THE MICROVASCULAR PATTERN OF THE ROTATOR CUFF

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Very little investigation has been undertaken into the microvascular bed of the rotator cuff. Lindblom (1939) described areas of relative avascularity in the supraspinatus tendon adjacent to its point of insertion, and a similar zone in the long head of the biceps near its origin from the supraglenoid tubercle. Moseley and Goldie (1963) also noted a zone of diminished vascularity near the insertion of the supraspinatus. They termed this the "critical zone" and they believed that it represented an area of anastomosis between the vessels derived from the bone at the point of insertion and the longitudinally directed vessels arising from the arterioles in the muscle belly. Rothman and Parke (1965) stated that the "critical zone" of relative avascularity was not a pathological state but was associated with advancing age.

It is, however, of interest that this zone of relative avascularity of the supraspinatus corresponds to the most common site of breakdown changes in the rotator cuff. It is at this site that rotator cuff tendinitis, calcification and spontaneous ruptures occur.

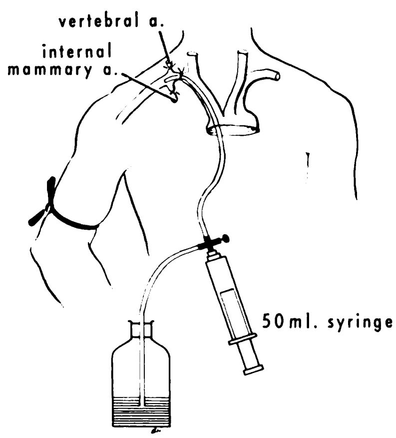

FIG. 1
Infusion technique.

In order to understand the significance of this "critical zone" further studies were undertaken to compare the microvascular bed of the supraspinatus with the other tendons in the rotator cuff, and to assess the relationship of the avascularity of the tendon with the histological changes that take place.

Previous investigators in their studies of the vascular bed of the supraspinatus have used modifications of the Spalteholz technique. Although this method permits an excellent demonstration of the vascular bed, it is difficult, and indeed almost impossible, to compare the vascular pattern with the histological appearance of the same part of the tendon. In the present investigation it was elected to study the vascular supply of the tendons by microangiography and to subject the same tendon to histological examination.

TECHNIQUE

The studies were carried out on cadavers as soon after death as possible. In order to fill the vascular bed of the rotator cuff of one shoulder, a tourniquet was placed around the arm as close to the axilla as possible (Fig. 1). The internal mammary and vertebral arteries were ligated and a polyethylene tube was firmly tied in the subclavian artery. With a fifty-millilitre syringe 500 millilitres of a 20 per cent suspension of micropaque were injected. In order to hold the micropaque in the smaller vessels, the initial injection was followed by an injection of 900 millilitres of a 20 per cent suspension of micropaque in 5 per cent gelatin. The injection was effected by simple hand pressure on the syringe. This produced better filling than constant pressure techniques and did not result in rupture of the smaller vessels.

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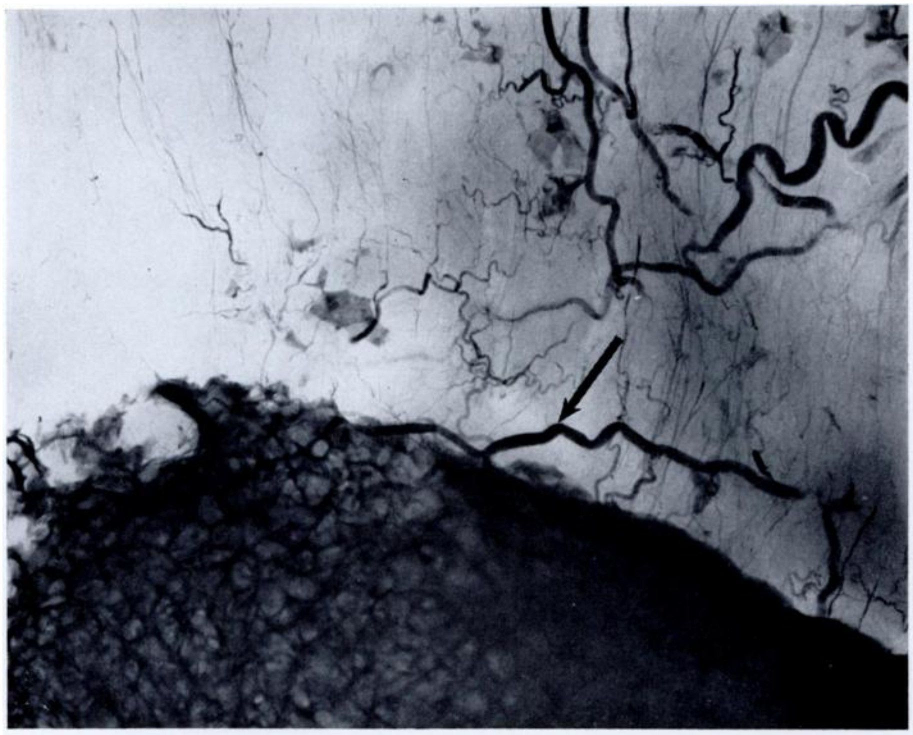


FIG. 2

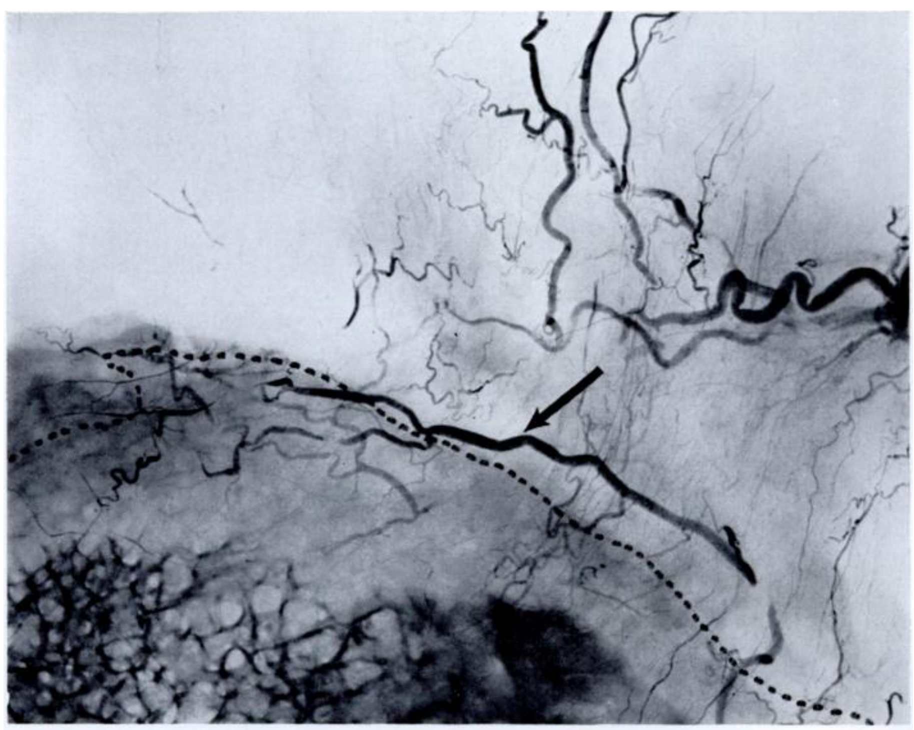


FIG. 3

Microangiographs of subscapularis at point of insertion of tendon to bone. In Figure 2 the radiograph has been taken before decalcification, and in Figure 3 after decalcification. The direction of the vessels within the bone is clearly shown after decalcification and it can be seen that the process has not leached out the barium from the vessels in the tendon.

After the injection the shoulder was bathed in iced water to allow the gelatin to harden. The head of the humerus and the attached tendons and muscles were then excised. The individual muscles were dissected free, leaving the bony insertion still attached to the tendon. After being fixed in formalin the specimens were decalcified. Previous trials had demonstrated that the decalcification process did not leach the micropaque out of the finer blood vessels (Figs. 2 and 3). Decalcification is essential to demonstrate the vessels passing between the bone and tendon (Figs. 4 and 5). Each tendon, along with the bony insertion, was divided longitudinally into sections three to four millimetres wide.

In order to demonstrate the fine vessels, a low voltage soft x-ray machine with a beryllium window was employed, exposing the specimen with a light sensitive photographic film (Kodalith Ortho) with a fine grain emulsion. Radiographs were taken in two planes in order to determine the position of the vessels demonstrated in the substance of the tendon (Figs. 6 and 7). The use of a plastic cassette did not affect the quality of the radiographs. Study of the details of the vascular pattern was made possible by enlargement of the negative. On enlargement, however, the contrast between the finer vessels and the surrounding tissue was lost, but this technical difficulty was overcome by using a cathode ray enlarger with a built-in computerised dodging device (Log-Etronic).

Injected suspensions of any material always form emboli at the capillary level of the vascular bed, and the method employed did not overcome this inherent difficulty of injection techniques. Nevertheless it was possible to demonstrate constantly and repeatedly vessels of the calibre of 15 to 20 microns (Fig. 8).

OBSERVATIONS

Each of the tendons constituting the rotator cuff showed a characteristic vascular pattern. The tendon of the subscapularis showed a coarse "railroad" distribution of vessels (Fig. 9); the teres minor a fine filigree pattern (Fig. 10); and the vessels of the infraspinatus a pattern halfway between these two (Fig. 11).

The vascular bed of the supraspinatus tendon was radically different. There was a constant area of relative avascularity related to its point of insertion (Figs. 12 and 13). Sometimes the zone of avascularity was a centimetre away from the point of insertion; at other times it extended right up to the point of insertion of the tendon. This zone of relative avascularity was present in specimens of all ages, even in cadavers under the age of twenty.

The most remarkable feature of the investigation was that this zone of avascularity was constantly seen in the supraspinatus tendon, whereas the other tendons comprising the rotator cuff showed good filling of the vascular bed, with the exception of an occasional specimen showing a zone of avascularity at the superior portion of the insertion of the infraspinatus.

It is difficult to understand why one tendon out of four, serving a similar function, should show such a marked difference in blood supply. In seeking a reason for this strange anatomical quirk, two points bear consideration: firstly, the distribution of the blood vessels within the tendon; and, secondly, the disposition of the tendon in relation to the head of the humerus. Unlike "round" tendons, whose blood supply is largely derived from the paratenon and enters at intervals along the length of the tendon, in "flat" tendons, such as those comprising the rotator cuff, the vessels course through the whole length of the tendon, running mostly in a longitudinal direction (Fig. 14), though some vertically directed vessels (Fig. 15) can be shown. This disposition of the vessels renders them susceptible to traction and direct pressure.

The infusion of micropaque was usually done with the arm of the cadaver by the side (adducted). When the opposite side was injected with the shoulder passively abducted, thereby relaxing tension on the supraspinatus, there was almost complete filling of all the vessels throughout the tendon to its point of insertion (Figs. 16 and 17). The effect of tension on the vascular bed of the tendon was also shown by the fact that the tendon of the subscapularis, which normally shows a profuse blood supply, had a zone of relative avascularity near its

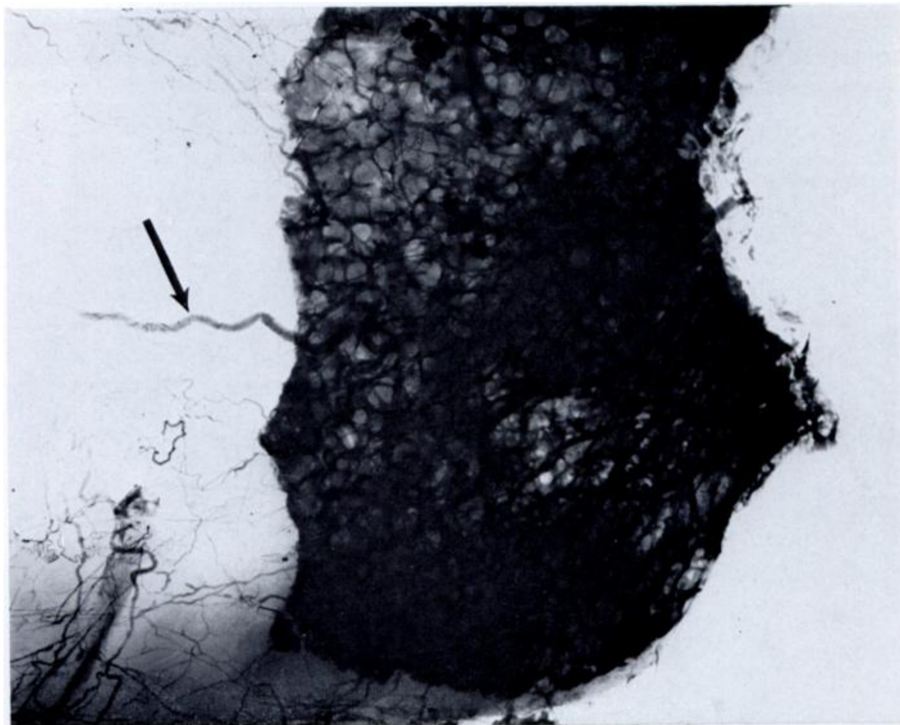


FIG. 4

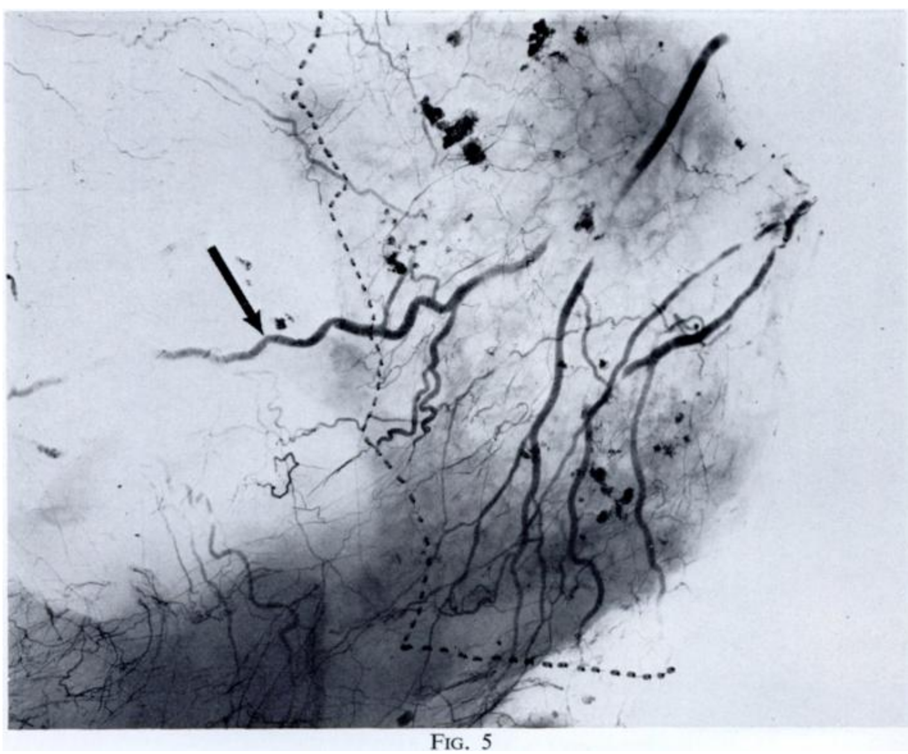


FIG. 5

The value of decalcification is seen in these two microangiographs taken before and after decalcification of the tendon-bone junction. In the undecalcified specimen in Figure 4 it cannot be determined whether the vessel denoted with an arrow is passing from the tendon to the bone or whether it is coursing in the other direction. In the decalcified specimen in Figure 5, by noting the direction of the branches and comparing these with other vessels shown, it can reasonably be concluded that this represents a vessel coming from the bone into the tendon.

FIG. 6

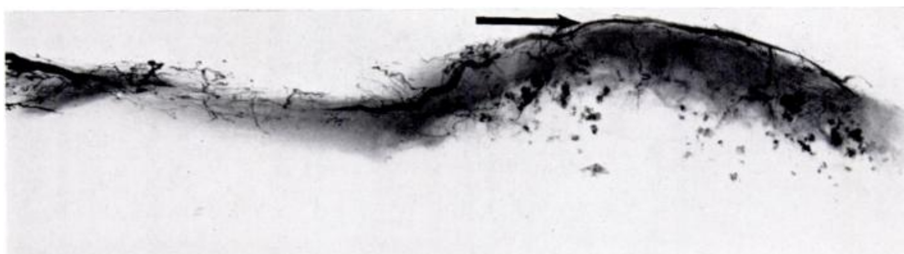


FIG. 7

Figure 6 is a microangiograph of the teres minor tendon taken perpendicular to the long axis of the tendon (antero-posterior). Figure 7 is a microangiograph taken at right angles to the long axis of the tendon (lateral). By taking radiographs in two planes, the spatial relationship of the vessels can be determined. The large vessel marked in Figure 6 with an arrow can be seen in Figure 7 coursing over the surface of the tendon as it inserts into the head of the humerus.

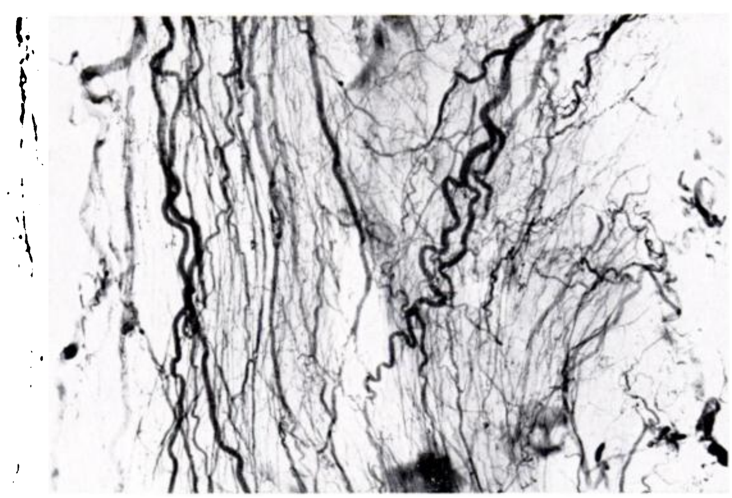


FIG. 8

Microangiograph of subscapularis tendon. The very small vessels demonstrated measured 15 to 20 microns in diameter.

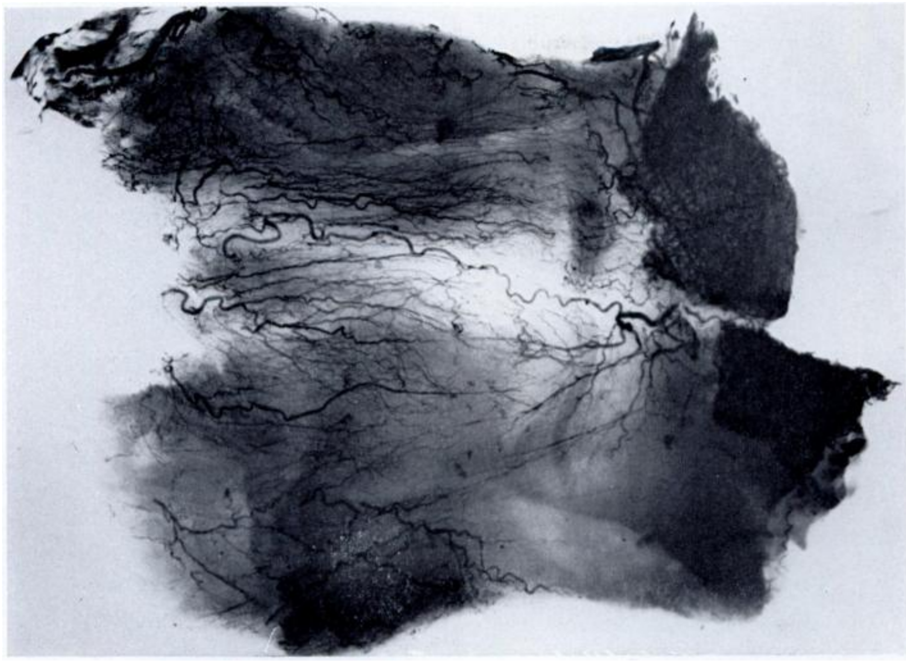


FIG. 9
The characteristic disposition of the vessels in the subscapularis tendon.

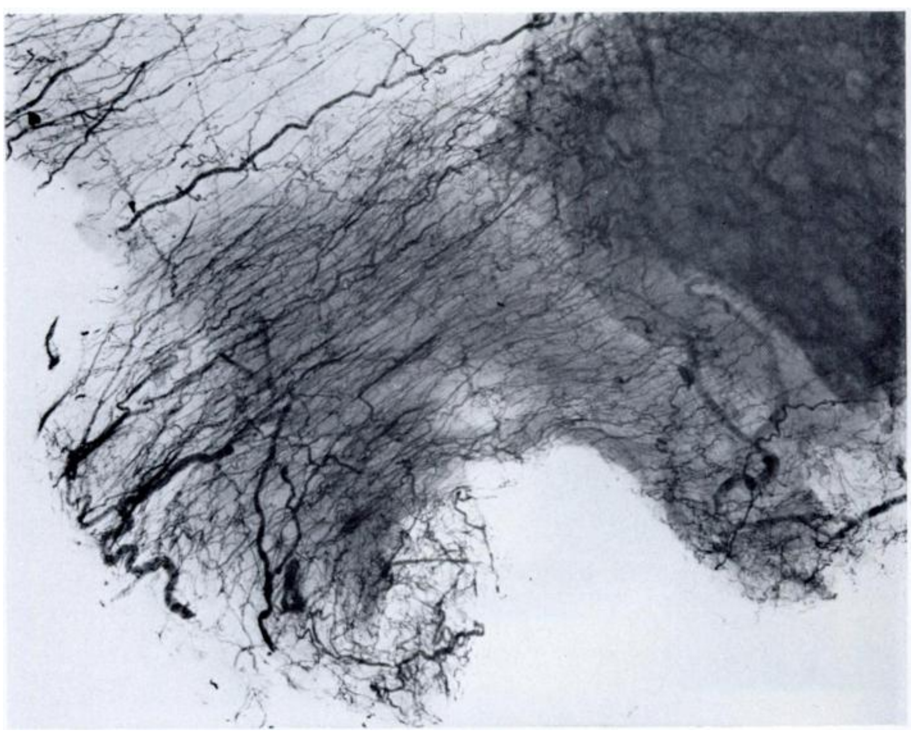


FIG. 10
The characteristic disposition of the vessels in the teres minor.

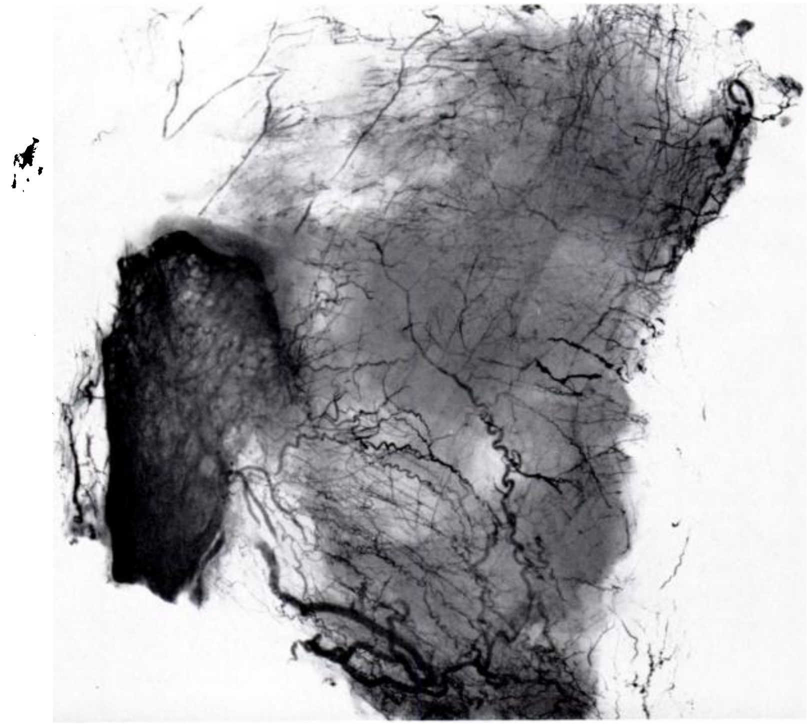


FIG. 11
The characteristic disposition of the vessels in the infraspinatus.

FIG. 12

FIG 13
The microvascular pattern of the supraspinatus tendon. Figure 12—In the antero-posterior view the zone of avascularity near the point of insertion to the tendon is clearly shown. Figure 13—The extent of the avascular zone is shown also in the lateral view of the tendon.

point of insertion when the cadaver was injected with tension applied to the subscapularis by holding the shoulder in forced lateral rotation (Figs. 18 and 19).

In the light of these observations the disposition of the tendon of the supraspinatus in relation to the head of the humerus is of interest (Figs. 20 and 21). It is possible that the constant pressure exerted by the head of the humerus on the tendon of the supraspinatus might "wring out" the vessels in this area. In this regard, it is of interest to note that the intracapsular portion of the biceps tendon, stretched in a similar manner over the head of the humerus, also shows an area of avascularity near its point of insertion (Fig. 22).

FIG. 14
Microangiograph showing the longitudinal disposition of arterioles within the substance of a "flat" tendon.

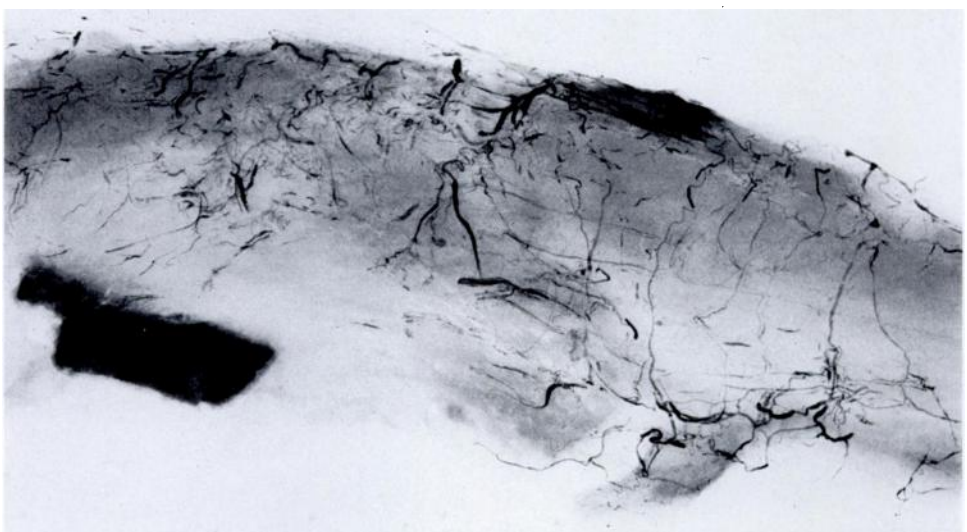


FIG. 15
A few vertically directed vessels were occasionally seen running from the surface to the deep portion of the tendon.

Two points are irrefutable in regard to the significance of the area of avascularity. Firstly, breakdown changes of tendinitis, calcification and rupture of the tendon are seen in the areas of avascularity. This observation applies not only to the supraspinatus, but also to the superior part of the insertion of the infraspinatus and the intracapsular part of the biceps tendon. Secondly, the avascular zone precedes, and is not the result of, the degenerative changes. Although an embarrassed blood supply cannot be indicted as the sole cause of the degenerative changes it is interesting that, in a tendon showing these changes, the parts that are well vascularised show healthy collagen fascicles adjacent to vessels well filled with micropaque (Fig. 23), the degenerative changes being confined to the avascular zone.

Secondary vascular changes follow the onset of degenerative changes in the tendon. Anderson and Moore (1960) reported increased vascularity of the tendon in areas showing degenerative changes. These changes were also noted in our study (Fig. 24). The degenerate part of the tendon appears to evoke a foreign body reaction with an inflammatory type of

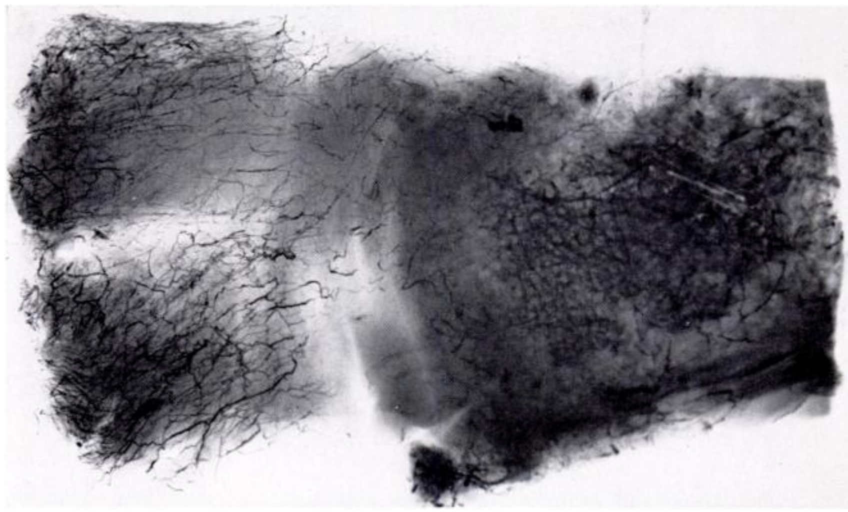


FIG. 16

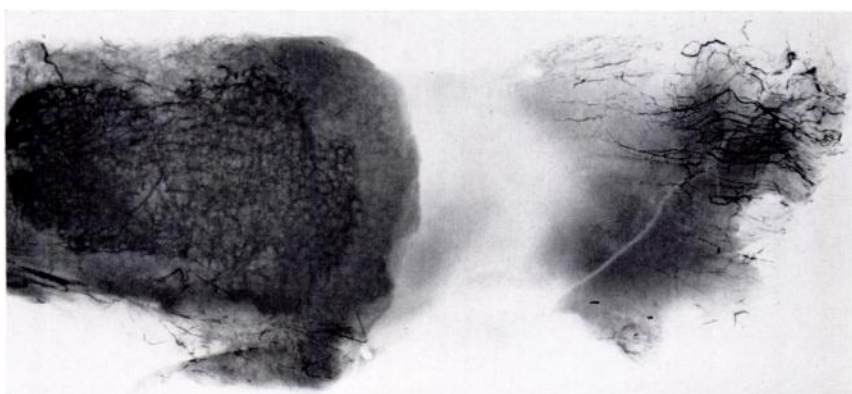


FIG. 17

Figure 16—The injection was made with the arm abducted, and in Figure 17 the injection was made with the arm by the side in neutral rotation. It is to be noted that with the arm abducted, there is almost full filling of vessels to the point of insertion of the tendon, whereas with the arm by the side there is a large area of apparent avascularity.

vascular response. This secondary vascularisation presents a characteristic picture on microangiography with rapid arborisation of small vessels forming vascular tufts (Figs. 25 and 26) that differ radically from the regular divisions of the small vessels normally seen. This secondary type of vascularisation was seen only in association with areas of gross disorganisation of the tendon.

As the degenerative changes proceed, the tendon becomes attenuated and in greater part avascular (Fig. 27). In all instances of massive rupture of the supraspinatus found in the

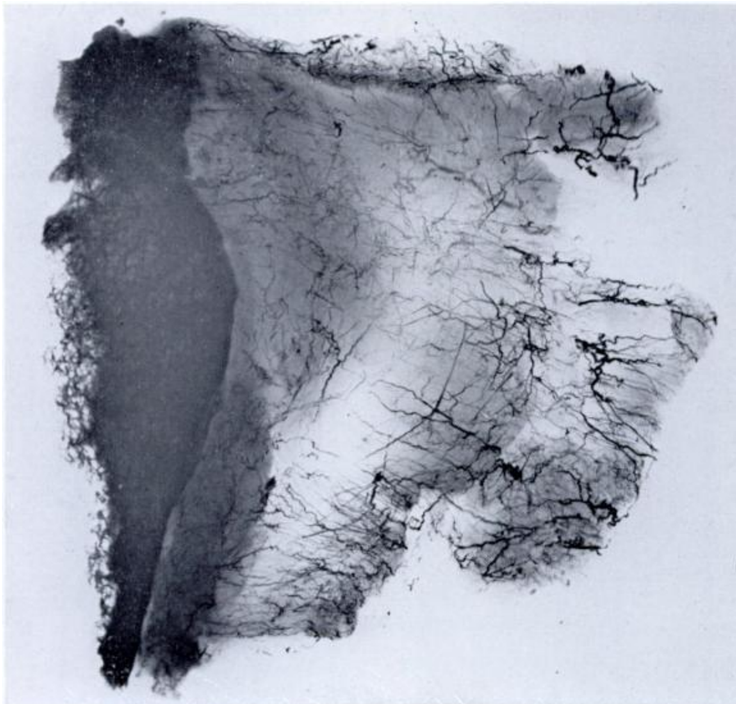


FIG. 18

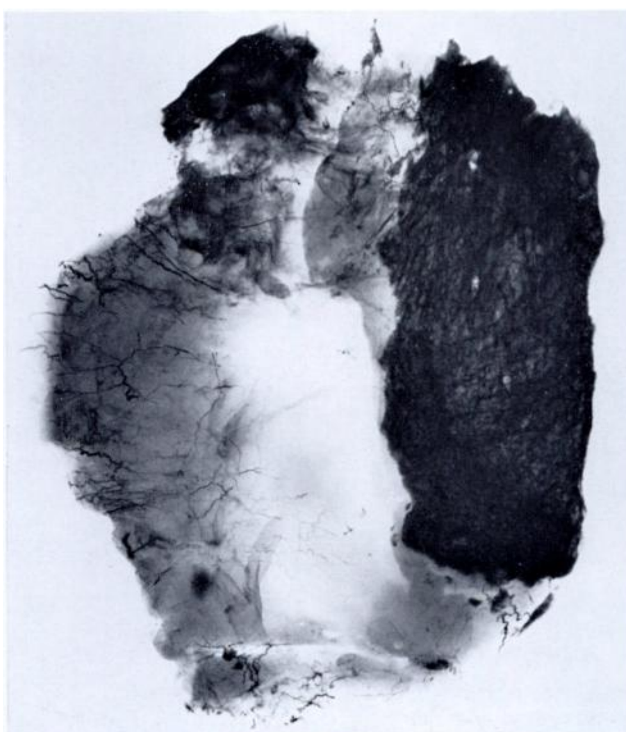
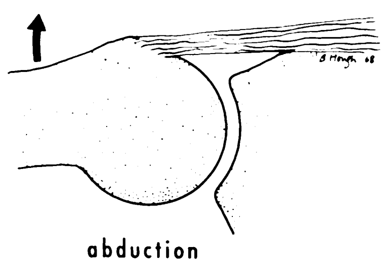


FIG. 19

Figure 18 shows the normal profuse blood supply of a subscapularis tendon. Figure 19 shows the area of avascularity that is produced when the injection is done with the shoulder held in forced lateral rotation.

present study, most of the tendon proximal to the rupture was avascular and showed marked degenerative changes.

In the surgical management of patients with complete avulsion of the rotator cuff, it seems illogical, therefore, to attempt to approximate the degenerate avascular edges of the tear. Ideally, the degenerate part of the tendon proximal to the tear should be excised and



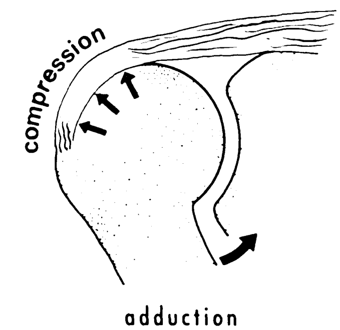


FIG. 20 FIG. 21

Figure 20 shows the theoretical disposition of the vessels in the tendon with the arm abducted and Figure 21 shows the possible mechanism of "wringing out" the vessels by compression when the arm is adducted.

FIG. 22

The avascular zone in the biceps tendon as it passes from the supraglenoid origin over the prominence of the head of the humerus.

healthy tendon sutured directly to bone. The anatomical disposition of the main arterial trunk and of the nerve supply to the supraspinatus makes it possible, as Debeyre, Patte and Elmelik (1965) have shown, to detach the muscular belly of the supraspinatus from the supraspinous fossa of the scapula. The degenerate part of the supraspinatus can then be excised, the muscle advanced and the healthy portion of the tendon sutured into the humerus.

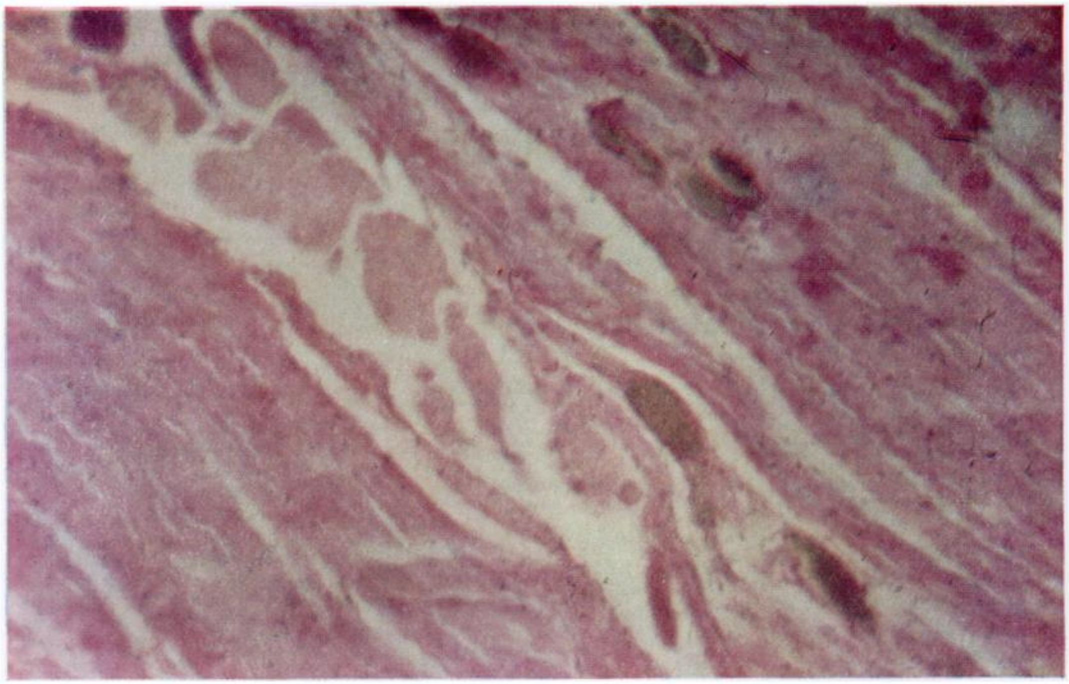


FIG. 23
The micropaque is shown as black islands in the photomicrograph. The collagen fascicles adjacent to them do not show breakdown changes. (Haematoxylin and eosin, ×25.)

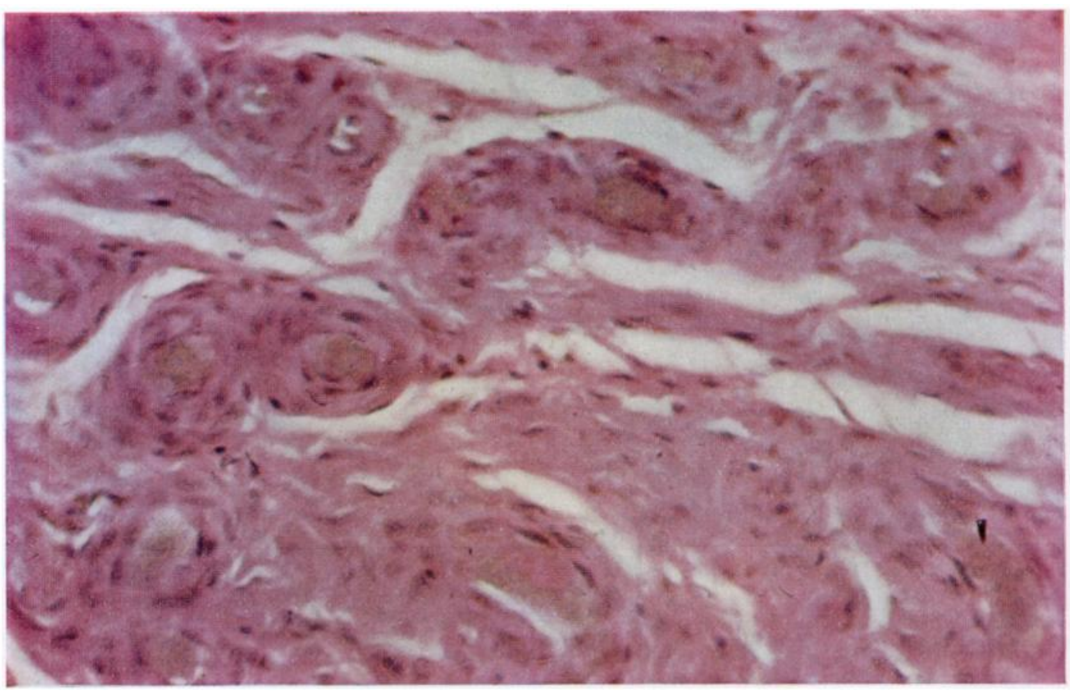


FIG. 24
Granulation tissue in an area of tendon degeneration. Many small vessels can be seen. Note the small calibre of the vessels that have been filled with micropaque. (Haematoxylin and eosin, ×250.)

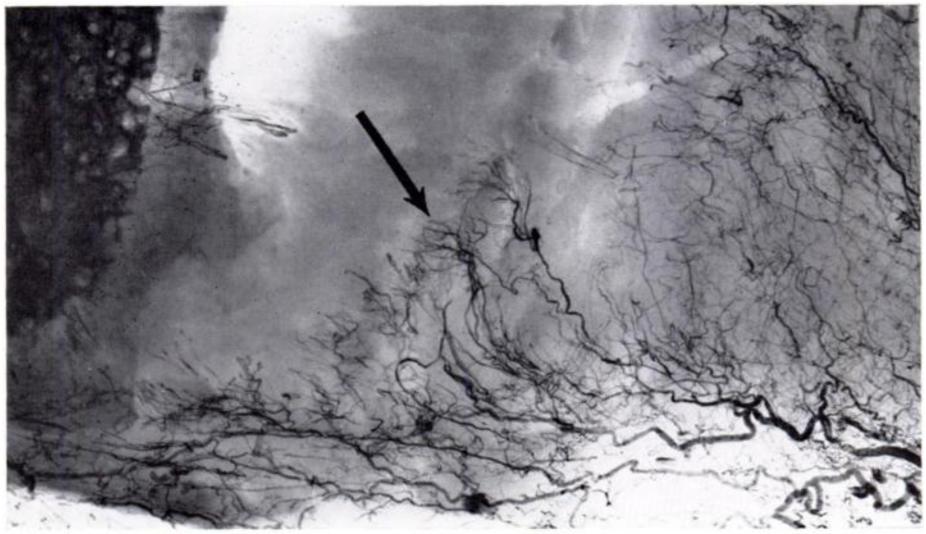


FIG. 25

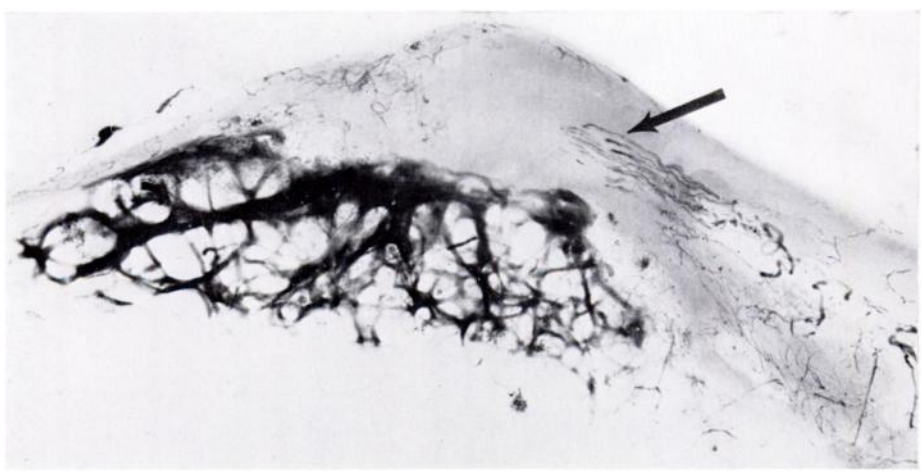


FIG. 26

Microangiographs showing the characteristic appearance of the vascular tufts in granulation tissue in a supraspinatus tendon. Figure 25—The antero-posterior view. Figure 26—The lateral view.

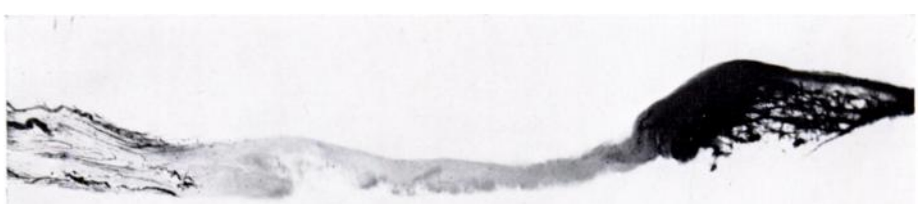


FIG. 27

Incipient rupture of the supraspinatus tendon. Note the attenuation of the tendon, the fragmentation of the deep surface and the extensive zone of avascularity.

SUMMARY

1. The avascular zone in the tendon of the supraspinatus near its insertion was not seen in the other tendons comprising the rotator cuff, except for the superior portion of the insertion of the infraspinatus which, on occasions, showed a small avascular area. The biceps tendon, however, also showed an avascular zone as it coursed over the head of the humerus. It is suggested that the anatomical disposition of these tendons makes them subject to constant pressure from the head of the humerus, which tends to wring out the blood supply to these tendons when the arm is held in the resting position of adduction and neutral rotation.

2. Although this study did not produce any evidence that the relative avascularity of the tendons over a prolonged period could be indicted as the sole cause of the degenerative changes that so commonly occur, it was noted that the degenerative changes occurred first and that they were always most extensive in the areas of avascularity. It was also observed that the zones of relative avascularity preceded, and were not the result of, the degenerative changes.

3. With the onset of tendon degeneration, secondary vascular phenomena were observed. Firstly, there was a reaction that appeared to be a foreign body inflammatory response with the development of vascular tufts of granulation tissue. It was thought that these vascular changes were secondary to the breakdown in the tendons and were not the cause of the breakdown as previously suggested by Anderson and Moore. It was noted, moreover, that with the progression of degenerative changes in the supraspinatus tendon, the tendon became much attenuated and, as it did so, the zone of relative avascularity appeared to extend. This secondary shut-down of the vascular bed might well be caused by an increased tension in the tendon. In those tendons in which spontaneous rupture had occurred, it was noted that the major part of the tendon proximal to the rupture was avascular and showed evidence of much degenerative change. This study therefore suggests that in the operative repair of such lesions it is necessary to excise the degenerate avascular tendon in order to effect a sound repair. It is also suggested that detachment of the supraspinatus muscle from the supraspinous fossa in order to advance the whole muscle belly is the only technique possible to enable the surgeon to replace healthy tendon directly into bone, as suggested by Debeyre and his colleagues.

REFERENCES

Anderson, W., and Moore, R. (1961): Clinico-pathological Study of the Shoulder Joint. In *Second Canadian Conference on Research in Rheumatic Diseases.* Toronto, October 28–29, 1960, p. 108. Toronto: Canadian Arthritis and Rheumatism Society.

Debeyre, J., Patte, D., Elmelik, E. (1965): Repair of Ruptures of the Rotator Cuff of the Shoulder. With a Note on Advancement of the Supraspinatus Muscle. *Journal of Bone and Joint Surgery,* **47–B,** 36.

Lindblom, K. (1939): On Pathogenesis of Ruptures of the Tendon Aponeurosis of the Shoulder Joint. *Acta Radiologica,* **20,** 563.

Moseley, H. F., and Goldie, I. (1963): The Arterial Pattern of the Rotator Cuff of the Shoulder. *Journal of Bone and Joint Surgery,* **48–B,** 780.

Rothman, R. H., and Parke, W. W. (1965): The Vascular Anatomy of the Rotator Cuff. *Clinical Orthopaedics,* **41,** 176.