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ASSESSMENT OF TRUNCAL EDEMA FOLLOWING BREAST CANCER TREATMENT USING MODIFIED HARPENDEN SKINFOLD CALIPERS

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ABSTRACT

After initial treatment for breast cancer, lymphedema often affects the trunk as well as the arm. Evaluation of truncal swelling by the clinical "pinch test" of the posterior axillary fold is unreliable. Our aim was to develop an objective measurement, using modified Harpenden skinfold calipers.

Standard Harpenden skinfold calipers exert a pressure of 12.6 g.mm^{-2}, which rapidly squeezes edema fluid out of the skinfold. Springs were substituted to exert a lighter but relatively constant load (3.7 g.mm^{-2}). Repeated skinfold thickness measurements on the same, normal subject then gave a relative standard deviation (r.s.d.) or coefficient of variation of 5%. The posterior axillary folds of 14 patients (age 56 ± 13 (s.d.) years) with an average 30% arm swelling were measured using the same procedure. Readings were taken at 10 s, and again after 60 s of sustained application to assess the rate of creep, or deformation with time, attributed to displacement of pressurized interstitial fluid.

Two patients had clinically observable axillary fold swelling. Eight patients, including the above two, showed axillary fold swelling by caliper measurement, defined as a 10% increase over the contralateral side (2 r.s.d.'s). Creep was greater on the affected side in all 14 patients. Thus, modified calipers can detect axillary fold edema, and thereby provide an objective method for assessing changes in swelling after lymphedema treatment.

Arm swelling can affect up to 38% of women after initial breast cancer treatment (1). Clinically observed truncal swelling, particularly affecting the posterior axillary fold (PAxF), frequently exists with "postmastectomy" lymphedema owing to the shared lymph drainage route in the axilla. Posterior axillary fold swelling is therefore considered to indicate truncal edema. Arm volume can be reliably measured by either water displacement, circumferential tape measure recordings or using a volumeter (2), but no method exists for quantitating truncal edema. Clinical assessment of truncal swelling is by the "pinch" test, in which both posterior axillary folds are grasped and the difference estimated subjectively. Truncal swelling is not only uncomfortable for the patient but its presence and extent may be important for determining the success of lymphedema treatment of the arm. Reduction in arm volume depends on encouraging drainage of lymph through collateral lymphatic routes and perhaps through tissue planes to normally draining lymph node sites. A congested or edematous trunk seems to impair this process. Therefore, the aim of this study was to develop a method which assessed the presence or absence of axillary fold edema and which could monitor changes in swelling during lymphedema treatment.

MATERIALS AND METHODS

Springs

TABLE 1
Specifications of Tested Springs as Stated by the Manufacturer

LEE SPRING STOCK #	OUTSIDE DIAM		WIRE DIAMETER		MAXIMUM LOAD		INITIAL TENSION		FREE LENGTH		SPRING RATE		MAX EXTENSION	
	mm	in	mm	in	N	lb	N	lb	mm	in	N/mm	lb/in	mm	in
LE-018C-9	6.35	0.25	0.46	0.02	4.89	1.10	0.44	0.10	44.45	1.75	0.03	0.17	149.41	5.88
LE-022C-9	6.35	0.25	0.56	0.02	9.34	2.10	0.89	0.20	44.45	1.75	0.09	0.50	96.52	3.80
LE-026C-6	6.35	0.25	0.66	0.03	13.79	3.10	1.78	0.40	44.45	1.75	0.21	1.20	57.15	2.25
LE-029C-6	6.35	0.25	0.74	0.03	19.13	4.30	2.45	0.55	44.45	1.75	0.37	2.10	45.36	1.79
LE-031C-6*	6.35	0.25	0.79	0.03	23.13	5.20	3.11	0.70	44.45	1.75	0.53	3.00	38.10	1.50
LE-034C-6	6.35	0.25	0.86	0.03	30.25	6.80	3.78	0.85	44.45	1.75	0.86	4.90	30.84	1.21
LE-037C-7	6.35	0.25	0.94	0.04	37.81	8.50	4.45	1.00	50.80	2.00	1.17	6.70	28.43	1.12

*optimal spring
N = Newton

A standard pair of Harpenden skinfold calipers (British Indicators Ltd., Burgess Hill, West Sussex, UK) has two springs that exert a pressure of 12.6 g.mm^{-2} (1260 cm H_2O) over the 90 mm^2 jaw anvils (our measurement; manufacturers specification: 10 g.mm^{-2}). This pressure is used for skinfold thickness measurements during assessment of body fat, but is undesirable for measurements of edema because it rapidly compresses the edema fluid out of the skinfold. We tested seven alternative springs (LE-018C-9, LE-022C-6, LE-026C-6, LE-029C-6, LE-031C-6, LE-034C-6, LE-037C-7; Lee Spring Ltd., Berkshire, UK) which were similar in dimension to the original springs but exerted lower loads *(Table 1)*. All springs were evaluated on the calipers clinically. Clinically acceptable springs exhibited the ability to grasp a skinfold without slippage but also without leaving sunken red marks on the skin. Springs that were not clinically acceptable were abandoned.

Physical Tests on Modified Calipers

The physical properties of the remaining springs when mounted on the Harpenden skinfold calipers *(Fig. 1)* were tested to determine the optimal pair. The caliper handle was clamped horizontally to a workbench to immobilize the upper caliper jaw. A 10 cm length of string with a loop on the end was tied to the bottom jaw of the caliper. Standard weights were hooked onto the string loop, using 10 g increments. Caliper jaw deflection was read off the dial after 10 s to the nearest 0.2 mm. Weights were added sequentially and then removed sequentially to evaluate the effect of the direction of application of load. Sensitivity to the rate of loading was evaluated by adding and removing the weights either rapidly, i.e. dropping the weight from 1 cm, or slowly, i.e. applying the weight as gently as possible to the existing load.

Subject Measurements

The posterior axillary folds of one healthy subject and 14 lymphedema patients were measured with the modified calipers. All measurements of fold thickness were taken using a standardized technique. The calipers were reset to zero at the beginning of each set of measurements. The posterior axillary fold

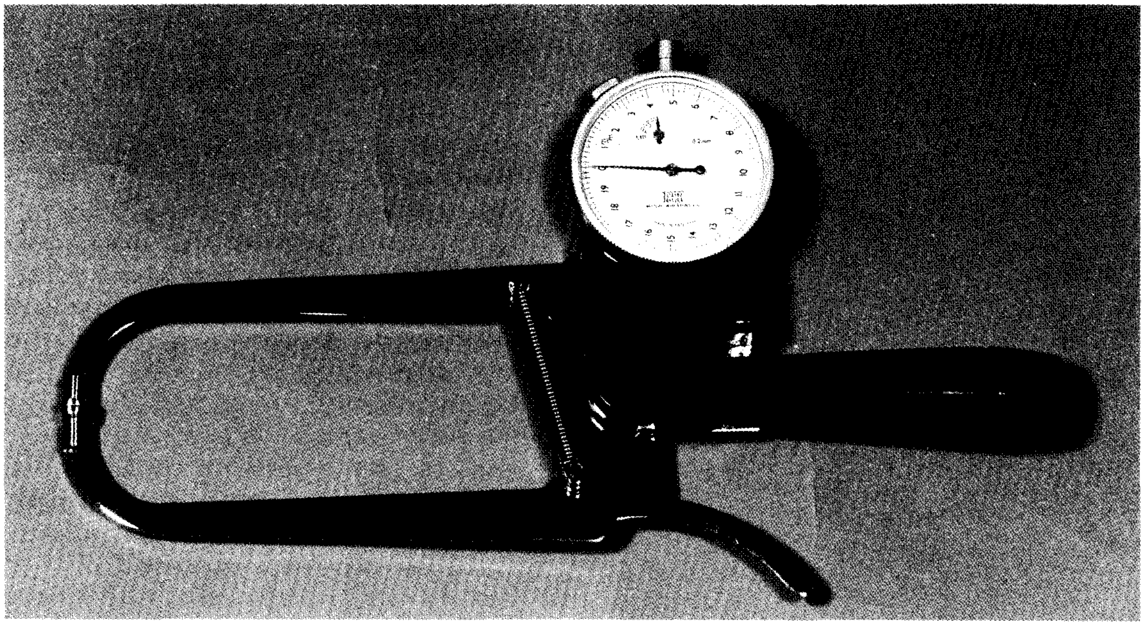

Fig. 1. Harpenden skinfold calipers.

on each side of the body was examined. The procedure was also attempted on the forearm but was found to be impractical because a skinfold could not always be lifted away from the swollen arm. Thus, the forearm site was abandoned. The subject was seated in a comfortably warm room with arms relaxed in the lap. The examiner was standing. Restrictive clothing near the area of measurement was removed. An ink dot was placed 3 cm below the apex of the posterior axillary fold on the truncal side. The dot was then extended into a 4 cm horizontal line with half the line falling on either side of the dot. The ends of the line were used to standardize the placement of the caliper jaws as described next and as illustrated in *Fig. 2.* A skinfold 1 cm above the line was grasped with the thumb and forefinger of the left hand. The calipers were opened approximately 1 cm wider than the skinfold and released briskly onto the skinfold so that the caliper jaws fell at each end of the drawn line *(Fig. 2).* Caliper measurements were read to the nearest 0.2 mm. Readings were taken at 10 s and again after 60 s of sustained application. The purpose of the measurement at 60 s was to assess the rate of creep (deformation with time), which is analogous to the gradual indentation that occurs during the "pitting test" for edema (3,4). The rate of creep was calculated by subtracting the 60 s reading from the 10 s reading. Each measurement was taken three times at each site and on each side of the body by the same examiner.

Other Measurements

Patient information including age, date of last menstrual period, medications, height and weight were recorded. A short questionnaire ranked the patient's personal assessment of truncal swelling and the examiner's clinical judgment of posterior axillary fold edema by the pinch test *(Table 2).* Arm volumes were measured using a volumeter (Perometer 300s, Pero-System GmbH, Wuppertal, Germany).

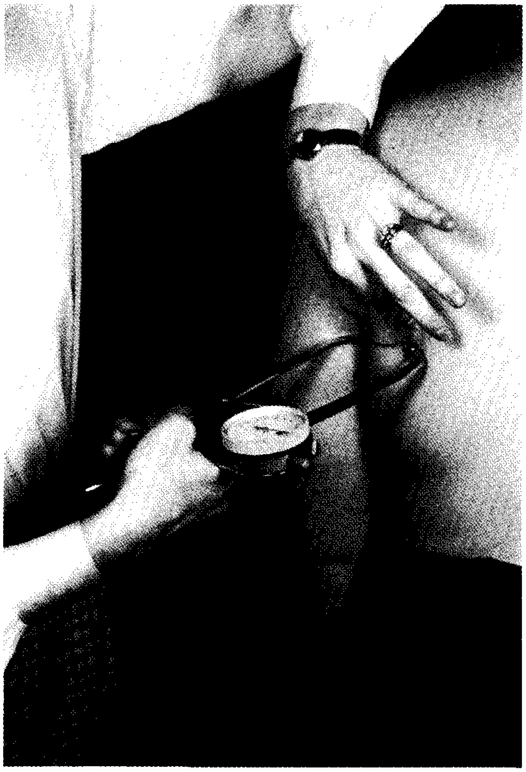

Fig. 2. The use of the "line" method in skinfold measurement.

RESULTS

Initial Selection of Springs

Springs LE-018C-9, LE-022C-6 and LE-026-6 did not exert enough pressure to hold a skinfold without slipping. Springs LE-037C-7 held a skinfold but left sunken red marks on the skin. Springs LE-029C-6, LE-031C-6 and LE-034C-6 all held a skinfold firmly without causing indentations, conforming to our definition of "clinically acceptable".

Caliper Performance with Selected Springs

Ideally, the calipers should apply a constant load at jaw deflections of 6 - 40 mm, the clinically relevant range. Although none applied constant loads in reality, springs LE-029C-6, LE-031C-6 and LE-034C-6, the three clinically acceptable springs, applied loads that varied by 10.5%, 9% and 11.3% respectively over the stated extension range. The LE-029C-6 and LE-031C-6 springs were evaluated further for (a) sensitivity to rate of loading and (b) direction of application of load. Hysteresis curves for the two springs with the best performance in the clinical range (6 - 40 mm) are shown in *Figs. 3A and B.* The load was found to vary both with the rate of loading and the direction of application (hysteresis), despite thorough lubrication. Spring LE-031C-6 showed the least variability and was therefore selected for patient measurement. The pressure it exerted was 3.6 $g.mm^{-2}$ to 3.8 $g.mm^{-2}$ over the extension range 6 to 40 mm, applied from a position of overextension.

Reproducibility of Measurement in Healthy Subject

A healthy male subject was measured twelve times over fifteen days using the previously described standardized technique to evaluate reproducibility. Results are shown in *Fig. 4.* The technique was found to have a relative standard deviation (r.s.d.) or coefficient of variation (i.e., s.d./mean) of 5%. Since 95% of normally distributed observations lie within two standard deviations of the mean, a difference of 10% (2 x r.s.d.) was adopted as the criterion for "axillary fold edema". On the same normal subject, when the ink dot was not extended into a line and the jaws were applied to the skinfold with the dot at the apex (the "dot" method), a r.s.d. of 19% was obtained.

Patient Measurements

Measurements were taken on fourteen patients (ages 27 - 75, mean 56 ± 13 (s.d.) years) who had arm swelling following breast cancer treatment. The increase in volume of the swollen arm, expressed as a % of the contralateral arm, ranged from 3% to 80%, with a mean of 30% ± 24% (s.d.). Eleven subjects were postmenopausal. A previous

TABLE 2
Patient Questionnaire and Scoring

	NO	SOME	YES
1. Have you noticed any truncal swelling?	0	1	2
2. Is your bra strap tighter on one side?	0	1	2
3. Does the examiner observe truncal swelling?	0	1	2
4. Is the skinfold difficult to lift?	0	1	2

	Question				
Subject	#1.	#2.	#3.	#4.	Score
1	0	0	0	1	1
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	1	1
5	0	0	0	0	0
6	0	0	0	0	0
7	1	0	1	0	2
8	0	1	0	1	2
9	0	0	1	0	1
10	0	0	0	0	0
11	0	2	2	0	4
12	2	2	2	2	8
13	1	0	1	1	3
14	0	0	0	0	0

study found no change in skinfold thickness with the menstrual cycle (5).

a) Measurements at 10 s. Results are shown in *Table 3*. Two patients (#11 and #12) had clinically observable posterior axillary fold swelling. Eight patients, including the above two, showed truncal swelling by caliper measurement, taking the criterion of a 10% increase over the contralateral side as the definition of posterior axillary fold edema (see above). The average excess thickening in the PAxFs of these 8 subjects was 4.7 mm ± 2.8 (s.d.), or 29%.

b) Creep measurements. The results of the creep measurement were even more striking, however. In the control PAxF the creep distance over 50 s averaged 0.6 mm ± 0.2 (s.d.) whereas on the side of the affected limb the 50 s creep distance was 1.2 mm ± 0.5 (s.d.). The increased creep rate on the affected side was statistically highly significant ($p = 0.0002$, paired t-test).

c) Reproducibility. Five of the twelve subjects were measured on two consecutive days *(Fig. 5)*. The correlation between the results for the same PAxF on the two days was high, with a correlation coefficient of 0.998 ($p = 0.0001$) on the swollen side, and of 0.993 ($p = 0.0007$) on the normal side. For the pooled swollen and normal readings, the regression slope of 1.09 was not significantly different from unity (line of equality), with a correlation coefficient of 0.994 ($p < 0.000001$).

d) Comparison with subjective results. The questionnaire, which encompassed both the patient's and examiner's judgment of axillary fold and related upper trunk edema, was converted into an aggregate numerical

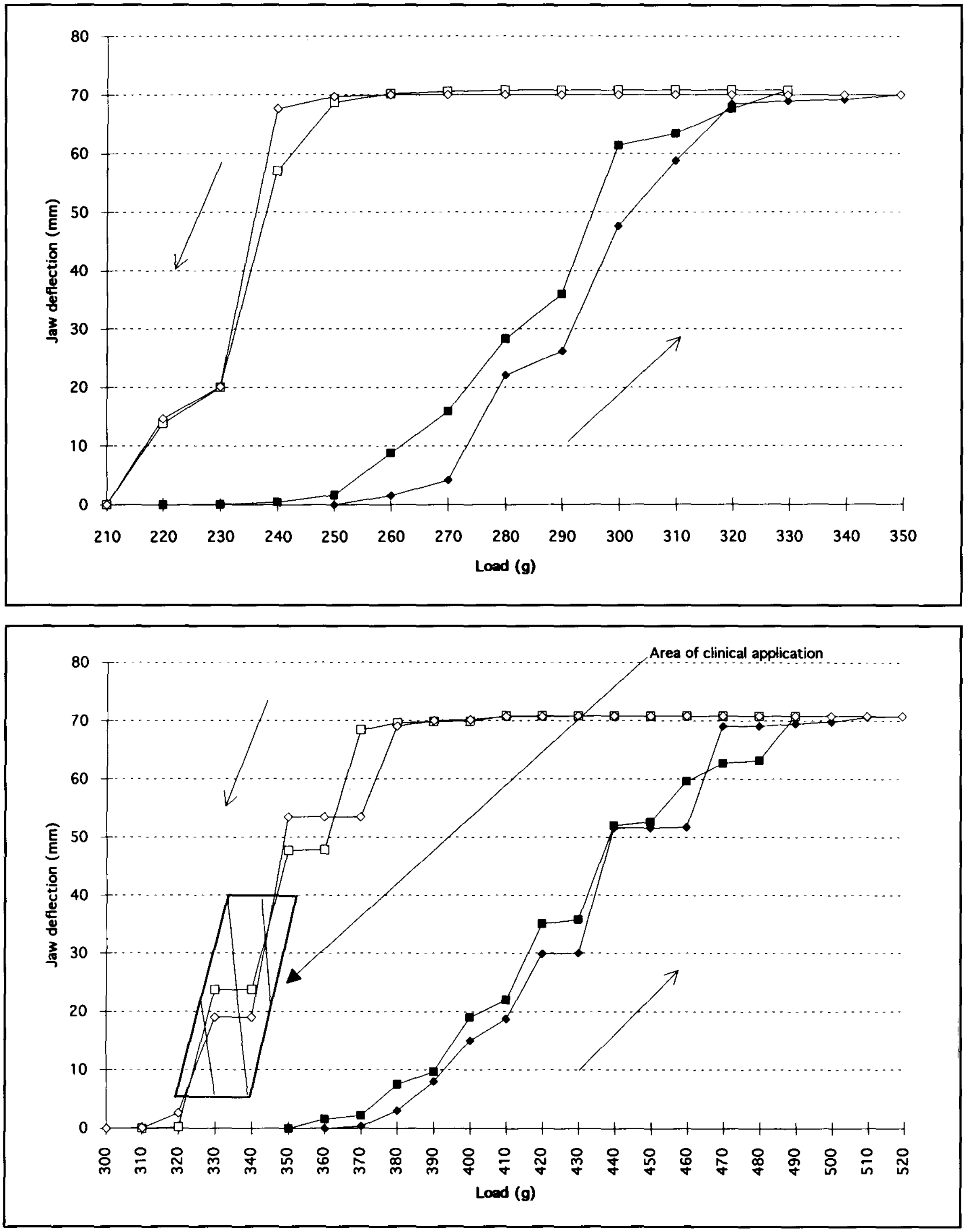

Fig. 3. Hysteresis curves produced by either rapid loading and removal (squares) or slow loading and removal (diamonds) for (a.) LE-029C-6, (b.) LE-031C-6.

TABLE 3
Posterior Axillary Fold Thickness, Creep, and % Increase in Arm Volume

	POSTERIOR AXILLARY FOLD			CREEP OVER 50 s			% ARM
Subject	Edematous side	Control side	Ratio E/C	Edematous side	Control side	Ratio E/C	SWELLING
1	20.2	20.8	0.97	0.9	0.6	1.5	34
2	24.4	24.7	0.99	0.8	0.4	2	21
3	18.9	20	0.95	0.5	0.4	1.25	27
4	25.1	27.2	0.92	1	0.3	3.33	77
5	15.8†	13.8	1.14	0.6	0.2	3	18
6	24.7	22.9	1.08	1	0.8	1.25	4
7	23.3†	19.3	1.21	1.2	1	1.2	3
8	20.4†	16.6	1.23	0.8	0.4	2	26
9	23.6†	21.3	1.11	1.8	0.8	2.25	29
10	27.3†	22.3	1.22	1.6	0.8	2	20
11*	11.2†	6	1.87	2.2	0.4	5.5	49
12*	31.0†	19.9	1.56	2	0.8	2.5	80
13	16.1†	12.1	1.33	1.4	0.6	2.33	3
14	17.5	17.5	1	0.6	0.4	1.5	34
mean	21.4	18.9	1.2	1.2	0.6	2	30
s.d.	5.7	5.5		0.5	0.2		24

*clinically obvious truncal edema
†truncal edema present as defined by >10% excess thickness, i.e. ratio > 1.10
E = edematous, C = control; all values are mm or ratios

score for each patient *(Table 2)*. The ratio of the posterior axillary fold thickness on the affected side (E) to the control side (C) was plotted against the score *(Fig. 6)* and found to correlate significantly ($r = 0.75$, $p = 0.0016$). The aggregate questionnaire score also correlated significantly with the difference in creep between the swollen and normal sides ($r = 0.65$, $p = 0.012$).

The size of the edematous arm did not correlate significantly with either the ratio of the thickness of the posterior axillary folds (E/C; $p = 0.44$) or the ratio of creep (E/C; $p = 0.08$).

DISCUSSION

The results indicate that modified calipers

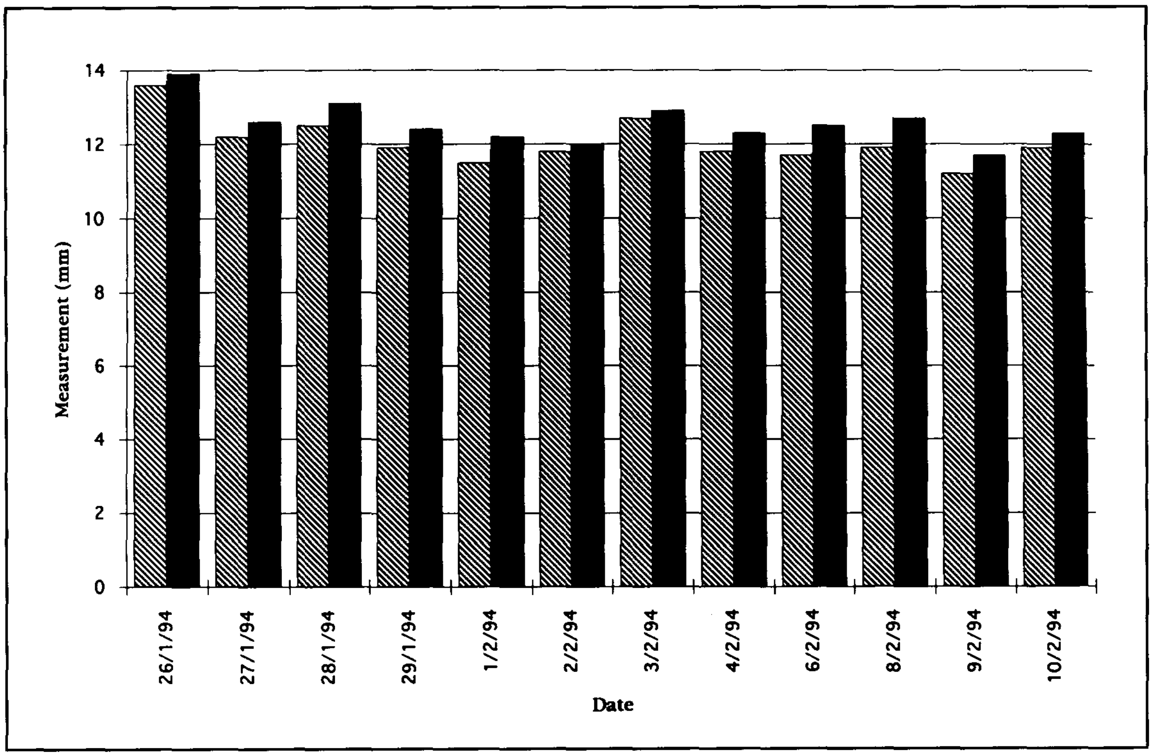

Fig. 4. Variation in measured posterior axillary fold thickness in a normal subject over 15 days. Left PAxF (diagonal lines) 12.1 mm ± 0.6 (s.d.); right PAxF (shaded) 12.6 mm ± 0.6 (s.d.), $p < 0.001$; the subject's right PAxF is significantly thicker than the left.

can detect abnormalities consistent with axillary fold edema. Creep, the decrease in measured thickness under load with time, was attributed to displacement of pressurized interstitial fluid with time, as in the pitting test used by clinicians and in tonometer measurements (4). The results also indicated that creep may be an even more sensitive indicator of edema than differences in thickness between sides, in that all 14 patients showed a greater rate of creep on the affected side than on the control side. A tonometer is less suitable for use here because of a) positioning, b) no hard backing to gauge pitting characteristics, and c) greater time-consumption.

It was not possible to validate these measurements by another, well-accepted standard method, because this is to the best of our knowledge the first objective method for assessing axillary fold edema. It was, however, reassuring to find significant correlations between subjective assessments (the questionnaire score) and the caliper results. The caliper results were also broadly similar to recently published results on the edematous forearm; using an electronic tonometer, Bates et al (3) found that the distance "crept" in a given time by a loaded plunger resting on the skin surface was on average four times greater in postmastectomy lymphedematous arms than in the contralateral control arms.

In the process of altering and assessing the Harpenden skinfold calipers, several areas for future technical improvement were identified. If a reproducible result is to be obtained, it is important that a constant pressure be applied to the skinfold throughout the usable range of the calipers, i.e. load should be independent of jaw gape (distance). Harpenden skinfold calipers are reported by

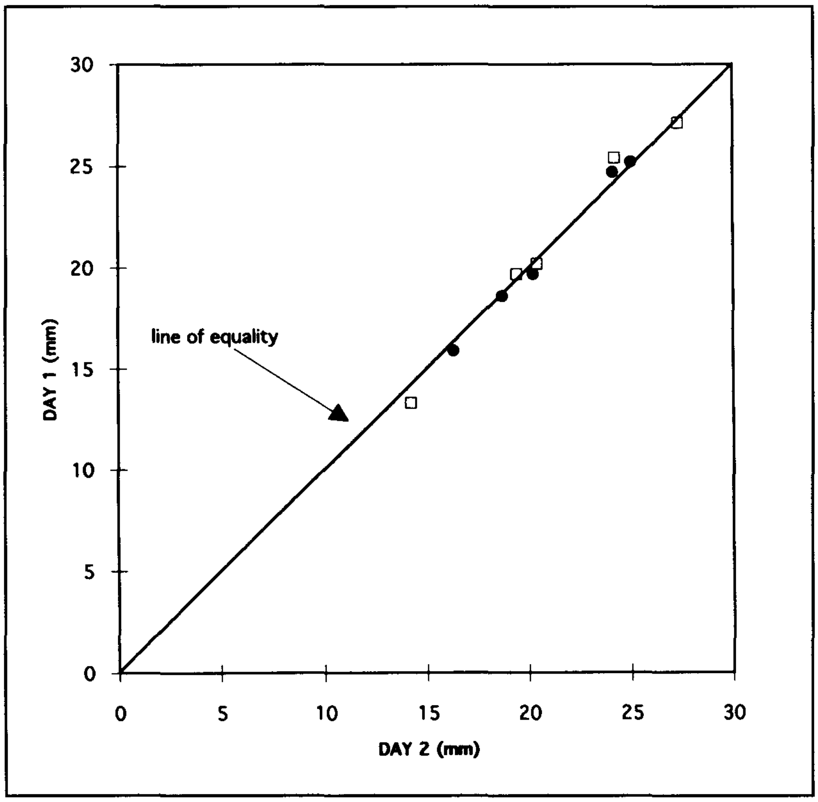

Fig. 5. Reproducibility of measurement in patients. Posterior axillary fold (PAxF) thickness measured in same subjects on two consecutive days. The slope of the regression line through the pooled data was 1.09, and the correlation coefficient was 0.99 ($p < 0.001$). PAxF measurements are represented by filled circles for the edematous side, and squares for the control side.

the manufacturers to apply a constant spring pressure of 10 $g.mm^{-2}$. Hooke's law states that force F exerted by a spring varies linearly with the distance stretched (X), the proportionality factor being the spring constant C; $F = XC$. To overcome the problem of increasing force with increasing length, the caliper designers angled the springs so that the perpendicular distance from the fulcrum decreases as the springs are stretched (6). In practice, however, the operating characteristics of our unmodified calipers were disappointing, with pressure varying by 14% (11.6 $g.mm^{-2}$ - 13.5 $g.mm^{-2}$) over an extension range of 6 - 40 mm. Other studies have reported average caliper pressures of 10.3 and 8.25 $g.mm^{-2}$ for Harpenden skinfold calipers (5,7). Different caliper brands have been shown to have significantly different characteristics (7). A potential improvement on skinfold caliper design would be a caliper that allows a specified load to be "dialed" up, which is then constant and insensitive to rate of application or direction of application of the calipers.

The desirability of the applied pressure being around 10 $g.mm^{-2}$ was suggested on the basis of experiments that compared pressures in the range of 2.3 - 19 $g.mm^{-2}$ for measuring non-edematous skinfolds (8). The latter study showed that repeatablity of skinfold measurements decreased as the applied pressure decreased. Despite these findings, we were compelled to decrease the spring pressure to 3.7 $g.mm^{-2}$ so that the excessive pressure did not express the fluid of interest out of the skinfolds. We still found excellent reproducibility, provided that the standard line-guided placement procedure was used. The latter was found to be vital for good reproducibility.

Another mechanical problem that we

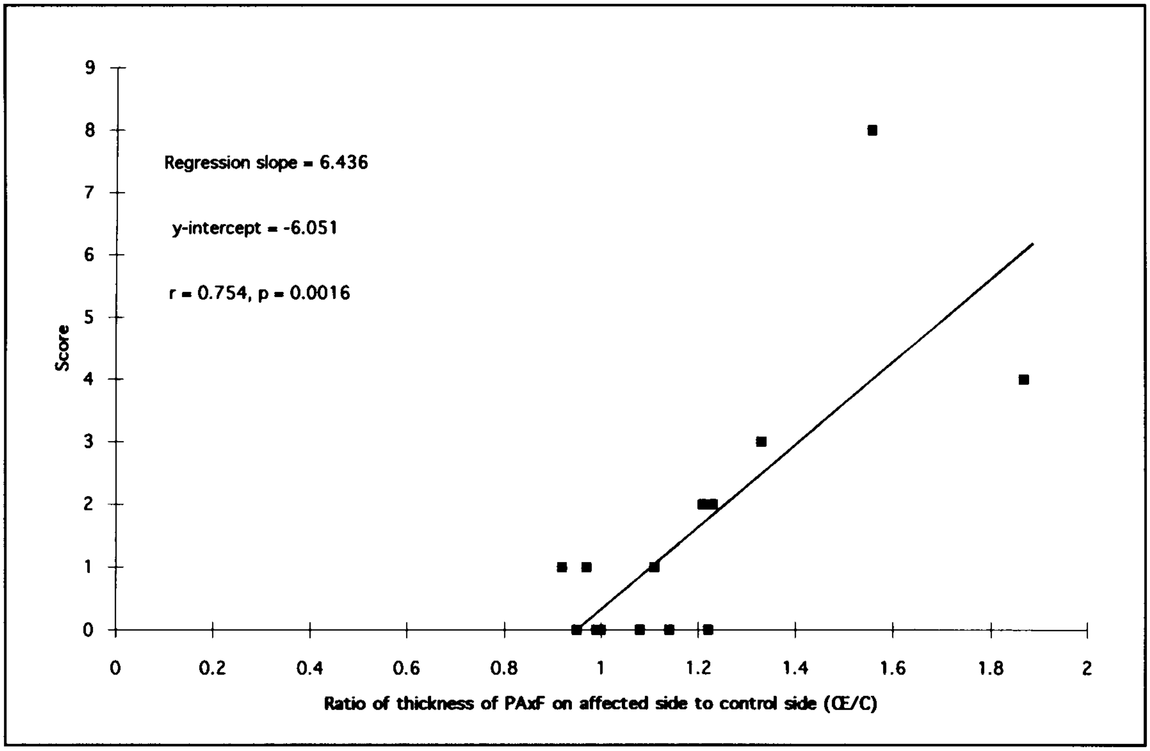

Fig. 6. Relation between subjective assessment of truncal edema (questionnaire score) and objective measurement (PAxF thickness ratio, affected side/control side).

identified related to the substantial friction around the pivot of the calipers. Friction was decreased by lubricating the joint with WD-40 oil, but not eliminated. The effect of friction is apparent in *Figs. 3A and B*: it caused horizontal steps where increases in load did not increase the gape; it caused a large degree of hysteresis; and it caused the extension to depend on rate of application of load. To minimize these problems, the calipers were always applied briskly to the skinfold from a fixed amount of overextension (1 cm).

The technique of identifying and marking the site proved to be very important. Originally, a single ink dot was marked on the skin and a skinfold lifted with the dot at the apex of the skinfold—a procedure widely used by scientists interested in skin fold thickness. The difficulty, however, was that a variable amount of skin and subcutaneous fat could be lifted with each measurement. This problem was solved with the "line" method, where the dot was extended to a horizontal line of fixed length. With the calipers applied to the ends of the line, the same size skinfold could be lifted each time. Because the swollen forearms were too firm to lift a skinfold, the method was only useful in axillary fold measurement.

Objective measurement of truncal swelling is vital if the contribution of such edema to overall control of postmastectomy lymphedema is to be understood. The effectiveness of lymphedema treatment can only be judged if validated instruments for quantification are available. Several methods for arm volume measurement exist but until now there has been no reliable means for measuring truncal swelling. To be useful, the instrument must be relatively quick and easy to use, reliable and reproducible, and portable between clinics. We believe the modified Harpenden calipers fulfill all these requirements.

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