and 'insertion' of the patellar ligament, from nine dissecting room cadavers (ages 71–89). The articular cartilages of all the knees were devoid of gross pathological change. The material was the same as that used in a previous study to analyse differences in the quantities and distribution of uncalcified fibrocartilage (Evans et al. 1990). The tissue was further fixed with 10% neutral buffered formal saline, decalcified in 2% nitric acid, dehydrated in graded alcohols, cleared in Inhibisol and embedded in 56°C paraffin wax. Sections were cut at 8 μm along the long axis of the tendon or ligament and at right angles to the bone surface. Five sections were collected from each of five sites by systematic random sampling at 500 μm intervals throughout the block; the sections were stained with haematoxylin and eosin (H & E) and Masson's trichrome. Five equally spaced marks (regions A–E) were made on one slide from each site (Fig. 1). Region 'A' was at the deepest part of the attachment and region 'E' at the most superficial part. At each of the resulting 25 sampling points, the ratio of total calcified tissue to bone marrow was determined by point counting and the thickness

Fig. 1.(g–c). Diagram to show sampling procedure. (a) Blocks cut from the central part of the insertion of the quadriceps tendon and attachments of the patellar ligament. (b) Sections collected from five equally spaced positions through each block. (c) Five equally spaced points marked along the attachment on each section.
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Fig. 2. The total calcified tissue/bone marrow ratio at the insertion of the quadriceps tendon (QT) and at the 'origin' (OPL) and 'insertion' (IPL) of the patellar ligament. Values are means ± standard error for all nine subjects. Ratios which differed significantly ($P < 0.05$) are underlined. Non-adjacent groups are joined by dotted lines.

Fig. 3. The total thickness (T) of the cortical calcified tissue, and the contributions to this total thickness of bone (B) and calcified fibrocartilage (C) at the insertion of the quadriceps tendon and at the 'origin' (OPL) and 'insertion' (IPL) of the patellar ligament. Values are means ± standard error for all nine subjects and those which differed significantly ($P < 0.05$) are underlined. Non-adjacent groups are joined by dotted lines.

Fig. 4. Variations in the total calcified tissue/bone marrow ratio at regions A–E of the attachment sites of the quadriceps tendon (QT) and the 'origin' (OPL) and 'insertion' (IPL) of the patellar ligament. Values are means ± standard error for all nine subjects. Within each attachment site, those which differed significantly ($P < 0.05$) from region E are marked with an asterisk.
Figs. 5-7. The insertion of the quadriceps tendon (Fig. 5) and the 'origin' (Fig. 6) and 'insertion' (Fig. 7) of the patellar ligament. Note that both the thickness of the cortical calcified tissue and the total amount of calcified tissue are greatest in Figure 5. (T) Tidemark. H & E x 80.
of the cortical zone of calcified tissue (calcified fibrocartilage and lamellar bone) was measured. The test area for point counting was 4 mm² and extended 2 mm below the tidemark. The total calcified tissue thus included both the constituents of the cortical zone and the cancellous bone immediately beneath.

Statistical comparisons were made with Student’s t test.

**RESULTS**

The mean, total calcified tissue/marrow ratio and the mean thickness of the cortical calcified tissue for each of the three attachment sites are summarised in Figures 2–4. The structure of the attachment sites is compared in Figures 5–7. Both the calcified tissue/marrow ratio and the total thickness of cortical calcified tissue are significantly greater (P < 0.05) at the insertion of the quadriceps tendon than at either attachment of the patellar ligament. However, there is little difference in the amount of calcified tissue between the ‘origin’ and ‘insertion’ of the ligament.

The greater amount of cortical calcified tissue at the insertion of the quadriceps tendon involves increases in the thickness of both lamellar bone and calcified fibrocartilage. Only the differences in the amount of bone are significant (P < 0.05).

At both the ‘origin’ of the patellar ligament and at the insertion of the quadriceps tendon, there was significantly less (P < 0.05) total calcified tissue in region A than in region E (Fig. 4). The difference was most marked at the ‘origin’ of the patellar ligament, where the amount of calcified tissue in both regions A and B was significantly less than in region E (P < 0.05). Thus, the total amount of bone and calcified cartilage was greatest at the superficial part of the attachment zone, where the collagen fibres had the greatest distance to travel before reaching the bone. However, there was little variation in the total calcified tissue/marrow ratio over different parts of the attachment zone at the ‘insertion’ of the patellar ligament (Fig. 4).

**DISCUSSION**

The greatest amount of total calcified tissue at the attachments of the quadriceps tendon and patellar ligament occurred at the insertion of the tendon. It is this site which is subjected to the greatest force (Eijden et al. 1986, 1987). Thus, the present results suggest that the larger force is resisted by a greater density of bone per unit area in the quadriceps insertion, as well as by an increase in the total area of the attachment zone that follows from the greater thickness of the tendon. Furthermore, the close similarity in the amount of bone and calcified fibrocartilage at the ‘origin’ and ‘insertion’ of the patellar ligament can be explained by the identical force at either end of this ligament.

Although no other workers have quantified the amount of calcified tissue at ligament or tendon attachments, Pedley & Meachim (1979) found a greater density of bone and total calcified tissue on the lateral compared to the medial side of the articular surface of the patella. They suggested that the differences may be due to differences in the mechanical environment at the two regions.

The relative importance of maximum force, the length of time for which it is applied and the rate of application of the force in determining bone density is unknown. However, the frequency and duration of the forces developed in the attachments of the quadriceps tendon and patellar ligament must be the same at each site. It is only the magnitude of the forces that differs. We therefore conclude that differences in maximum force alone can produce a greater density of calcified tissue at ligament or tendon attachments.
Figure 4 shows that the amounts of total calcified tissue vary in different regions of the attachment sites at the insertion of the quadriceps tendon and the 'origin' of the patellar ligament. This suggests that more force is transmitted through the superficial fibrocartilage. It is unclear why there was little regional difference in the amount of bone at the 'insertion' of the patellar ligament.

The interface between calcified fibrocartilage and bone in tendon or ligament attachments is irregular. Large numbers of measurements of the thickness of calcified fibrocartilage and lamellar bone are thus necessary for a statistically reliable result with the methodology that we employed. Although the cortical thickness was estimated at five regions (A–E) throughout each attachment, statistically reliable data could only be presented for the total of all five regions.

**SUMMARY**

Differences are reported in the total calcified tissue/bone marrow ratios and in the total thickness of cortical calcified tissue (lamellar bone and calcified fibrocartilage) between the attachment sites of the quadriceps tendon and the patellar ligament in man. The greatest amount of calcified tissue is at the insertion of the tendon and this is correlated with the larger force that the tendon transmits. It is concluded that differences in maximum force alone can produce a greater density of calcified tissue at ligament or tendon attachments. The similar amounts of calcified tissue at each end of the patellar ligament reflect the identical force that each attachment transmits. At the insertion of the quadriceps tendon and the 'origin' of the patellar ligament, there was more calcified tissue beneath the superficial than the deep parts of the attachment. This suggests that more force is transmitted through some parts of an attachment zone than others.

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**REFERENCES**


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