The effects of food restriction and exercise on site-specific differences in adipocyte volume and adipose tissue cellularity in the guinea-pig

1. Superficial and intra-abdominal sites

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1. The volume and number of adipocytes were measured in fourteen anatomical sites of adult guinea-pigs kept in small cages and fed *ad lib.*, kept in small cages and on restricted diet or fed *ad lib.* and exercised.

2. In the sedentary *ad lib.*-fed animals, there was no significant correlation between percentage body-weight as adipose tissue, as determined by direct dissection, and mean adipocyte volume based on samples from many different sites. The correlation was significant, though not high, for sedentary, restricted-diet animals and for exercised specimens.

3. The correlations between the volume of adipocytes from left–right pairs of sites, and from sites around the same limb, were highly significant under all conditions studied. The correlation between the volume of adipocytes from sites other than left–right pairs of sites was weaker and in some cases statistically insignificant in sedentary *ad lib.*-fed guinea-pigs. The volume of adipocytes from sites in the groin region, the mesenteries and medial to the trapezius muscle failed to correlate in many cases with the volume of adipocytes from other sites sampled.

4. The number of adipocytes at each site was similar in the exercised and sedentary *ad lib.*-fed animals. The restricted-diet, sedentary group had fewer adipocytes at all sites studied except the omental and mesenteric fat mass and the groin sites.

5. It is suggested that moderate regular exercise or fasting gives rise to closer coordination between adipocytes at different sites because central factors regulating adipocyte volume become more prominent than local factors.

Many studies on laboratory rodents, domestic livestock and humans have shown that the volume of adipose cells is determined by the current diet, previous dietary history, exercise regimen, age and various genetic and endocrinological factors (Kirtland & Gurr, 1979; Sjöström, 1980; Gurr *et al.* 1982). These factors all act systemically on the adipose mass as a whole, and their effects were documented by the study of tissue from one or a small numbers of sites. The possibility that the conclusions reached may depend on the site from which the adipocytes were taken is rarely considered, although there is increasing evidence of substantial differences in morphology and biochemistry between adipocytes from different sites of the same animal (Krotkiewski & Björntorp, 1976; Lithell & Boberg, 1978; Gurr *et al.* 1982). In the present paper and the accompanying paper (Pond *et al.* 1984), we have recorded changes in volume of adipocytes from a much greater number and variety of anatomical sites than are usually studied. We demonstrated that changes in diet and exercise regimen alter the relationship between adipocytes from different sites, as well as affecting the mean cell volume.

The experimental animal chosen was the guinea-pig (*Cavia porcellus*) because this species often has unusually large adipocytes, even at moderate levels of obesity (Kirtland & Gurr, 1979). They nonetheless show the typical mammalian pattern of anatomical distribution of larger and smaller adipocytes, as described by Pond (1984*a*).

MATERIALS AND METHODS

Pure-bred guinea-pigs of three strains, Dunkin Hartley (Albino), Bolivian and Abyssinian were bred and maintained at the authors' laboratory. All animals were maintained until

at least 15 weeks of age on an *ad lib.* diet and housed in standard laboratory guinea-pig cages (area 0·44 m², largest dimension 0·74 m). They were fed *ad lib.* on breeding-grade guinea-pig chow (33 g crude oil/kg, 9205 kJ metabolizable energy/kg), plus small quantities of hay, carrot, cabbage, turnip and fruit three times weekly. Vitamin C (0·1 mg/ml) was added to the drinking-water. Group 1, consisting of nine males and nine females (nine Dunkin Hartley, five Abyssinian and four Bolivian), was maintained under these conditions throughout life, in single-sex groups of three to six animals. Group 2 (eight males, eight females; eight Dunkin Harley, three Abyssinian and five Bolivian) were housed in similar cages but ate a chow containing slightly less fat (26·2 g crude oil/kg, 8305 kJ metabolizable energy/kg) and the same non-synthetic foods and water; they were given access to the chow for only 3 h/d. This 'restricted' diet began when the animals were about 134 d old (SD 26·5 d, minimum 105 d), and continued for an average period of 76 d (SD 34 d) before they were killed. Beginning at about the same age (mean 144 d, SD 34 d), group 3 guinea-pigs were transferred in four single-sex groups of five to seven animals to outdoor pens, consisting of an enclosed, gravel-covered run of area 6 m² and a hutch of area 1·5 m². The food and the water were placed at opposite ends of the run, 3·75 m apart; the animals were fed *ad lib.* on the same diet as group 1. Group 3 consisted of ten males and thirteen females, eight Dunkin Hartley, seven Abyssinian, eight Bolivian. After an initial period of adjustment, accompanied by some weight loss, these 'outdoor' animals regained their weight and were observed to exercise spontaneously, including galloping from one end of the pen to the other. They were put outside in early June 1982 and remained there for an average period of 121 d (SD 27 d) before being killed in mid-autumn.

Each animal was weighed every 2 weeks and on the day it was killed. Animals were killed by an overdose of urethane (6–10 ml of a 500 mg/ml solution injected intraperitoneally). The intact body was stored at 4–8 ° overnight and dissected within 24 h of death. Cooling the body made the adipose tissue, particularly that in the mesenteries, easier to handle and thus facilitated accurate quantitative dissection of the tissue. The adipose tissue, with small, closely-associated nerves and blood vessels was dissected from the fourteen sites listed on Table 1. These fourteen sites together comprised at least 85% of the total dissectible fat. A further 10–12% was found in two intermuscular fat pads in the hind-limb, a detailed study of which is reported in an accompanying paper (Pond *et al.* 1984).

The nomenclature of adipose deposits is in confusion and several different terms are used by different authors for what is probably the same site. The full description of each site on Table 1 specifies the exact location of each site. The perirenal, pelvic and gonadal deposits have not been distinguished because consistent differences in the volume of adipocytes from these sites could not be found. For similar reasons, omental and mesenteric deposits were treated as a single category. In the case of four sites (in front of arm (IFA), in front of shoulder (IFS), under muscles of neck (UMN) and behind arm (BA)), homologous samples from the right (R) and left (L) sides were studied separately.

The tissue was usually frozen at −15 to −17° for 1–20 d before adipocyte volume measurements were made. Adipose tissue is a robust tissue, the cellular structure of which deteriorates only slowly after death. Tests showed that freezing made no difference to the results. The diameter of about forty cells from each site was measured. The samples were taken from randomly-chosen sites in the middle of each fat mass with fine surgical scissors. The samples were globular and about 0·5 mm in diameter. The adipocytes and any associated connective tissue were placed in one drop of phosphate-buffered saline and measured as an unfixed, unstained whole mount using transmitted light and a Leitz Labrolux microscope. The samples were analysed in a random order, always by the same person. The diameter measurements were normally distributed and the standard deviation was less than 10% of the mean in most cases. When the standard deviation exceeded 15%

Table 1. *Anatomical location of fat deposits studied*

Site	Description
Dorsal wall of abdomen	All adipose tissue on or near dorsal wall of abdomen; includes perirenal, gonadal and 'retroperitoneal' fat and fat in pelvic channel
Attached to guts	Omental and mesenteric fat
Groin side	Fat anterior to femur from hip to knee, lateral to abdominal wall, medial to panniculus muscle
Groin ventral	Medial, ventral fat on outside of abdominal wall between hind-limbs
Behind arm, right and left	Fat posterior to humerus and in axilla, extending laterally over chest muscles
In front of arm, right and left	Fat on anterior and lateral surface of fore-limb, anterior to biceps brachii muscle and in groove of elbow
In front of shoulder, right and left	Fat anterior to deltoideus and lateral to trapezius and omotransversarius muscles
Under neck muscles, right and left	Medial to trapezius and cleidobrachialis muscles, lateral to serratus ventralis, anterior to supraspinatus
Interscapular–dorsoscapular	Superficial, medial fat between dorsal crests of scapulae, extending anteriorly and posteriorly over thoracic and cervical vertebrae
Chin	Superficial medial fat in groove between lower jaws

of the mean, the measurement was repeated. The mean adipocyte volume for each sample was calculated from the diameter measurements using the formula published by Goldrick (1967). Both conventional computing systems and Statistical Package for Social Sciences (Nie *et al.* 1975) were used to analyse the results. MEANCS (mean cell size) was the arithmetic mean of the volume of adipocytes from sixteen body sites, including all fourteen of the sites listed in Table 1 and the centre samples from each of the two intermuscular sites studied in the accompanying paper (Pond *et al.* 1984). The number of cells was calculated for each site separately, from the gross weight of the depot and the mean adipocyte volume for that site, assuming a density of 0·873 (Di Girolamo *et al.* 1971). The values for the two intermuscular sites studied by Pond *et al.* (1984) were included in the calculation of the total number of adipocytes per guinea-pig.

RESULTS
Size and number of adipocytes in relation to body composition
The age, lean body-weight, percentage body-weight as fat and the number and mean adipocyte MEANCS of animals in the three treatment groups are shown in Table 2. There was no significant difference in the age of any of the three groups, nor between strains or sexes. The lean body-weight was highly significantly different (Student's *t* test, *t* 6·08–2·69, $P < 0.01$ in all cases) between sexes and treatment groups, except for group 2 males and females, which had similar lean body-weight (*t* 0·897, $P > 0.05$). In planning these experiments, we hoped that the Abyssinian strain would be larger and the Bolivian smaller than the Dunkin Hartley strain under similar conditions, thus providing a wider range of body sizes. This hope was not realized and there was no consistent difference in body-weight between the three strains. The males were more active than the females when outdoors and underwent a small net loss of weight (mean 4%) while outside; the females showed a small

Table 2. *Age, body composition and weight change of male and female guinea-pigs in the three treatment groups†*

(Mean values and standard deviations)

Group... Treatment...		1 Sedentary, ad lib.-fed		2 Sedentary, restricted-diet		3 Exercising, ad lib.-fed	
		Mean	SD	Mean	SD	Mean	SD
Age (d)	♂	284	195	210	46	251	30
	♀	222	24	212	20	275	24
	All	253	138	211	34	265	29
Lean body-wt (g)	♂	893	52·7	686	75·5	791	82·8
	♀	765**	72	660	88	708*	64·1
	All	826	88·6	673	80	744	82·5
Percentage body-wt	♂	14·8	2·4	6·1	1·5	8·2	3·2
as fat	♀	16·0	2·0	7·2	2·8	13·9**	2·1
	All	15·2	2·5	6·7	2·5	11·4	3·9
Adipocyte MEANCS	♂	1·587	0·326	0·867	0·331	0·759	0·174
(nl)	♀	1·687	0·234	0·990	0·453	1·246**	0·242
	All	1·610	0·304	0·949	0·413	1·034	0·324
No. of fat cells	♂	118·47	23·83	71·79	27·75	109·79	31·47
($\times 10^6$)	♀	99·52	23·65	68·37	16·85	111·25	27·34
	All	108·64	25·30	70·49	22·63	110·61	28·50
Percentage body-wt	♂			17·1	8·0		
lost	♀			16·7	7·8		
	All			16·9	7·6		

MEANCS, mean cell size, calculated as explained on p. 417.

Age was not significantly different between sexes or treatment groups ($P < 0.05$). For other values, differences between treatment groups were highly significant ($P < 0.01$).

There were no significant differences between the sexes, except: *$P < 0.02$, **$P < 0.01$.
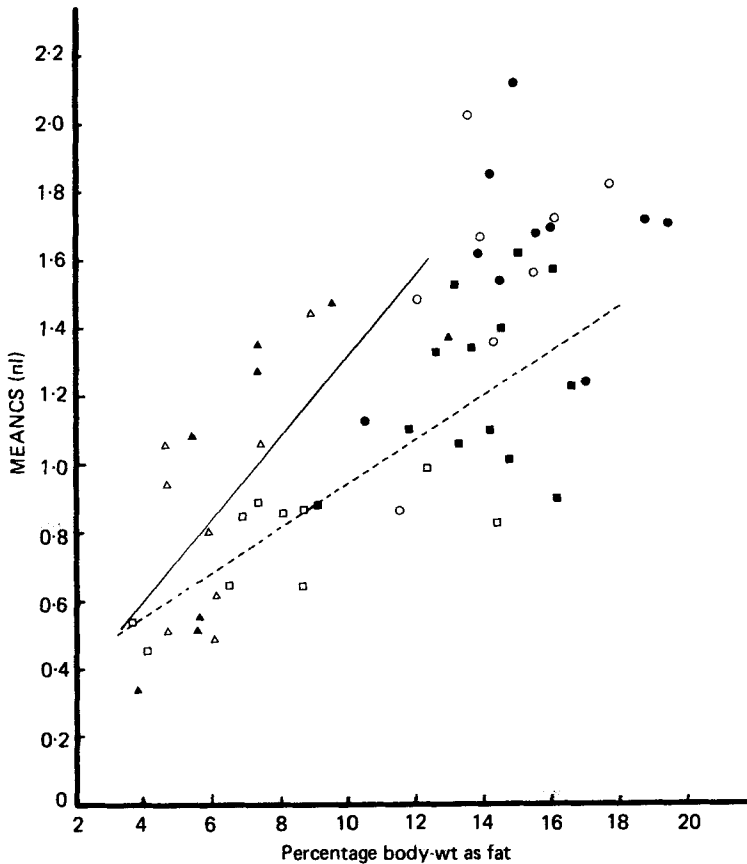
† For details of treatments, see p. 416.

Fig. 1. Relationship between adipocyte mean cell size (MEANCS; nl), based on samples from sixteen anatomical sites, and percentage body-weight as adipose tissue, as determined by direct dissection. (O, △, □), Males; (●, ▲, ■), females. (O, ●), Group 1 (sedentary, *ad lib.*-fed); (△, ▲, (———)) group 2 (sedentary, restricted-diet); (□, ■, (------)) group 3 (*ad lib.*-fed, exercising). Correlation coefficients are: group 1, $r\,0.30$, not significant at $P < 0.05$ for 16 df; group 2, $r\,0.71$, $P < 0.01$ for 14 df; group 3, $r\,0.77$, $P < 0.01$ for 21 df.

net gain (mean 6.5%) during the same period. In the two *ad lib.*-fed groups, Abyssinians were slightly fatter than members of other strains, but this difference was due entirely to an increase in cell number; there was no significant difference in MEANCS between strains in any treatment group. In group 3, the average number of adipocytes was 129.83×10^6 (SD 23.7×10^6) for Abyssinians, compared with 91.67×10^6 (SD 28.3×10^6) in Bolivians and 112.74×10^6 (SD 22.1×10^6) in Dunkin Hartleys. The mean number of adipocytes was similar in groups 1 and 3, but highly significantly fewer ($t\,4.64$, $P < 0.01$) for both sexes and all strains in group 2. The MEANCS were similar in groups 2 and 3 but the adipocytes of group 1 animals were significantly larger ($t\,5.26$, $P < 0.01$). In other words, groups 1 and 3 had the same number of adipocytes, but those of group 1 were 70% larger. Groups 2 and 3 had adipocytes of the same average volume, but group 2 animals contained 36% fewer cells than group 3.

Fig. 1 shows the relationship between MEANCS and percentage body-weight as fat, as determined by direct dissection, for animals in the three treatment groups. Although MEANCS was based on measurements of sixteen well-defined adipose sites, there was no

Table 3. *Correlation coefficients between the volume of adipocytes from fourteen adipose depots in group 1 (ad lib.-fed) (upper right portion) and group 3 (exercising, ad lib.-fed) (lower left portion) guinea-pigs*

							Group 1 (*n* 18)							
Sites	IFSR	IFSL	UMNR	UMNL	IFAR	IFAL	BAR	BAL	GS	GV	HUMP	DC	ATG	DWA
Group 3 (*n* 23)														
IFSR	—	0·993	0·402 NS	0·722	0·727	0·659	0·706	0·695	0·448 NS	0·495 NS	0·651	0·615	0·783	0·757
IFSL	0·975	—	0·396 NS	0·706	0·735	0·670	0·708	0·703	0·461 NS	0·478*	0·679	0·630	0·806	0·756
UMNR	0·823†	0·827†	—	0·860	0·786	0·828	0·721	0·774	0·300 NS	0·384 NS	0·602	0·628	0·003 NS	0·383 NS
UMNL	0·826	0·836	0·997	—	0·822	0·819	0·763	0·771	0·416 NS	0·483 NS	0·649	0·680	0·378 NS	0·546*
IFAR	0·892	0·916	0·955	0·966	—	0·986	0·969	0·966	0·336 NS	0·374 NS	0·819	0·687	0·404 NS	0·659
IFAL	0·884	0·903	0·936	0·946	0·976	—	0·972	0·958	0·285 NS	0·363 NS	0·783	0·665	0·337 NS	0·599
BAR	0·877	0·882	0·869	0·888	0·936	0·929	—	0·955	0·240 NS	0·335 NS	0·747	0·605	0·404 NS	0·621
BAL	0·897	0·907	0·878	0·890	0·923	0·908	0·972	—	0·386 NS	0·419 NS	0·833	0·694	0·391 NS	0·682
GS	0·836†	0·838†	0·738†	0·738	0·822†	0·790†	0·806†	0·835†	—	0·903	0·691	0·552*	0·568*	0·764
GV	0·827†	0·825	0·664†	0·659	0·754†	0·726†	0·755†	0·803	0·979	—	0·648	0·585	0·529*	0·753
HUMP	0·894	0·907†	0·955†	0·947†	0·939	0·923	0·875	0·913	0·819	0·774	—	0·622	0·506*	0·855
DC	0·886†	0·885	0·941†	0·943†	0·944†	0·937†	0·896†	0·902†	0·772	0·702	0·959†	—	0·431 NS	0·604
ATG	0·860	0·843	0·790†	0·786	0·928†	0·828†	0·803†	0·848†	0·891†	0·878†	0·850†	0·835†	—	0·908
DWA	0·832	0·822	0·795†	0·796	0·842	0·817	0·810	0·860	0·940	0·914	0·850	0·799	0·908	—

NS, not significant.

IFSR, IFSL, in front of shoulder, right and left; UMNR, UMNL under trapezius muscle of neck, right and left; IFAR, IFAL, in front of arm, right and left; BAR, BAL, behind arm, right and left; GS, side groin; GV, ventral groin; HUMP, interscapular hump; DC, 'double' chin; ATG, mesenteric and omental fat; DWA, kidney, gonadal and pelvic intra-abdominal fat; for further details, see Table 1.

* Barely significant ($0.01 < P < 0.05$); all other values highly significant ($P < 0.01$).

† Differences between corresponding correlation coefficients in the two groups were significant ($P < 0.05$).

Table 4. *Calculated number of adipocytes* ($\times 10^6$) *in the adipose depots studied, for the three treatment groups*

Group...	1 Sedentary, *ad lib.*-fed		2 Sedentary, restricted-diet		3 Exercising, *ad lib.*-fed		Group 2 values as a percentage of group 3 values
Treatment...							
Site	Mean	SD	Mean	SD	Mean	SD	
IFS	4·59	2·05	2·18	2·06	5·66	2·40	38·5
UMN	8·00	2·23	3·10	2·70	9·31	4·60	33·3
IFA	2·59	1·04	1·61	0·83	3·13	1·63	51·4
DC	5·34	2·28	2·13	1·44	6·50	3·43	32·8
BA	7·32	2·32	4·92	1·72	7·58	2·01	64·9
HUMP	14·12	3·85	9·37	2·89	16·64	5·53	56·3
Groin	15·81	4·56	13·17	5·04	15·86	6·60	83·0
ATG	25·83	13·99	18·66	9·79	22·62	5·85	82·5
DWA	23·46	5·99	12·73	4·41	21·15	5·83	60·2

IFS, in front of shoulder, UMN, under trapezius muscles of neck; IFA, in front of arm; DC, 'double' chin; BA, behind arm (IFA and BA are the sum of values from left and right sides); HUMP, interscapular hump; groin sum of ventral groin and left and right-side groin; ATG, mesenteric and omental; DWA, kidney, gonadal and pelvic intra-abdominal fat; for further details, see Table 1.

significant correlation (r 0·30, $P > 0·05$, 16 df) between this value and percentage body-weight as fat in group 1. The correlation between the same measurements was highly significant in the other groups: group 2, r 0·71, $P < 0·01$, 14 df; group 3, r 0·77, $P < 0·01$, 21 df.

Relationships between adipocytes from different anatomical sites

The correlation coefficients between the volumes of adipocytes from the fourteen anatomical sites studied are shown in Table 3. Groups 1 and 3 were compared here because the total number of adipocytes per animal was the same (see Table 2). The correlation between the volumes of adipocytes from left–right pairs of sites was very high in all cases; the correlation coefficient between the volumes of cells from non-homologous sites in the same group of animals was lower than that between homologous sites and, in some cases, was statistically insignificant. The correlation coefficients were generally lower for the values from group 1 animals than from group 3 animals, but the difference between the correlation coefficients in the two groups was significant at $P < 0·05$ using Fisher's z-transformation test in the cases indicated. The pattern of correlation coefficients for the group 2 values was similar to that of group 3. The relationship between the volumes of adipocytes from different sites was thus similar in the thinner animals and the exercising group, in spite of the fact that the former had 36 % fewer cells than the latter.

Table 4 shows the number of adipocytes at each depot studied, calculated as explained previously. There was no significant difference between groups 1 and 3 in the number of cells at any site, indicating that an increase in exercise *per se* did not cause more or fewer adipocytes to develop at certain sites. In Table 4, group 2 values are expressed as a percentage of those found for group 3. The smaller sites on the anterior of the body ('double chin' (DC), IFS, UMN, IFA) contained about half as many cells in the group 2 animals as in the two *ad lib.*-fed groups. The mid-body sites (behind arm (BA), interscapular (HUMP)) contained about one-third fewer cells, while the two groin sites (groin side (GS) and groin ventral (GV)) and the mesenteric and omental deposits (ATG) contained less than 20 % fewer cells than in the *ad lib.*-fed groups. Analysis of variance using log-transformed

data failed to reveal any effect of status on the number of cells at the groin sites in either sex or any strain which was significant at $P < 0.05$. There was, however, a barely-significant difference between the sexes ($P = 0.05$), with males having the greater number of cells at the two groin sites. Similar analysis showed that status was the major component of differences in adipocyte numbers at all sites studied; there were no differences between strains or sexes which could not be accounted for by differences in body size or fatness. The exceptional behaviour of the adipocytes in the groin sites was particularly noticeable in the thinner specimens of group 3, where the volume of adipocytes in these sites was up to ten times greater than that of cells from the smaller peripheral sites of the same animal.

DISCUSSION

The accuracy and reliability of the various methods for estimating adipocyte volume have been widely discussed (Martinsson, 1968; Gurr & Kirtland, 1978). The present methods were believed to be satisfactory because independently measured left–right pairs of samples correlated closely, both in the case of large adipocytes (group 1) and small adipocytes (group 3; see Table 3). Almost all the present adipocyte-volume measurements fell within the range reported by Kirtland et al. (1976) for 3-month-old guinea-pigs. The smaller number of adipocytes in the group 2 animals was not anticipated in the original experimental design. Hirsch & Han (1969) found that the full complement of adipocytes was present in rats by the age of 105 d. Since guinea-pigs, although larger than rats, are precocious at birth and can be weaned at an early age, it was expected that the full complement of adipocytes would be functional by the time the special treatments began. It is possible that filling or formation of adipocytes was still in progress when food restriction began. However, within group 1 animals (age range 95–500 d) there was no significant correlation between age and number of adipocytes in the body; the possibility that adipocytes disappeared during food restriction in the group 2 animals, therefore, cannot be eliminated from our results.

Our results show that all sites except the two groin sites and ATG were almost equally effected by dietary restriction, including small depots such as IFA, DC and IFS, which have relatively small adipocytes in guinea-pigs and other mammals (Pond, 1984a). UMN, which always contains very small cells, sometimes as small as 10% of the volume of adipocytes from elsewhere in the same animal (Pond, 1984b), was also extensively depleted by the restricted diet imposed on the group 2 animals. Butler-Hogg & Wood (1982) found that the omental site was among the fastest-growing fat deposits in domestic pigs, cattle and sheep, which may account for the relatively-small reduction in adipocyte numbers found in the ATG site of our group 2 animals. The present results do not, however, indicate any relationship between relative volume of adipocytes in different sites and the susceptibility of that site to depletion in cell number following dietary restriction. Although two large cell sites (ATG and groin sites) were only slightly affected, two other large cell sites (DWA and POP (see Pond et al. 1984)) were depleted as much as most of the other sites were.

The two sites GS and GV behave as a 'homologous pair' in that their adipocyte volumes correlate closely under all conditions studied (see Table 3). However in guinea-pigs and in fourteen other mammalian species, GV adipocytes are consistently larger than GS cells (Pond, 1984a). In ad lib.-fed sedentary animals (group 1), adipocytes from both groin sites assume volumes unrelated to those elsewhere on the body. Several other studies have hinted that the behaviour of groin adipocytes may not be typical of the adipose mass as a whole. Larson & Anderson (1978) removed the epididymal fat pads and the 'inguinal' mass from one side of adult rats. It is not clear from their account whether the operation included all or part of the GV site. They found some evidence for regeneration at the inguinal site, but no regeneration of the intra-abdominal deposits 13 weeks after surgery. In humans, the adipose tissue on the anterior surface of the thigh probably corresponds most closely to

the groin sites in rodents. Krotkiewski *et al.* (1975*a*) and Kissebah *et al.* (1982) found that adipocytes from human thighs failed to respond to stimulation with various hormones. They referred to these cells as 'inert' but, since they studied samples from only a few other body sites, the exceptional behaviour of the thigh cells was not as noticeable as in the present study. Ashwell *et al.* (1978) measured the circumference of the thigh at the level of the trochanter in obese women who were trying to lose weight. They reported that the circumference of the thigh changed less than that of the waist as the subjects became thinner, in spite of the large quantity of fat in the trochanteral site.

The results indicated that adipocytes from different sites in the same animal often differ in volume by a factor of three and can differ up to tenfold. This observation is consistent with the report by Gurr *et al.* (1982) that certain adult humans have adipocytes of widely differing volumes at different body sites.

The correlation between the volume of adipocytes from left–right pairs is generally higher than between non-homologous pairs, particularly in group 1 animals. Whatever maintains the closer correlation between adipocytes at different sites acts as effectively in animals which have the full complement of adipocytes (group 3) as in those which have 36% fewer cells (group 2). In the group 1 animals, anatomically proximal sites, such as IFS and IFA, or ATG and DWA, differ as much as anatomically distant sites such as DC and HUMP. However, the two sites from the anterior and posterior of the fore-limb (IFA and BA), and the two groin sites (GS and GV) correlate as closely as left–right pairs. Therefore, being subjected to similar mechanical forces during movement is more plausible as a cause of close correlation between sites than factors such as similarity of size of deposit or shared blood supply.

High correlation between the volumes of adipocytes in all sites studied was found only in groups 2 and 3. The present findings are consistent with the hypothesis that closer correlation between adipocytes at different sites is maintained only when regular fasting or frequent exercise promotes release of storage lipids from the adipose tissue. If energy demands can be continuously satisfied by feeding, the adipocytes are rarely stimulated to release triglyceride. Local factors which determine adipocyte volume in different sites become more prominent relative to central regulators of adipocyte volume and, hence, the correlation between the size of cells at different sites breaks down.

Weakening or failure of the mechanism which maintains coordination between the volumes of adipocytes at different sites would give rise to untypical body shapes in humans. Skerlj *et al.* (1953) distinguished eight 'figure types' in women; all except the one classified 'normal' were more pronounced in older, more obese women. Pronounced differences in the relative sizes of different adipose deposits are also more typical of older, less physically active women (Krotkiewski *et al.* 1975*b*); while younger, more active women have 'normal' figures. A modest level of excerise or regular fasting may help to prevent the development of untypical 'figures' in both women and guinea-pigs.

A consequence of these uncoordinated changes in adipocyte volume in *ad lib.*-fed, sedentary animals is that percentage body-weight as fat cannot be estimated from measurements of adipocyte volume alone, even when different sites are sampled (see Fig. 1). The present findings show that adipocyte volume is a reliable guide to total fatness only in restricted-diet or exercised animals; since many human patients and laboratory animals probably do not qualify for either category, estimates of fatness based on adipocyte volume measurements (e.g., Di Girolamo *et al.* 1971; Hirsch & Batchelor, 1976; Knittle *et al.* 1977) must be treated with caution.

CONCLUSIONS

There is no statistically significant relationship between total body fatness, as determined by complete dissection, and mean adipocyte volume, based on samples from sixteen different anatomical sites in sedentary *ad lib.*-fed guinea-pigs. Such a correlation becomes significant in exercised and restricted-diet animals.

A moderate level of exercise of dietary restrictions also increases the correlation between the volume of adipocytes from different anatomical sites. In sedentary *ad lib.*-fed animals there is no significant correlation between the volume of adipocytes from certain sites; homologous left–right pairs and sites from around the same limb correlate closely under all conditions studied.

It is suggested that in sedentary *ad lib.*-fed animals local factors become more important than systemic factors in determining adipocyte volume, causing some sites to vary independently. Moderate regular exercise or fasting may promote the role of systemic factors and thus give rise to closer correlation between the volume of adipocytes at different sites.

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