THE STRUCTURE AND WEIGHT OF SYNOVIAL FAT PADS

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Several functions have from time to time been ascribed to synovial fat pads. It is of historical interest to recall that Clopton Havers (1691) regarded them as the agents of synovial fluid secretion. The term Haversian glands is still used for these pads but more particularly for the fat pad in the floor of the acetabulum. More modern views as to their function are that they occupy the dead spaces in joints in the various positions, that they serve to ensure that a wedge-shaped interval of suitable dimensions is maintained between the male and female articular surface, thus ensuring effective lubrication (MacConaill, 1950), and that they act as pad oilers (Davies, 1950). Some fat pads have been considered to have more specific functions. Thus the acetabular fat pad may form a soft bed for the ligamentum teres and protect this from damage during movement.

If any of the above-mentioned theories is true, then it could be reasonably expected that these fat pads should differ in their physiological behaviour and possibly in structure from the collections of adipose tissue which occur elsewhere and serve as storehouses of nutritive material. It is often stated that the fat in the subcutaneous tissue of the palms of the hands and soles of the feet is primarily mechanical in function and remains when other fat deposits in the body are depleted (Clark, 1958). Scammon (1919) has investigated the buccal or sucking pad of fat in different states of nutrition. Though it does not differ materially in structure from ordinary subcutaneous adipose tissue, its persistence into adult life is unrelated to the state of nutrition and its degree of development may be asymmetrical. It is well developed in individuals dead of wasting diseases. There is there no apparent relation in the adult between the size of the buccal fat pad and age. Similarly, in the cat, the epidural fat varies in quantity and distribution, but these variations cannot be correlated with the sex, weight, size (as measured by bone length), or nutritional state of the animals (Ramsey, 1959).

The synovial fat pads in human subjects of varying states of nutrition have been studied to determine whether their sizes change in keeping with the general subcutaneous fat stores or remain relatively constant, thus resembling the buccal fat pads.

MATERIAL AND METHODS

Two distinct racial groups, Europeans and Africans, of various ages have been investigated. In the former only the infrapatellar fat pad has been examined whilst in the latter the fat pads from the hip and ankle joints also have been studied. With the exception of the acetabular fat pad these structures are not encapsulated and circumscribed. To obviate errors arising from varying methods and areas of removal all the fat pads from Europeans have been removed by one worker and the African specimens have been obtained locally by another. Records have been made of the age, sex, height and weight of the individuals and the thickness of the subcutaneous fat in the following positions: immediately to the right of the umbilicus, below the inferior angle of the scapula and at the middle of the back of the upper arm. The thickness of the subcutaneous fat has been measured directly after incising through the skin to the deep fascia. All the fat pads have been weighed and any arthritic changes in the joints noted. The details of the material available are set out in Tables 1 and 2. In addition, specimens from two juvenile European subjects, one newborn and one aged 8 months, and four African juveniles aged 2 months, 8 months, $1\frac{1}{2}$ years and 2 years have been examined.

Table 1. *Data concerning the source of the material, weights of infrapatellar fat pads and thickness of the subcutaneous fat in thirty-one European subjects, together with the mean and standard deviation* (S.D.)

(Arranged in increasing order of subcutaneous umbilical fat thickness.)

No.	Sex	Age	Body weight (kg.)	Body height (cm.)	Weight of intrapatellar pad (g.)	Subcutaneous fat thickness (mm.) Umbilical	Scapular	Brachial	Cause of death
14	M.	63	40	163	14·0	1	1	2	Neoplasm of liver
32	M.	76	41	163	17·2	1	5	4	Sarcoma of humerus
11	M.	65	40	155	21·1	2	3	1	Carcinoma of prostate
19	F.	68	34	142	14·4	3	2	5	Miliary tuberculosis
23	M.	55	65	180	27·0	8	3	3	Renal failure
3	M.	67	62	163	21·7	9	8	9	Lung abscess
5	M.	66	49	173	25·1	9	3	3	Carcinoma of colon
13	M.	70	64	170	21·5	9	6	8	Carcinomatosis
7	M.	57	76	183	26·9	10	9	6	Lymphoma
8	M.	66	50	168	24·1	10	11	8	Cardiac failure
6	M.	59	64	173	22·9	12	8	13	Carcinoma of bronchus
18	F.	57	48	173	18·3	13	6	6	Cardiac failure
16	F.	66	51	160	17·6	15	10	10	Cancer of bile duct
25	M.	76	51	163	19·0	15	5	7	Coronary thrombosis
9	F.	64	69	168	23·3	18	10	15	Malignant peritonitis
10	M.	56	—	165	22·2	18	16	15	Coronary thrombosis
15	M.	61	63	155	22·5	18	8	8	Carcinoma of oesophagus
28	M.	66	80	178	29·1	20	13	10	Cardiac failure
29	F.	80	67	155	19·2	20	10	10	Carcinomatosis
20	F.	58	52	163	16·0	22	8	13	Carcinomatosis
31	M.	72	76	165	27·2	24	14	11	Cardiac failure
24	M.	64	70	178	27·8	25	18	12	Cardiac failure
26	F.	76	76	152	16·5	25	18	10	Abdominal carcinoma
1	M.	60	—	178	22·6	26	10	9	Cerebral haemorrhage
21	M.	55	81	168	22·7	26	9	5	Cardiac failure
22	F.	77	57	157	16·5	32	14	10	Diabetes melitus
12	F.	46	57	163	22·1	35	10	12	Bronchopneumonia
4	M.	56	99	183	22·3	36	15	13	Cardiac failure
17	M.	78	93	180	31·8	38	20	10	Acute pancreatitis
2	M.	62	—	170	28·6	45	13	18	Cardiac failure
27	F.	67	73	173	25·1	59	20	23	Cardiac failure
Mean and S.D.		65 ± 8	62·4 ± 16·1	176·1 ± 9·9	21·9 ± 4·5	18·4 ± 13·2	9·4 ± 5·4	8·8 ± 4·5	

All the synovial fat pads have been fixed in 10 % formalin. Representative blocks of these tissues have been imbedded in paraffin and sections, cut at 8μ, have been stained with haematoxylin and eosin and with orcein for elastic tissue fibres. Frozen sections have been prepared also and coloured with Sudan red and Sudan black for fat. In all the histological work the technique has been standardized both with respect to strength of solutions and times. Similar preparations of the subcutaneous fat from the various regions have also been prepared from the European series.

Table 2. *Data concerning the source of the material, weights of fat pads and thickness of subcutaneous fat in twenty-four African subjects together with the means and standard deviations* (S.D.)

No.	Sex	Age	Weight (kg.)	Height (cm.)	Weights of fat pads (g.)						Subcutaneous fat thickness			Cause of death
					Hip		Knee		Ankle		Umbilical	Scapular	Brachial	
					L.	R.	L.	R.	L.	R.				
854	M.	75	57	168	2·4	2·9	6·5	3·5	4·4	1·4	—	—	—	Cardiac failure
855	F.	35	36	155	2·0	2·1	3·0	3·1	2·3	3·5	—	—	—	Tuberculous peritonitis
858	M.	20	20	155	1·1	1·3	5·5	3·4	2·6	2·0	—	—	—	Cardiac failure
868	F.	30	45	160	2·3	2·2	6·6	6·0	3·1	2·8	—	—	—	Carcinoma of vercix
876	M.	—	33	175	2·5	2·8	4·2	7·1	3·7	2·0	—	—	—	?
883	M.	31	38	150	1·6	2·0	4·5	4·6	1·4	1·6	—	—	—	?
890	M.	41	60	163	2·0	1·9	5·1	3·9	1·9	1·9	—	—	—	?
891	M.	16	30	150	1·0	0·9	7·7	7·4	2·3	3·1	—	—	—	Dysentery
897	M.	—	37	150	1·6	1·5	5·3	4·8	1·9	1·8	—	—	—	?
899	M.	17	46	160	1·9	1·6	5·2	6·3	4·6	3·4	—	—	—	Acute pancreatitis
900	F.	17	40	157	1·4	1·4	6·3	4·9	2·1	2·3	—	—	—	Diabetic coma
901	M.	37	38	163	0·9	1·7	6·8	7·4	2·9	3·0	—	—	—	?
903	F.	35	29	157	2·0	2·0	—	—	—	—	—	—	—	Infected ovarian myofibroma
907	M.	25	52	168	1·8	2·3	9·6	6·4	3·6	5·2	—	—	—	Ruptured aneurysm of aorta
920	F.	24	48	155	0·9	0·9	8·2	6·2	1·9	2·0	—	—	—	Uraemia
958	M.	40	49	157	2·2	2·1	10·2	7·4	3·6	3·8	3	6	4	Carcinoma of stomach
987	M.	15	40	165	1·2	1·3	8·3	13·5	2·8	3·1	3	3	3	Sarcoma
1509	M.	35	43	163	3·2	1·9	8·8	9·0	3·9	5·2	3	4	4	Retroperitoneal sarcoma
963	F.	30	28	160	1·4	1·6	3·9	4·4	2·8	2·8	4	3	4	Intestinal obstruction
996	F.	35	43	165	1·4	1·4	8·0	6·4	2·9	2·3	4	5	4	Cardiac failure
957	M.	25	55	178	2·1	2·5	4·7	4·8	3·9	3·7	6	5	8	Mitral stenosis
983	F.	17	34	152	1·7	1·3	7·4	7·6	2·8	3·9	6	3	10	?
980	M.	45	52	173	3·4	2·7	7·2	8·7	3·9	2·9	7	5	5	?
975	F.	30	49	160	1·2	1·6	4·7	3·6	3·0	2·9	17	5	9	?
Mean and S.D.		31 ± 13	41·8 ± 10·0	160·4 ± 7·1	1·8 ± 0·7	1·8 ± 0·6	6·4 ± 1·9	6·0 ± 2·3	3·0 ± 0·8	2·9 ± 1·0	5·9 ± 4·4	4·3 ± 1·1	5·6 ± 2·5	

RESULTS

In the adult, the form, structure and weights of the fat pads are unrelated to the age or sex of the individual or to the presence or absence of arthritic change in the joints. These factors will therefore not be discussed further.

(1) *Structure of the synovial fat pads*

The amount of fatty tissue in the different pads varies, being abundant in those from the knee and ankle but much less in the acetabular pad, which is more fibrous than fatty.

In all cases the fat is divided into lobules by well-developed septa rich in elastic tissue; the elastic fibres run in various directions but predominantly along the lengths of the septa as they are traced towards the synovial surface (Pl. 1, fig. 1). The larger blood vessels lie in the septa and are also richly supplied with elastic tissue and usually show prominent external elastic laminae.

In well-nourished subjects the fat cells within the lobules are closely packed and rounded or polyhedral in shape from mutual compression (Pl. 1, fig. 2). As in subcutaneous tissue, the fat cells contain a single globule of fat and an eccentric nucleus lying in the pellicle of cytoplasm. No moruloid fat cells are seen. In all cases the fat lobules are separated from the joint cavity by a single layer of synovial cells or an areolar type of synovial membrane.

In subjects exhibiting moderate wasting or undernourishment, as judged by height–weight figures given by Sanderman & Boerner (1949), there is no detectable histological change.

In severe wasting, the total weight of the body being less than 50 kg, there is a detectable reduction in the size of the fat globule; at this stage the fat globule develops a mottled appearance (Pl. 1, fig. 4). The fat cells cease to be spherical and become stellate with branched processes, resembling fibrocytes (Pl. 1, fig. 6), and both the absolute and relative amount of cytoplasm increases. In addition to a single large fat globule there now appears in the cytoplasm a number of smaller fat globules (Pl. 1, fig. 5). In extreme wasting the majority of the cells contain only small scattered fat globules. At this stage blood vessels in the tissue become engorged and prominent, and the cells are separated by conspicuous intercellular spaces (Pl. 1, fig. 6).

In the juvenile specimens, though the fat pads are neither as large nor as heavy as in the adolescents or adults, the structure is similar and the fat cells and globules are only slightly smaller in size than those of the adult (Pl. 1, figs. 2 and 3). In the newborn the vascularity of the articular fat pad with its dilated and engorged capillaries is a prominent feature. The amount of elastic tissue in the septa is much less in the newborn than at later ages. By 2 months of age the amount of elastic tissue has noticeably increased and the individual fibres are thicker. In the 1½-year-old specimen the relative proportion of elastic tissue in the septa and the diameter of the elastic fibres have reached adult proportions.

(2) *Weight of the synovial fat pads*

There is a very significant difference in the mean weights of the African and European subjects. This difference is greater than would reasonably be expected on either genetic or racial grounds, and is therefore probably attributable to differences in the standards of nutrition. In the European series there are nine cases excessive in weight in proportion to height, as judged by the normal standards provided by Sanderman & Boerner. None of the Africans appear to be overweight: the majority, if not all, are probably undernourished. It seems, therefore, that the two series are not comparable and that a separate analysis of fat pad weights has to be performed for Africans and Europeans.

(*a*) *European Series. Infrapatellar pad weight and thickness of subcutaneous tissue*

In all subjects the umbilical fat thickness correlates well with the brachial fat thickness (Pearson's correlation coefficient, $r = 0{\cdot}79$) and with the scapular fat thickness ($r = 0{\cdot}83$). However, the correlation of the umbilical fat thickness with the infrapatellar fat pad weight is poor ($r = 0{\cdot}32$). Thus undernourishment reduces the thickness of subcutaneous fat in all three sites measured, but has considerably less effect on the synovial fat pad. As shown in Table 1, only in extreme emaciation is the synovial fat pad reduced in weight.

The weight of the synovial fat pad is found to bear a closer relation to body height ($r = 0{\cdot}73$) than to body weight ($r = 0{\cdot}65$). This indicates that the fat pad is probably related to skeletal size. On the other hand, as shown by previous workers, the subcutaneous fat thickness correlates much more closely with body weight than with body height.

(*b*) *African Series. Synovial fat pad weight and subcutaneous tissue thickness*

In view of the reported frequent asymmetry in the development and retrogression of the buccal fat pad, the opportunity has been taken to compare three synovial pads on the left and right sides of the body. The acetabular fat pads correlate well ($r = 0{\cdot}82$) but the pads from the knee and ankle seem less symmetrical, probably because of difficulties in removing exactly comparable portions in the two sides.

The remaining data in Table 2 have been subjected to statistical analysis but no very significant results emerge. The only significant correlation found is between the body weight and the scapular fat thickness ($r = 0{\cdot}82$). No significant relation is found between the subcutaneous fat thicknesses at the three sites, nor between the synovial fat pad weights and the body height. The evident reason for these negative results is the emaciation of most of the subjects.

DISCUSSION

It has long been recognized that the fatty tissues vary in their physical properties and structure according to the functions they perform. When storage and packing are the main requirements the fatty tissue is soft, richly supplied with blood vessels and lymphatics and enmeshed in relatively delicate and loose fibrous tissue. This distorts rapidly and easily and regains its form slowly after removal of the distorting agent. Where the fatty tissue is mainly supportive in function as in the palms of the hands, the heels and soles of the feet and over certain bony prominences such as the ischial tuberosity, it is much firmer and its fibrous tissue septa are stronger and rich in elastic tissue. This latter type is appropriately termed adipose-elastic tissue and distorts slowly when subjected to pressure but regains its form quickly when the pressure is removed (Kuhns, 1949). The type found in articular fat pads is clearly adipose-elastic, and doubtless the elastic tissue here as elsewhere in the synovial membrane prevents nipping of the tissue between the articulating surfaces (Davies, 1945). At the same time it will allow movement and distortion to ensure efficient lubrication as suggested by MacConaill (1950). Ramsey draws attention to the heavy septa of loose collagen bundles in fat from the knee joint of the cat, the stroma becoming less fibrous and more delicate towards the joint surface. No mention is made of elastic fibres.

It has often been claimed that the degree of development of adipose-elastic tissue is independent of the state of nutrition of the individual (Batty Shaw, 1901; Wells, 1940; Kuhns, 1949). Scammon (1919) noted a similar lack of relation between the size of the buccal fat pad and the amount of subcutaneous adipose tissue. The relation between nourishment of the individual and size of articular fat pads has been subject to doubt. Stack & Chasten (1949) and Lewin (1952) claim that there is no apparent relation between the infrapatellar fat pad size and the state of the subcutaneous fat of the individual. Fisk (1952), on the other hand, states that the fat in the synovial membrane shares in the changes which affect the fatty tissues of the body generally and finds no difference in the chemical composition of the synovial fat from that of the subcutaneous tissue. None of these workers, however, advance any figures or measurements in support of their contentions. Furthermore, the fat pads in joints other than the knee never seem to be considered in these claims.

The results of the present study accord with the statement of Stack & Chasten and of Lewin, in that the synovial fat pads are independent of the subcutaneous fat thickness except in extreme emaciation. There is a high and significant correlation between subcutaneous fat thicknesses in the different regions of the body (Edwards, 1960). When, however, the subcutaneous tissue becomes depleted, or nearly depleted of fat, its thickness is in the region of 5 mm. or less; with further wasting the subcutaneous tissues in the various regions do not undergo comparable reductions in the thickness. In the much undernourished subjects in the African series dealt with here, a comparable state of affairs as regards depletion of fat in the articular pads and in the subcutaneous tissue has been reached and the correlation coefficients are low, whilst in the much better nourished European series the reverse is true.

Edwards (1950) estimates that fat virtually disappears from the subcutaneous tissues in the adult of average height when the total weight of the body is 80 lb. or less. At approximately this stage the fat in articular pads begins to waste and the fat cells and their contained fat globules are first seen to decrease in size. In other words, there is a tendency for synovial fat to remain unchanged until that in the subcutaneous tissues and possibly elsewhere has been depleted.

With loss of fat from the synovium there is first a change in the appearance of the fat globule. With further reduction a number of smaller peripherally situated globules of fat appear in the cell; these remain when the central large globule has disappeared. These regressive changes are similar to those described by Batty Shaw and Wells in the subcutaneous fat cells during deposition of fat and are retained in so-called glandular fat. During the early stages of fat depletion from the articular pads there is increased vascularity which may be a factor in fat removal and an alteration in the appearance of the fat globule, possibly indicative of a change in composition. The engorgement of the blood vessels and increased prominence of the tissue spaces, with presumably the presence of more tissue fluid, may indicate a compensatory mechanism to maintain the size of the fat pad. As the fat disappears, not only do the cells change in form but the amount of their cytoplasm appears to be increased.

The form and structure of the synovial fat pads in the newborn are similar to those of the adult, though the fat globules are smaller and the elastic fibres have not fully differentiated. Increase in the size of fat pads during growth must occur mainly by the differentiation of new fat cells. When the African and European series are compared, it would appear that this differentiation of new fat cells after birth may be inhibited in the undernourished and that after a certain stage in postnatal development no new fat cells can be formed. This suggestion reminds one of the findings of Hammond (1950) on the influence of feeding on the pre- and postnatal development of tissues generally.

SUMMARY

1. The structure and behaviour of articular fat pads in different states of nutrition have been studied in thirty-two European and twenty-four African adults and in five juveniles.

2. The articular fat pads consist of elastic-adipose tissue and in the well or moderately well nourished the fat cells are of the usual type seen in fatty tissue elsewhere. In the newborn the cells and fat globules approach adult size but the elastic tissue is not fully developed until about two years of age. In markedly wasted individuals the single large fat globule disappears, the fat cells become stellate and their cytoplasm contains scattered small globules of fat.

3. With wasting, the depletion of the fat from the synovial fat pads does not begin until that in the subcutaneous tissues has been virtually removed; it is accompanied by increased vascularity and enlargement of the intercellular spaces.

4. Except in extreme emaciation, the weights of synovial fat pads are unrelated to the state of nutrition.

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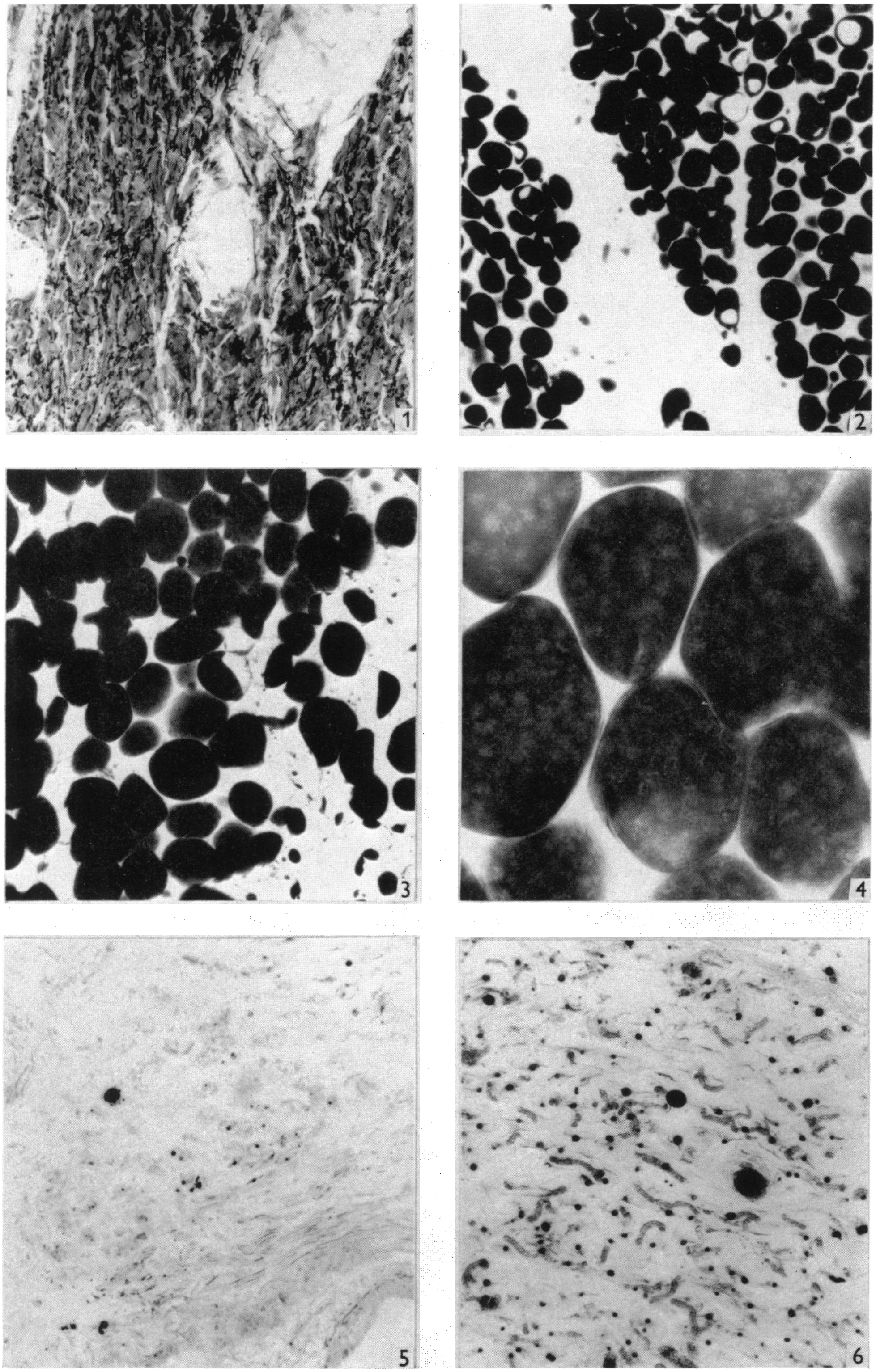

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EXPLANATION OF PLATE

Fig. 1. Section to show the fibrous septa in the infrapatellar fat pad to demonstrate the elastic fibres, most of which are cut transversely. Human aged $1\frac{1}{2}$ years. Coloured with orcein. $\times 100$.

Fig. 2. Frozen section of the infrapatellar fat pad of a human newborn. Coloured with Sudan black. $\times 100$.

Fig. 3. Frozen section of the infrapatellar fat pad of a European male aged 64 years (no. 84). Coloured with Sudan Black. $\times 100$.

Fig. 4. Frozen section of the fat pad from the front of the elbow joint from a severely wasted subject (case 879) to show mottling of the fat globules. Coloured with Sudan black. $\times 400$.

Fig. 5. Frozen section of the infrapatellar fat pad of a severely wasted subject (case 858). Coloured with Sudan black. $\times 100$.

Fig. 6. Frozen section of the infrapatellar fat pad of a severely wasted subject (case 876). Note the scarcity of fat globules and the increased vascularity. Coloured with Sudan black. $\times 100$.