THEORETICAL AND PRACTICAL CONSIDERATIONS IN Z-PLASTY PRACTICE

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Submitted to the University of Glasgow

for the Degree of Ch.M.

March 1971

Theoretical and Practical Considerations
in Z-plasty Practice : Ian A. McGregor

SUMMARY

The Z-plasty is used in 2 main sets of circumstances, in contractures and in facial scars. In these situations it functions for practical purposes in a single plane, or, more accurately, its theoretical basis can be discussed in terms of 2 dimensions. There is, however, a group of miscellaneous uses for the Z-plasty which involve a third dimension, creating a curving Z-plasty.

In all of these circumstances certain modifications of method are necessary to make full use of its virtues. Many of these modifications arose initially in the context of hand surgery, because of the strict limitations imposed by the anatomical factors operating in the hand.

The theoretical background of the Z-plasty and the practical considerations arising therefrom are discussed in relation to these 4 aspects of its use.

When the Z-plasty is used in contractures the lengthening which relieves the contracture is achieved at the expense of shortening in the axis perpendicular to the contracture. The amount of lengthening and the corresponding amount of shortening is shown to result from variation in the size of the Z-plasty angles and the length of the Z-plasty limbs. Formulae are developed to prove this fact and derive quantitative results. The formulae also permit elucidation of the factors which limit angle size and limb length of the Z-plasty as used in practice. A rationale is also provided for the use of the multiple Z-plasty, a modification of standard Z-plasty technique used when tissue available for shortening is strictly limited.

Used in scars, the Z-plasty, by virtue of the fact that the central limb of the completed Z-plasty lies at an angle to its pre-operative line, is able to break the continuous line of the scar. Assuming that it is possible to design the Z-plasty so that its central limb lies post-operatively on or parallel to a wrinkle the Z-plasty will have the effect of converting a long and relatively conspicuous scar into a series of short and less conspicuous scars connected by lines (represented by each Z-plasty central limb) lying in or parallel to the wrinkles. The method developed to enable the central limb to be placed with precision in terms of length, position and direction, initially for the 60^{o} angled Z-plasty and subsequently for the Z-plasty of unspecified angle size, is described.

An attempt has been made to explain, in terms of the phenomena of lengthening and shortening already discussed, the empirical finding that the Z-plasty is effective in treating certain conditions, 4 of which are described as typical examples of the problem, which involve curves, conditions in which its rationale is not readily apparent. The fact is established that in the circumstances attending these conditions lengthening has the effect of deepening a hollow while shortening makes a hollow more shallow, eventually, if the shortening be sufficient, eliminating it completely. It is shown that, reasoning in this way, it is possible to explain the way in which the Z-plasty exerts its effects, still in terms of lengthening and shortening. An explanation is also provided for the modifications of standard design which have been found necessary to make the Z-plasty fully effective in certain of these conditions.

The Z-plasty as used in the hand is discussed with reference particularly to limitations placed on design by the anatomical factors which operate in the hand, the lack of extensibility of the palmar skin and its comparative fixation deeply, coupled with the need to make use of the flexure lines for scar placement. The effect of these restraints on placement, design and execution of the Z-plasty is discussed.

"Dreams apart, numerical precision is the very soul of science, and its attainment affords the best, perhaps the only criterion of the truth of theories and the correctness of experiments."

Sir John Herschel, quoted by
D'Arcy Wentworth Thompson,
On Growth and Form, p.2

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CHAPTER 1

INTRODUCTION AND HISTORICAL BACKGROUND

In its simplest and classic form the Z-plasty is a local plastic procedure in which two interdigitating triangular flaps are designed with the overall form of a Z, each flap subtending an angle of 60°. The flaps are raised and the procedure is completed by transposing them (Fig. 1).

Transposition has several effects and it is the exploitation of these which makes the Z-plasty one of the most useful as well as one of the most widely used procedures in plastic surgery. The first description of its use, in the treatment of ectropion, is generally considered to have been by Denonvilliers in 1856 and since then many authors have described its possible role in other surgical contexts. At first it was regarded as mainly of use in contractures but it has gradually become recognised that this is only a small facet of its potential usefulness.

Many of the geometrical properties of the Z-plasty were worked out by the Leningrad surgeon, A. A. Limberg, and he published his findings, in 1929, in Russian. At that time,

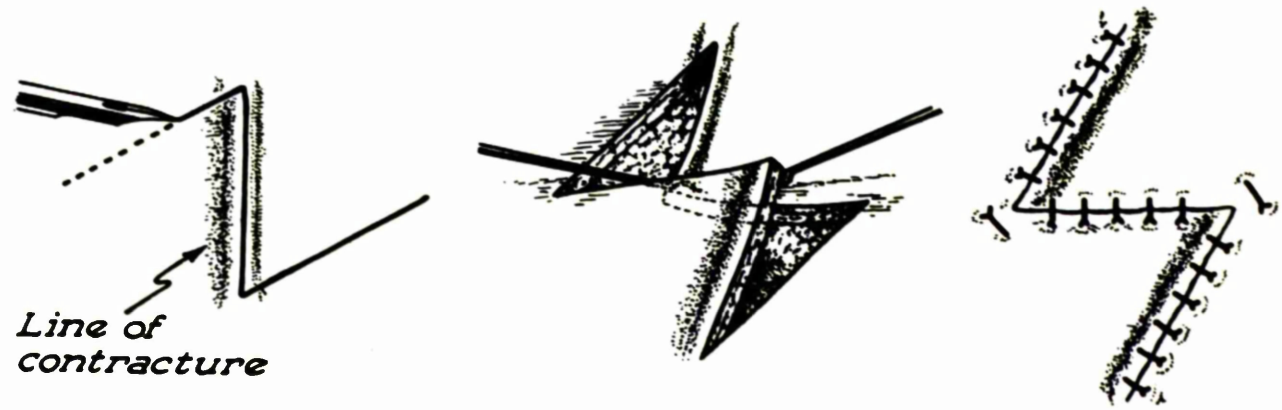

Fig. 1 : The Z-plasty in its simplest form, showing how the triangular flaps are outlined, raised and transposed.

he confined his analysis to a geometrical one. Not altogether surprisingly it was fully 10 years before any reference to his work appeared in the Anglo-American literature though in the interval, Staige Davis, who was also deeply interested in the Z-plasty, had written in 1931 on its empirical use in various situations. However, in 1939, Davis and Kitlowski brought Limberg's work to the notice of the English-speaking world by publishing what was virtually a translation of his geometrical analysis, with the addition of some practical observations of their own. Unfortunately, this early analysis was complicated, difficult to understand and seemed to have little practical relevance. As a result it made little impact on plastic surgical thought.

In the period following 1929, Limberg carried on with his analytical studies, collecting them into a monograph which was published, again in Russian, in 1946. This monograph contained a much more detailed mathematical analysis of the theory of local flaps using the more sophisticated tools of trigonometry. Throughout the analysis Limberg's approach differed from the conventional one in that he tended not to regard the Z-plasty as a technique in its own right. Rather he considered it merely as a special example of the more general plastic surgical manoeuvre in which triangular flaps of various shapes and sizes are moved. Viewed in the context of his analysis, concerned as it was with many types of triangular flap transfers, Limberg's may have been a valid attitude, but the Z-plasty has such widespread applicability in ways which he did not take into consideration that it can claim with good reason to be discussed as a specific technique on its own merits. In any event, his monograph went as unnoticed outside Eastern Europe as his 1929 paper and in the few papers which appeared, mainly in the American literature (Spina, 1950; Dingman, 1955), Limberg's name was mentioned only in relation to his 1929 contribution and that only via the Davis and Kitlowski translation. In Textbooks too (Kazanjian and Converse, 1949; Smith, 1950), an air of empiricism continued to pervade descriptions of the procedure.

In 1957, having read the Davis and Kitlowski translation of Limberg's 1929 paper and realising that elementary trigonometry would provide the answers to certain questions which seemed relevant much more easily and elegantly than the cumbersome geometrical figures of the 1939 Davis and Kitlowski paper, I undertook such an elementary analysis. It was only after the theoretical findings, with a discussion of their relevance in actual Z-plasty practice, had been published (McGregor, 1957) that I received from Limberg a copy of his monograph which included an account of the same theoretical findings.

It is clear nevertheless in comparing the two approaches that, although Limberg's starting point is the same as my own, we have since moved in quite separate directions. He is much more interested in the mathematical pattern for its own sake and less in the application of his findings to the realities of plastic surgery. In 1957 and to an even greater extent since (McGregor, 1960, 1966, 1967) my own concern has been to use the theoretical concepts to elucidate certain empirical findings long accepted in clinical practice and increase the precision with which they can be applied.

It is important in any case not to be carried away as Limberg has tended to be by the niceties of theory or to assume that the accuracy of a mathematical calculation can be translated into clinical terms (Gibson and Kenedi, 1967). The realities of the clinical situation must always be borne in mind. The flaps of the Z-plasty may be scarred and this may affect blood supply, the extensibility of the two flaps may differ, the state of tension on each side of the contracture may differ - any or all of these may exist and have to be taken into account in actual design. Even more significant than these factors, which relate to a specific situation, is the general criticism that the theory can only be strictly applied to non-extensile material and makes no allowance for the elastic properties of skin. These elastic properties are unfortunately extremely complex and in the present state of knowledge their inclusion as a factor to be considered would be quite impossible. We must simply recognise that it is too much to expect such theoretical findings to be quantitatively applicable with absolute accuracy to the clinical situation in all circumstances.

With this reservation these findings are nonetheless sufficiently accurate to be of great use in practice. Possibly their most valuable contribution is in showing the effects of variables in construction of the Z-plasty, and in demonstrating trends as effects alter with change in their causal variable.

CHAPTER 2

THE ROLE OF THE Z-PLASTY

As already stressed, prior to the development of this theoretical background, the value of the Z-plasty in many situations was recognised on an empirical basis. In fact, its worth had been proved in certain well defined circumstances. The two principal ones were :

1. The treatment of contractures.
2. The management of facial scars.

Used in contractures, it was usually as a single Z-plasty. The role of the multiple Z-plasty, which has more recently replaced it in many situations, was unknown and, if it was used occasionally, there was no appreciation of its peculiar advantages over the single Z-plasty and only the vaguest recognition of factors limiting usage of both types.

In the management of facial scars, it was recognised that there was cosmetic advantage to be gained by breaking the scar line with a Z-plasty but there was little awareness of how the Z-plasty might be fitted into the face. And even where awareness of the need to place the Z-plasty existed, there was no understanding of how it could be made to fit in the precise terms of size, site and direction.

The basis for converting this empirical, hit or miss, procedure into a rational technique with a theoretical basis broad enough to explain variations in practice has been described in three publications (McGregor, 1957, 1960, 1966). Taken together, these provide an account, though not a strictly chronological one, of the stages of elucidation of the theory.

The Z-plasty used in contractures and scars functions for practical purposes in a single plane or, to be more precise, it is possible to explain its behaviour adequately by discussing it purely in terms of two dimensions.

It has been found, however, that a further group of miscellaneous uses for the Z-plasty exists in which the complication of a third dimension has been added, creating a curving Z-plasty. This miscellaneous group consists of such diverse problems as notching of the lip occurring as a residual deformity after the treatment of cleft lip, bridle scars, congenital ring constrictions of the limbs, webbing of the fingers, and others. Here too (McGregor, 1966) it has proved possible to provide a background of theory to explain behaviour in practice and rationalise seeming vagaries.

An unfortunate consequence of the fact that these theoretical considerations have been published in several papers is that each paper has tended to deal with a particular aspect of the problem and the picture presented has been a fragmented one in which the overall pattern has been obscured by the need to concentrate on one particular viewpoint. The breaking up of the Z-plasty into its various roles in this way has also created an impression of separate methods rather than a single method with modifications.

This thesis incorporates the work recorded in these papers which, as already stressed, provides the theory underlying much current Z-plasty practice but presents it within the broad framework of a single method with several effects, each of which is exploited in turn to produce a specific result. Much of the detail concerns modifications of technique found necessary in specific surgical contexts. An example of such a context is in the hand and indeed many modifications designed originally for use in hand surgery (McGregor, 1967) were subsequently used elsewhere. For this reason it is proposed also to discuss the Z-plasty in the hand specifically since it is in the hand that the local anatomical factors impose particularly strict limitations and the reasons for the modifications developed can be seen the more readily.

The Basic Technique

The classic Z-plasty has two interdigitating triangular flaps with the overall form of a Z, the three limbs of the Z being equal in length and each flap subtending an angle of 60^{o}.. The flaps are raised and the procedure is completed by transposing them (Fig. 2). It will be apparent that the limbs of the flaps must be equal in length because they have to fit together in their transposed positions. Transposition of the flaps has two effects which concern us :

1. A process of lengthening CD → C'D' and shortening AB → A'B' takes place.
2. The post-operative common limb A'B' of the Z lies at an angle - in this case a right angle - to the pre-operative common limb CD.

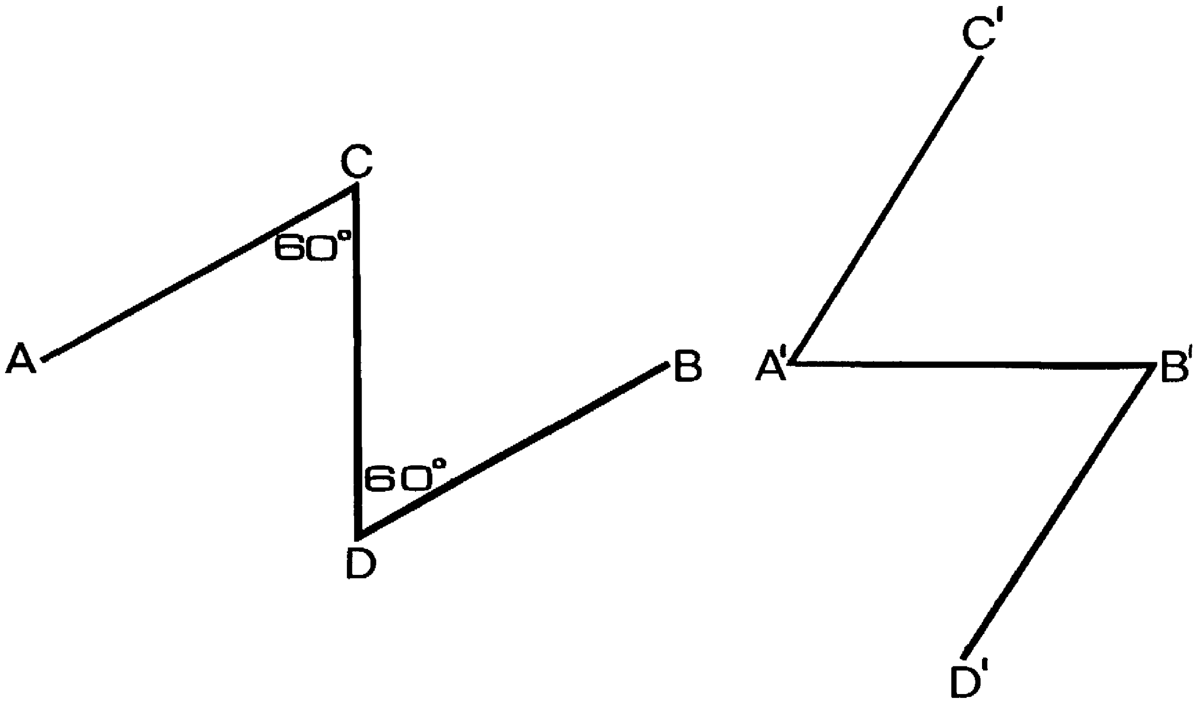

Fig. 2 : The effects of transposing the Z-plasty flaps.

(a) The common limb CD becomes changed in direction to A'B'.

(b) CD becomes lengthened to C'D'.

(c) AB becomes shortened to A'B'.

In plastic surgery, the Z-plasty exploits one or other, occasionally both, of these effects.

If we exclude for the moment the miscellaneous groups of conditions using the curving Z-plasty already referred to, an analysis of the ways in which we use the Z-plasty shows very clearly that we can separate them into two main categories :

(a) Where we wish to correct a contracted scar or prevent its development by making use of the phenomenon of lengthening (Fig. 2).

(b) Where a facial scar is present which in revision would be improved if its line, or even part of its line, could be altered in direction as the common limb was altered in Fig. 2.

The correction of a contracted scar may coincidentally alter the line of the scar to its cosmetic betterment. Similarly, the breaking of a scar line by a Z-plasty does at the same time produce lengthening and shortening. Nevertheless, it is usually only one of the two aspects which concerns us at any particular time. The simultaneous and inescapable accomplishment of the other is at best a bonus, at worst a nuisance.

It will be convenient at least initially to separate the two uses completely.

CHAPTER 3

THE Z-PLASTY IN CONTRACTURES

"We are apt to think of mathematical definitions as too strict and rigid for common use, but their rigour is combined with all but endless freedom."

D'Arcy Wentworth Thompson,
On Growth and Form, p. 269.

When the Z-plasty is used in a contracture, the common limb, i.e. the central limb of the Z, lies along the line of the contracture to be released. Although the angle size can be varied, and the effect of such variation will be fully discussed, it is convenient for the present to continue using 60° as the angle size. With such a construction, the triangles together form a parallelogram with two axes, the pre-operatively shorter one - the Longitudinal or Contractural Axis, the longer one pre-operatively - the Transverse Axis (Fig. 3).

To complete the manoeuvre (Fig. 4), the triangular flaps are elevated and at the same time the fibrous contracture is divided. To make the steps easier to understand, the elevation of the flaps and the division of the contracture have been artificially separated into two distinct steps (Fig. 4, C and D) in the procedure as shown schematically in Fig. 4. Division causes the contracture to spring apart and the parallelogram changes shape (Fig. 4, C and D). With this change in shape, the Contractural Axis lengthens and the

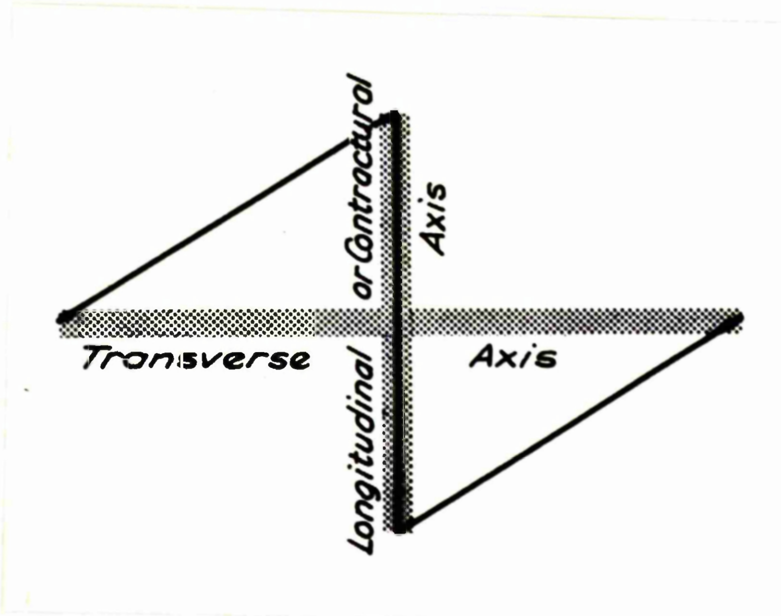

Fig. 3 : The axes of the Z-plasty.

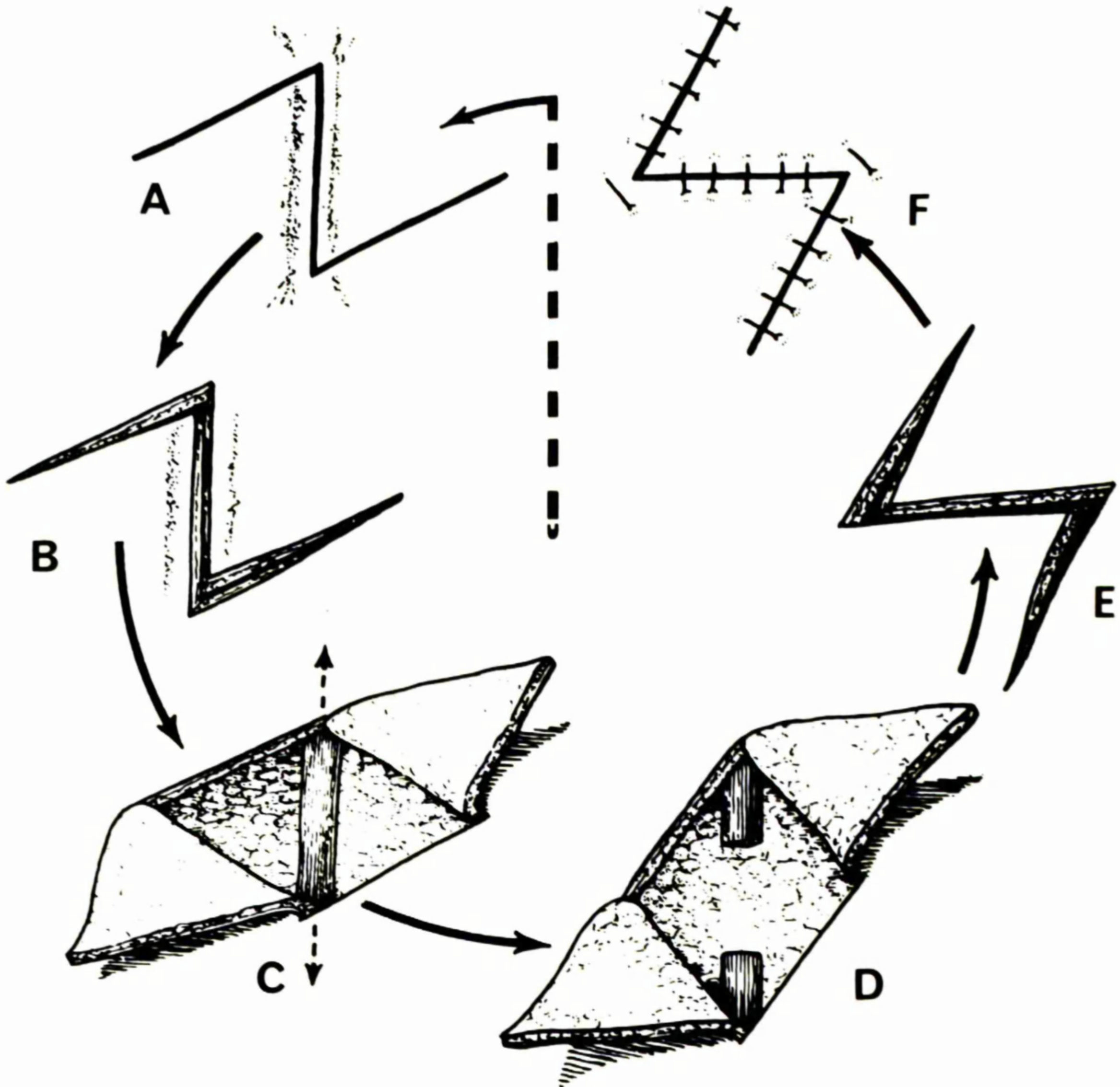

Fig. 4 : The stages in the completion of a Z-plasty shown schematically. The crucial change in parallelogram shape takes place between Step C and Step D when the contracture is divided.

Transverse Axis shortens correspondingly. At the same time, the triangular flaps are automatically transposed.

When the completed Z-plasty diagram is compared with the pre-operative diagram (Fig. 4, A and F, and Fig. 5), it will be apparent that certain changes in length have occurred. The pre-operative contractural axis equals the post-operative transverse axis in length and the pre-operative transverse axis equals the post-operative contractural axis.

Translating this into practical terms we can say that lengthening of the contractural axis has taken place at the expense of the transverse axis which has shortened by the same amount as the contractural axis has lengthened.

In practice, this lengthening of the contractural axis is the change desired and lengthening is consequently the aspect of the procedure which has received most attention in the plastic surgical literature. It must nevertheless be understood that at all times and in all circumstances lengthening in one axis is accompanied by a corresponding simultaneous shortening in the other axis. As a most important corollary it is also true that, without the

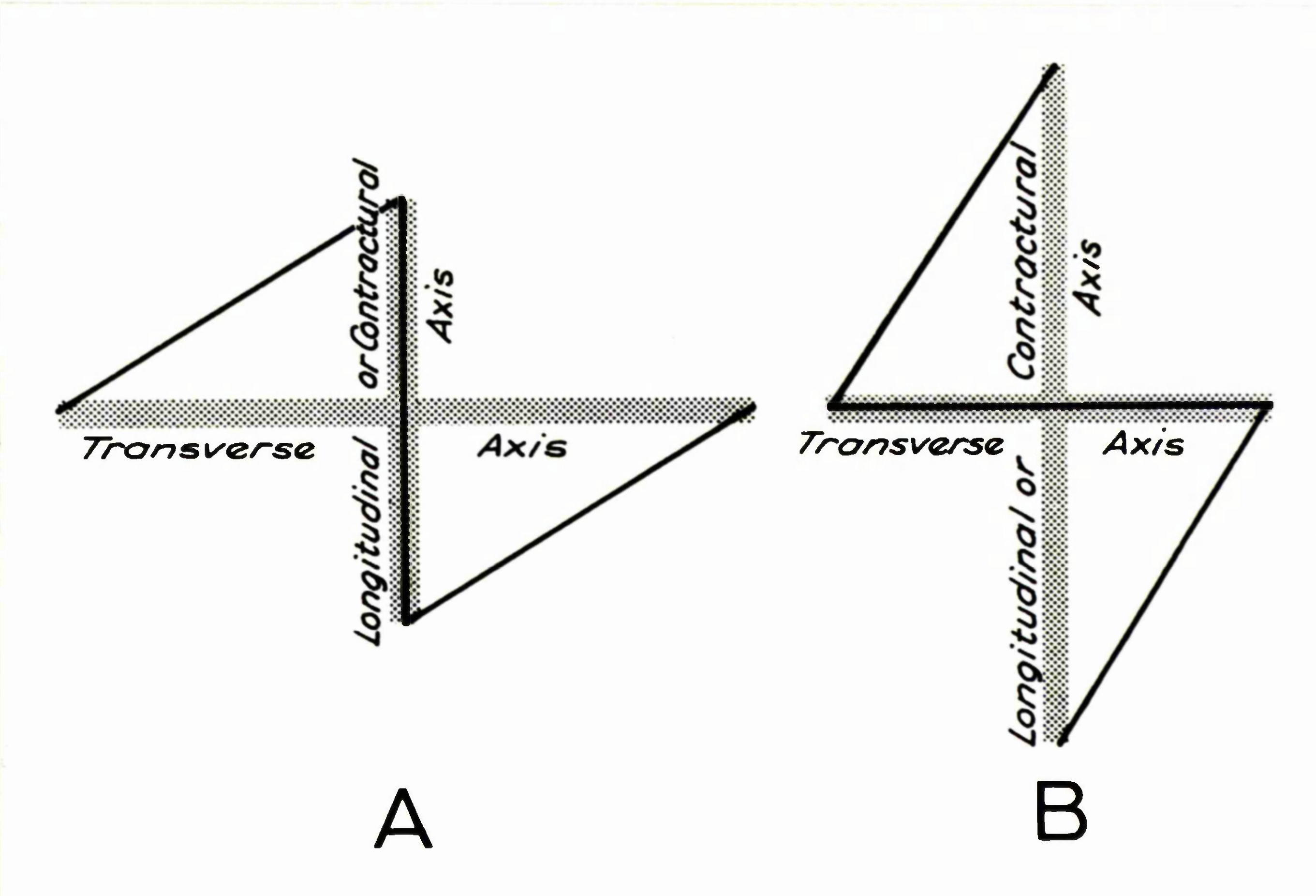

Fig. 5 : The axes of the Z-plasty, (A) before and (B) after transposition, showing how transposition lengthens the Contractural or Longitudinal Axis and at the same time shortens the Transverse Axis.

shortening, lengthening cannot take place.

THE VARIABLES IN Z-PLASTY CONSTRUCTION

When a Z-plasty is constructed, there are certain variables which can affect the result. The two main ones in practice are :

1. The size of the Z-plasty angle.
2. The length of the Z-plasty limb.

As already stressed, the limbs must be of equal length since they must fit in their transposed position but no such limitation applies to the angles. They are usually constructed so that they are equal but they can just as readily be unequal. In fact, the Z-plasty with equal angles is really only a special case, albeit the most often employed, of the general Z-plasty where angle size is unspecified.

The Z-plasty Angles as Variables

To assess the effect of varying the angles of the Z-plasty on lengthening and shortening of the axes, the problem can be translated into one of finding a formula which expresses lengthening and shortening in terms of the Z-plasty angles.

In the first instance a formula applicable to the general Z-plasty, with angle sizes unspecified, can be developed and subsequently applied to the special case of the Z-plasty with equal angles.

With two independent variables, in this instance limb length and angle sizes, it is necessary to eliminate one to find the effect of the other acting alone. Limb length as a variable can be eliminated so that angle sizes may be considered alone by estimating not actual increase in length but the ratio of post-operative to pre-operative length. Such a ratio can readily be expressed for convenience as a percentage of the original length. Percentage increase in length has generally been felt to depend on angle sizes.

Stating the problem in more precise terms, if it can be shown that the ratio -

$$\frac{\text{length after flap transposition}}{\text{length before flap transposition}}$$

is a mathematical function of the angle sizes, then these variables alone are responsible for percentage lengthening.

To prove this, it is necessary first of all to show that the ratio of the axes of a Z-plasty represents the change in length which takes place when the flaps are transposed. This is demonstrated in Fig. 6 which shows the Z-plasty drawn out before and after flap transposition, with angles a and b; M = the length of the Z-plasty limbs; and the limbs before transposition = BOAD, after transposition = GFHE.

With triangles OAD and GFH congruent because

$$\text{Angle OAD} = a = \text{angle GFH}$$

and $\quad OA = AD = FG = FH = M$, it follows that

$$OD = GH.$$

At the same time, angle AOD = angle FHG = $\dfrac{180^\circ - a}{2}$

and thus $\quad$ angle BOD = angle GHE = $b + \dfrac{180^\circ - a}{2}$

Considering triangles BOD and GHE,

$$OD = GH$$

$$BO = EH = M$$

and $\quad$ angle BOD = angle GHE = $b + \dfrac{180^\circ - a}{2}$

But for the fact that triangles BOD and GHE are mirror images, they would be congruent and consequently EG = BD.

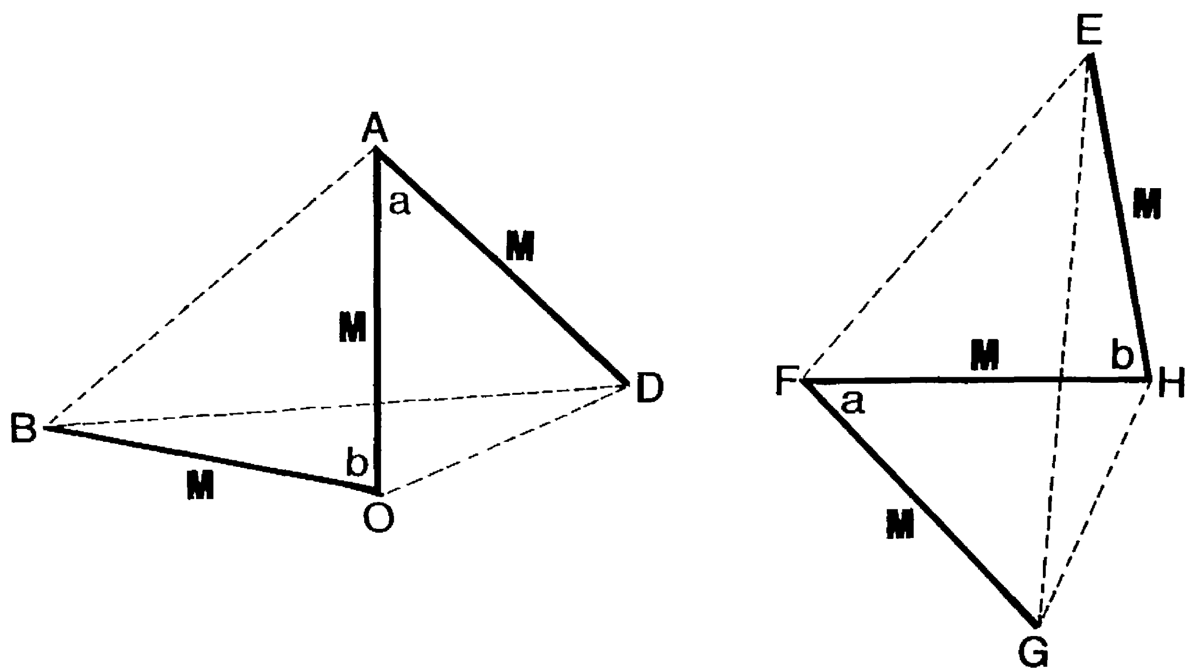

Fig. 6 : The Z-plasty, lettered to correspond with Figs. 7, 8 and 10, drawn before and after flap transposition, showing that the contractural axis (AO) before equals the transverse axis (FH) after, and the transverse axis (BD) before equals the contractural axis (EG) after, and that since EG/OA equals the lengthening which has occurred, BD/OA also equals the lengthening which has occurred.

This equality can be more formally proved by reflecting figure GFEH in the bisector of the angle GFH. This produces figure GIFEH (Fig. 7).

Then, by congruency, BD = IH

and by symmetry, IH = GE

Thus BD = GE.

The lengthening of the Z-plasty which has taken place is represented by $\frac{EG}{OA}$, but EG = BD and the lengthening is consequently represented by $\frac{BD}{OA}$ which is the ratio of the axes of the Z.

With M as the limb length OA, it remains to establish the length BD and hence the ratio $\frac{BD}{OA}$. This can be done using co-ordinates.

The Z-plasty, lettered BOAD, is laid out on XOX' and YOY' axes as in Fig. 8 with OA the central limb length (M) representing the length before transposition, and BD for the reasons already discussed above, the length after transposition. The other Z-plasty limbs are OB and AD, the angles a and b.

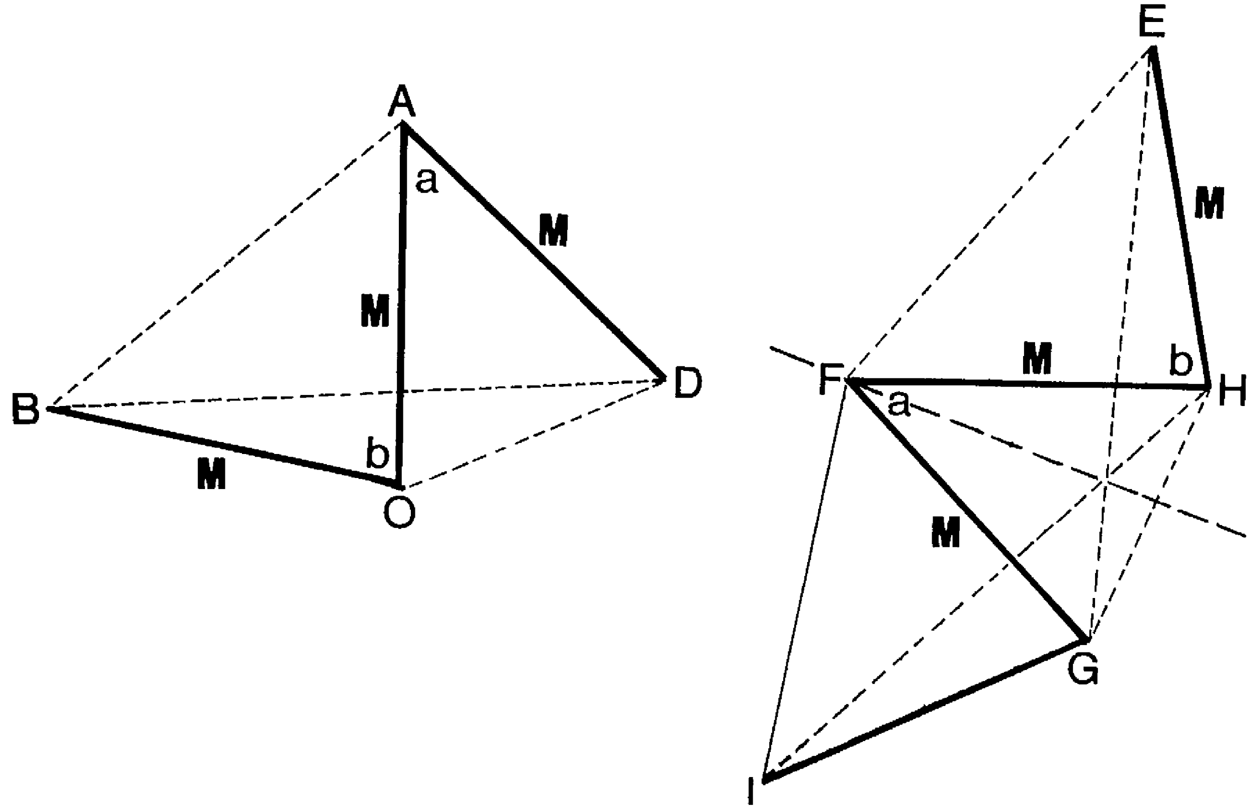

Fig. 7 : Fig. 6, amended to demonstrate the formal proof that EG = BD.

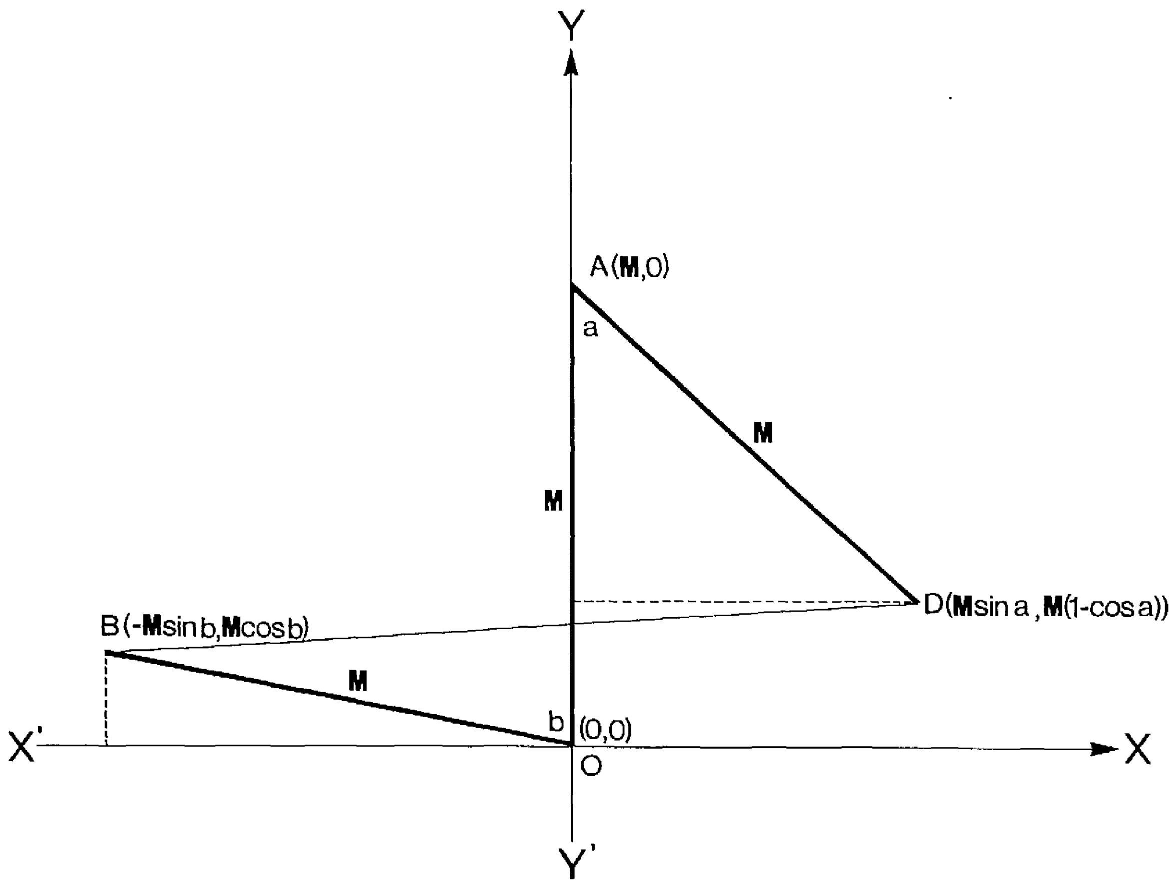

Fig. 8 : The Z-plasty BOAD, lettered as in Figs. 6, 7 and 10, and placed in axes XOX', YOY' to derive the length BD.

The co-ordinates of point B are $(-M\sin b, M\cos b)$ and of point D are $(M\sin a, M(1 - \cos a))$.

The distance formula states :

Distance of point (p, q) from point $(r, s) = ((p-r)^2 + (q-s)^2)^{\frac{1}{2}}$.

Applying this to the length BD,

$$BD = ((-M\sin b - M\sin a)^2 + (M\cos b - M(1 - \cos a)^2)^{\frac{1}{2}}$$

$$= M((\sin a + \sin b)^2 + (\cos a + \cos b - 1)^2)^{\frac{1}{2}}$$

Since

$$M = OA$$

the ratio $\frac{BD}{OA} = ((\sin a + \sin b)^2 + (\cos a + \cos b - 1)^2)^{\frac{1}{2}}$.

This formula thus gives the ratio of Z-plasty lengths before and after transposition, and the ratio is a function of a and b, the Z-plasty angles. From this fact it follows that percentage lengthening depends solely on the sizes of the Z-plasty angles.

It is not common in practice to use a Z-plasty with dissimilar angles. Unequal angles tend to be used only when a line of scarring already present restricts the choice of one angle and even when such a limitation exists the angle sizes tend to vary within certain well-defined limits. The lower limit is determined by blood supply, for the smaller the angle the narrower the flap, and reducing the width of a flap reduces the blood supply particularly to its tip. In the face where the skin is particularly vascular the angle can often be safely reduced to 30° but elsewhere in the body such reduction would be extremely hazardous. The upper limit is less easy to define but in practice would be less than 90°. In fact, if flaps with angles of 30° and 90° were used, one would think of the procedure not as a Z-plasty at all but more as a straight transposition of the narrow flap (Fig. 9), i.e. as an example of a shifting triangular flap. This is so because the large angled flap moves so little in comparison with the small angled flap and the greater the disparity between the angles the more is this apparent.

Limberg (1946), as already pointed out, regards the Z-plasty as a particular example of shifting triangular flaps in which the angles are equal or almost equal to one another. This may be so in theory but nevertheless it is the particular example which has the widest range of usefulness and is by far the most commonly used. Certainly in the minds of most surgeons the two procedures are quite distinct. It would be

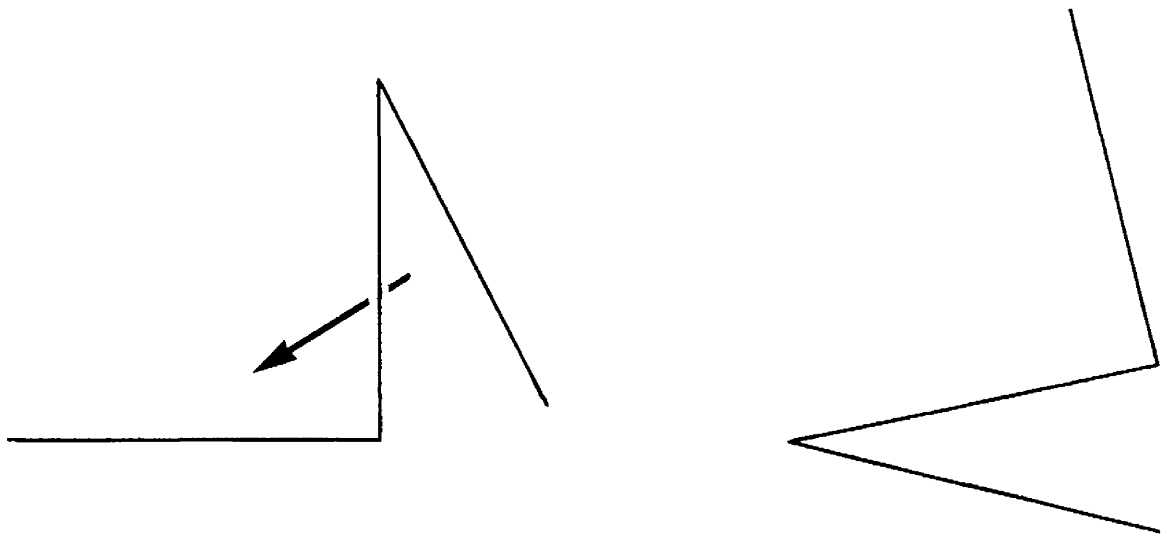

Fig. 9 : The Z-plasty with grossly dissimilar angles (30^{o}, 90^{o}), showing how the small amount of movement of the large angle flap and the large amount of the small angle flap create the appearance of transposition of the small angle flap rather than of a Z-plasty.

worth pursuing the concept of unity between the two if the exercise increased insight into either but in fact it does not. In practice then, if one is thinking of the procedure as a Z-plasty and not as shifting triangular flaps, any difference in angle size is seldom more than 45°, usually considerably less, and both tend to be in the range between 30° - 75°.

The Z-plasty with Similar Angles. A formula applicable to the Z-plasty with similar angles can be derived from the formula reached to describe lengthening in the Z-plasty with dissimilar angles. If the angles are equal and we call the angle Θ, then $\Theta = a = b$ (as in Fig. 10), AO is the length before flap transposition and BD is the length after flap transposition.

The formula for lengthening with dissimilar angles, $((\sin a + \sin b)^2 + (\cos a + \cos b - 1)^2)^{\frac{1}{2}}$, becomes

$$\begin{aligned}
\frac{BD}{AO} &= ((\sin\Theta + \sin\Theta)^2 + (\cos\Theta + \cos\Theta - 1)^2)^{\frac{1}{2}} \\
&= ((2\sin\Theta)^2 + (2\cos\Theta - 1)^2)^{\frac{1}{2}} \\
&= (4\sin^2\Theta + 4\cos^2\Theta - 4\cos\Theta + 1)^{\frac{1}{2}} \\
&= (4(\sin^2\Theta + \cos^2\Theta) - 4\cos\Theta + 1)^{\frac{1}{2}} \\
&= (5 - 4\cos\Theta)^{\frac{1}{2}}, \text{ since } \sin^2\Theta + \cos^2\Theta = 1.
\end{aligned}$$

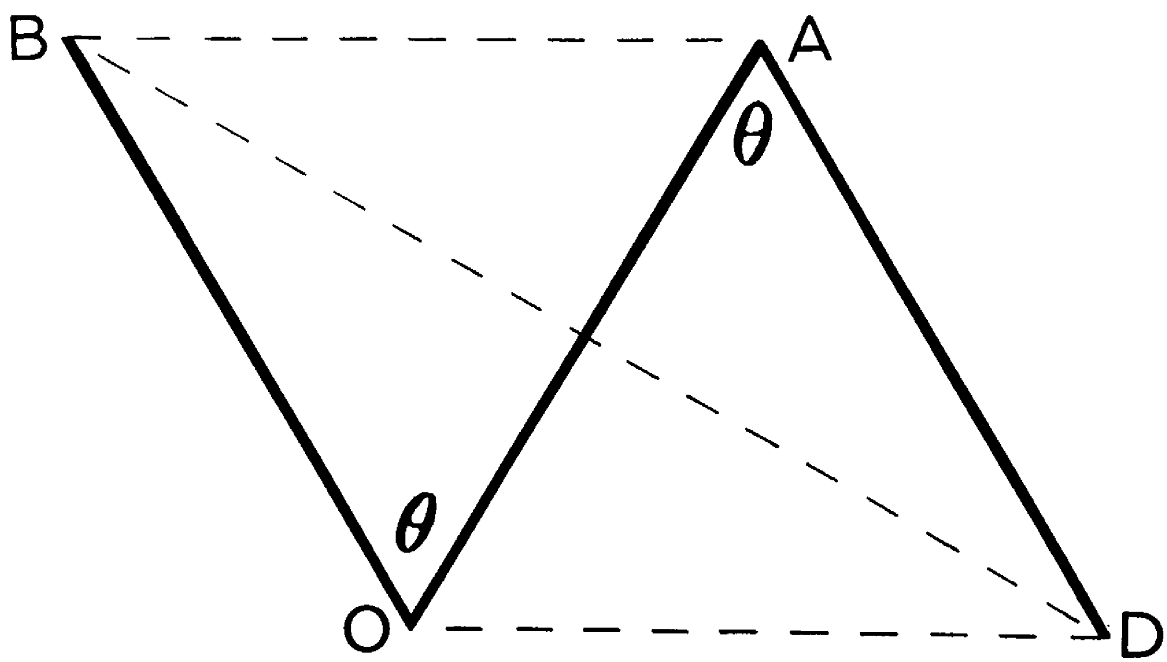

Fig. 10 : The Z-plasty BOAD, lettered as in Figs. 6, 7 and 8, with similar angles (Θ) used in establishing the formula for percentage lengthening.

From this formula it becomes possible to graph (Fig. 11) percentage increase in length against Z-plasty angle. Allowing for conversion into practical terms, the graph is found to be almost linear over the practical range of values, namely $30^{\circ} - 90^{\circ}$, and to an adequate degree of accuracy the percentage increase with angles 30°, 45° and 60° may be taken as 25%, 50% and 75% respectively (Table 1).

It would be possible to work out a corresponding table to give readings of percentage lengthening for the various combinations of angles, but the effort is not worthwhile for several reasons :

1. The Z-plasty with unequal angles is seldom used and where it is used in contractures it is not necessary to calculate actual lengthening.
2. To an adequate degree of accuracy the actual lengthening to be achieved can be demonstrated by drawing out the full Z-plasty and measuring the appropriate axis.

An estimate of percentage lengthening can in fact be made by taking the lengthening expected from equal angled

Angle Size in Degrees	Increase in Length.	Angle Size in Degrees	Increase in Length.
	Per cent.		Per cent.
...	...	...	...
10	3	100	139
20	11	110	152
30	24	120	164
40	39	130	175
50	56	140	184
60	73	150	191
70	91	160	196
80	108	170	199
90	124	180	200

Table 1 : Increase in length with increase in angle size, calculated from the formula $(5 - 4\cos\Theta)^{\frac{1}{2}}$.

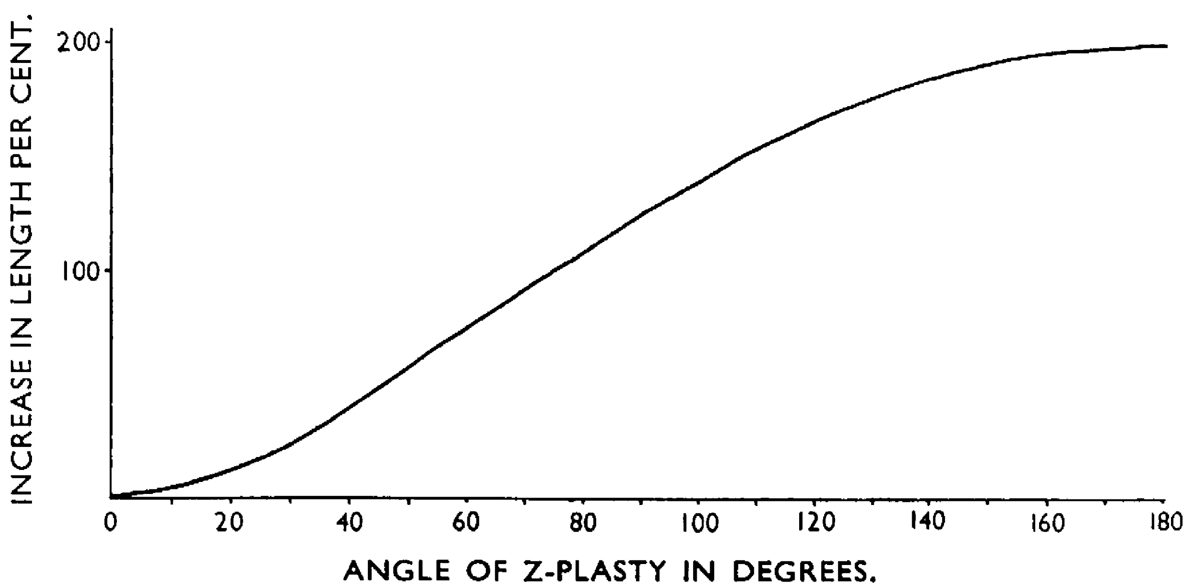

Fig. 11 : Graph of percentage increase of length against angle size constructed from Table 1.

Z-plasties of the two angle sizes and taking the average of the two lengthenings. It is true that this is not completely accurate, as can readily be demonstrated by working out an example, but given the fact already stated that the angles vary in the range $30^{\circ} - 75^{\circ}$, the approximation is accurate enough in practice.

Limb Length as a Variable

In contrast to angle size which controls percentage gain in length, actual gain is determined by the length of the limb of the Z-plasty since for any angle size the increase in length is a percentage of the original length. Increase in limb length by a given factor thus increases the final length by the same factor.

Limiting Factors in Variation of Angle Size and Limb Length

Both angle size and limb length can vary in magnitude. Although the effects of variation in both directions, and the limiting factors thus introduced will be discussed, the important limitations in practice arise as a result of increase rather than decrease in magnitude. That this should be so follows from the fact, as already stated, that lengthening of the contractural axis takes plac at the expense of the transverse axis. Real increase in length, whether due to angle size or limb length, is accompanied by a similar decrease in transverse length.

Angle Size. It has been found empirically that 60° is the most useful angle size and, using this as a mean, the consequence of variation upwards and downwards can be discussed.

1. Angles decreasing from 60° produce less lengthening. With increase in length as the desired effect when the procedure is used in contractures, reduction of angle size to any marked extent would render the whole procedure pointless. Reducing the angle, as has already been stressed, also narrows the flap to the detriment of its blood supply. On both counts therefore, significant reduction would appear to be undesirable.

2. Angles increasing from 60° produce more lengthening. They also produce more shortening in the transverse axis and

it is this latter effect which is the limiting factor. In practical terms it means that, unless loose tissue is available in the transverse line, the flaps cannot be transposed because the transverse tension becomes too great. Although under certain circumstances, as for example in the eyelids, such tissue may be available in the transverse axis such availability is far from widespread in the body and a 60° angle is about the maximum which is tolerable. Furthermore, even were such tissue available, the amount of tissue turning required would call for a degree of elasticity not widely present on the body surface.

For these reasons 60° is the compromise used and minor variation in angle size tends to be downwards rather than upwards.

<u>Limb Length</u>. The arguments used in discussing limiting factors in angle sizes apply equally to limb length. Increase in limb length increases the amount of lengthening achieved until a situation is reached where the degree of corresponding transverse shortening called for creates an intolerable tension in the transverse axis. Transverse tension thus becomes the limiting factor.

In practice it is usual to fix the angle at 60^{o} and to vary the limb length to achieve the maximum degree of lengthening which the clinical situation will tolerate. Why this should be so is not completely clear though it is of interest to speculate on possible reasons since "it is always wise to respect the empirical findings of practical surgeons" (Kenedi, 1965).

Increase in limb length, as already shown, causes increase in lengthening by a straight factor and this can readily be visualised by the surgeon. Even a small increase in angle size has a much greater effect on lengthening and hence on transverse shortening than an apparently comparable increase in limb length. The graph of lengthening in relation to angle size (Fig. 11) is virtually linear over the relevant range, namely 40^{o} - 90^{o}. In this range, if we calculate from the figures in Table 1, the increase is almost constant, as one would expect from the linear graph, but it is a considerable increase, 16% - 18% for each 10^{o}. This means that lengthening and shortening are increasing quite rapidly as the angle increases, so that even a small and not very obvious increase in angle size has a noticeable effect on transverse tension.

It follows that limb length is a much finer adjustment in controlling the effect of the Z-plasty, and this provides a possible explanation of why limb length rather than angle size is used in practice as the limiting factor in adjusting lengthening and shortening.

THE MULTIPLE Z-PLASTY

In most discussions of the Z-plasty, it is the lengthening which is discussed; the shortening which makes it possible receives scant mention. One can recognise even now the remnants of empiricism in comments still made on limitations of use such as "the Z-plasty does not do well in broad scars" or "large Z-plasties cannot be used in the limbs." Both of these statements, true as they are, result from the fact that the Z-plasty is only possible if slack is available in the transverse axis, to be taken up by the transverse shortening which takes place. From the second of these statements, however, grew the idea of using more than one small Z-plasty in the limbs, though the underlying rationale was not recognised. A Z-plasty which is on the borderline as regards lateral tension has an added problem arising from the fact that the tension is concentrated in a single line, the post-operative transverse axis, and this can prove disastrous to its blood supply.

The modification required is one which will achieve the desired lengthening and at the same time reduce transverse shortening to an absolute minimum, in addition eliminating, if possible, the single transverse tension line.

The solution lies in dividing the contracture into segments and using a Z-plasty in each segment. In Fig. 12 a comparison is made between a single large 60° angled Z-plasty and a strictly comparable series of small Z-plasties. A single Z-plasty which will achieve 2 cm. of lengthening at the expense of 2 cm. of transverse shortening is compared with four small Z-plasties each with limb length a quarter of the limb length of the single large Z-plasty. Each of the small Z-plasties lengthens 0.5 cm. and shortens 0.5 cm.

When the overall change is considered, however, the lengthening is found to be <u>in series</u> and is consequently

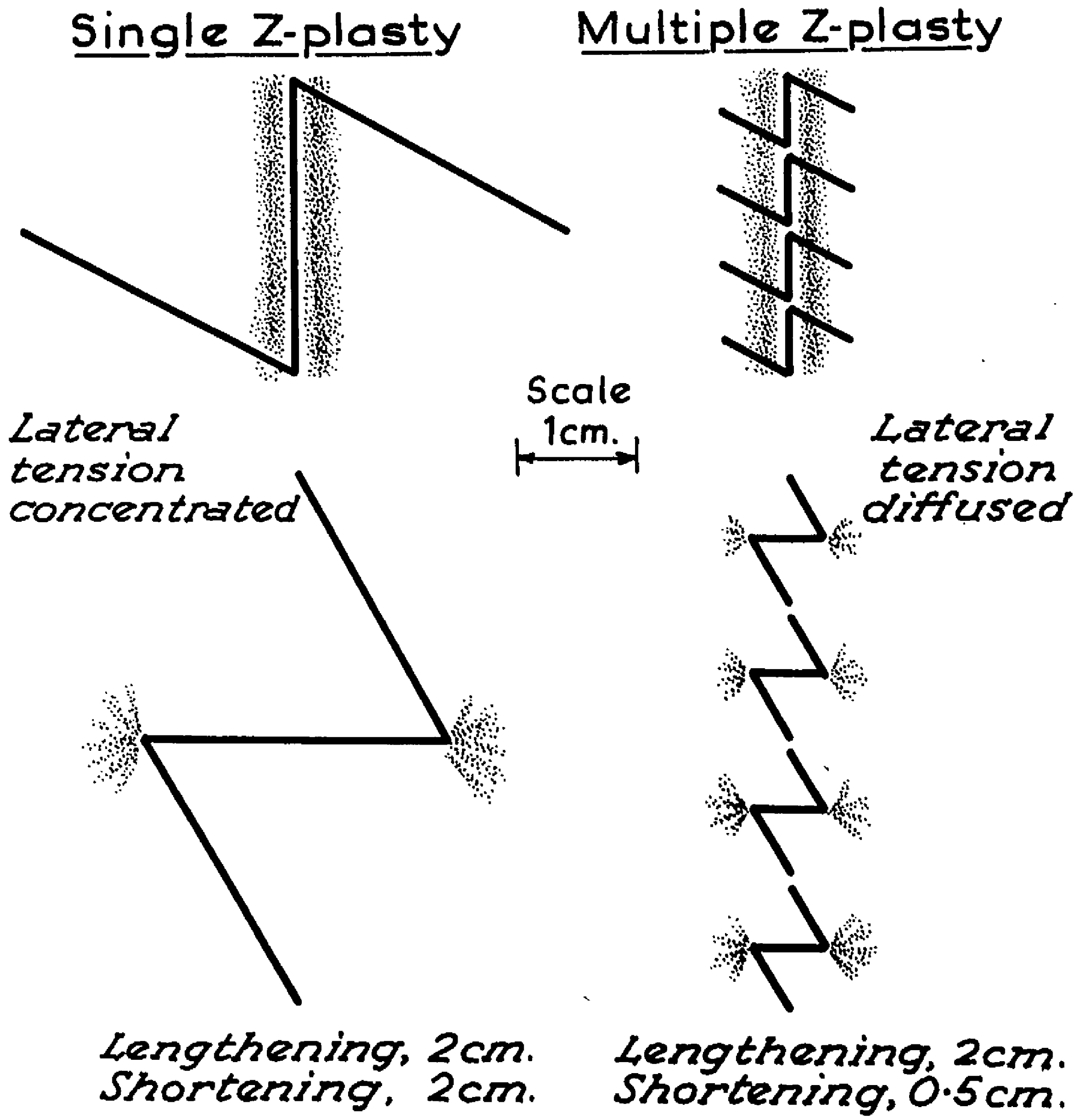

Fig. 12 : The single and multiple Z-plasty of similar total lengths of contractural axis, compared from the point of view of lengthening and shortening. In both, the amount of lengthening is similar, but in the multiple Z-plasty shortening is reduced by a factor equal to the number of Z-plasties, in the illustration, four. The alteration in lateral tension is also seen.

additive so that it achieves a total lengthening equal to that of the single large Z-plasty. Shortening on the other hand at each transverse axis is in parallel and is consequently not additive.

The total desired increase of 2 cm. is thus still achieved but instead of an impossible 2 cm. of shortening concentrated at one transverse axis we have an entirely possible 0.5 cm. of shortening repeated at the transverse axis of each of the small Z-plasties. The multiple small Z-plasty has the added effect of reducing the overall amount of tissue displacement. The Z-plasty modified in this way also reduces the vascular hazard due to concentration of tension along one line. The vascular hazard is further lessened by the reduction in the size of the flap and the magnitude of the tension.

The construction of the series of small Z-plasties is referred to as a multiple Z-plasty and when each is separate the total construction is a multiple discontinuous Z-plasty. There is no reason why they should not all run together (Fig. 13), and the result is then called a multiple continuous

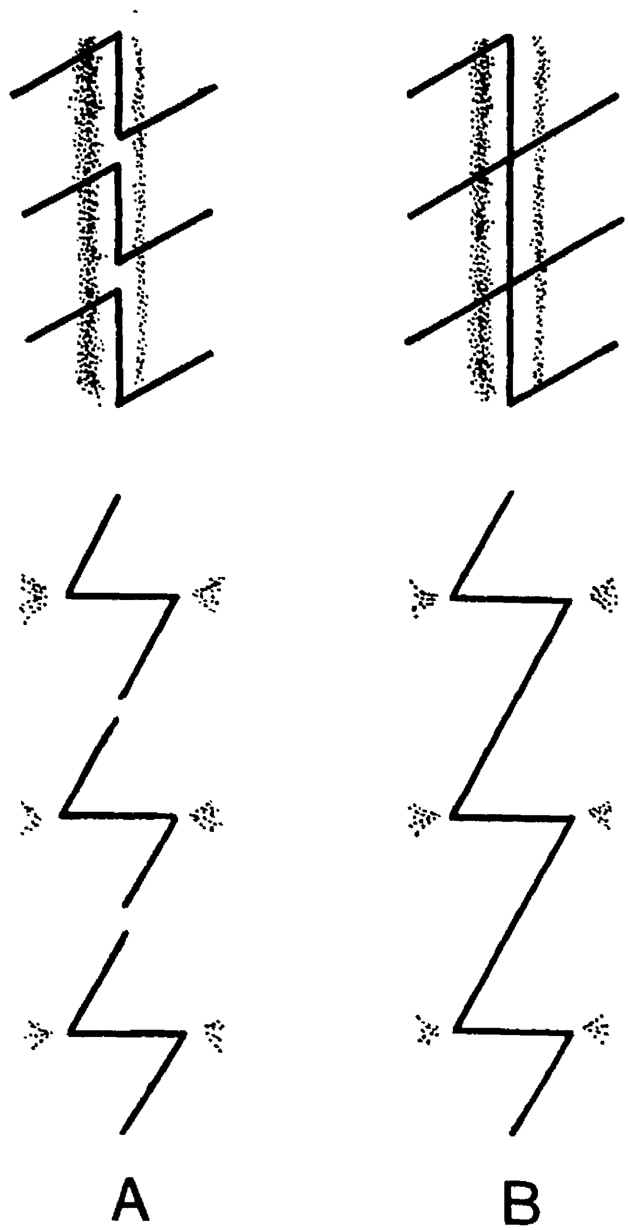

Fig. 13 : The multiple continuous Z-plasty (B), showing its development from the multiple discontinuous Z-plasty (A).

Z-plasty. The multiple continuous Z-plasty is the type most often used in practice.

Since its rationale was established (McGregor, 1960), the obvious advantages of the multiple Z-plasty have resulted in its displacing the single large Z-plasty in many situations. In the hand particularly, where its advantages are most apparent, it has allowed the development of new techniques in the treatment of Dupuytren's contracture and other conditions. These are discussed more fully in the section on Hand Surgery.

CHAPTER 4

THE Z-PLASTY IN SCARS

" . . . and partly in the automatic effect of shearing strain, by which it tends to displace parts which grow obliquely to the direct lines of tension and of pressure, while leaving those in place which happen to lie parallel or perpendicular to those lines : an automatic effect which we can probably trace as working on all scales of magnitude . . . "

D'Arcy Wentworth Thompson,
On Growth and Form, p. 241.

It is well recognised that scars in the face tend to be more acceptable the more nearly they lie in a line of election and the Z-plasty is used to modify scars so that part of their length will lie in such a line. It is necessary, however, to establish first of all what a line of election is.

Until quite recently it was generally accepted that the proper lines for scars were Langer's lines (Langer, 1861), which map out the lines of dermal cleavage (Jones, 1941). In fact, investigation shows clearly that, despite the belief, frequently expressed by surgeons, in the relevance of Langer's lines accurate maps of his lines were not closely scrutinised. The myth was effectively demolished in 1951 when Kraissl provided reproductions in detail of the lines in the face from Langer's original paper. Taking as his basic premise the self-evident fact that appropriate lines for scars lie along the pattern of wrinkles, Kraissl was able to demonstrate that in virtually no part of the face did the pattern of wrinkles coincide with the pattern of Langer's lines (Fig. 14). It is obvious enough now that Kraissl (1951) has pointed out the

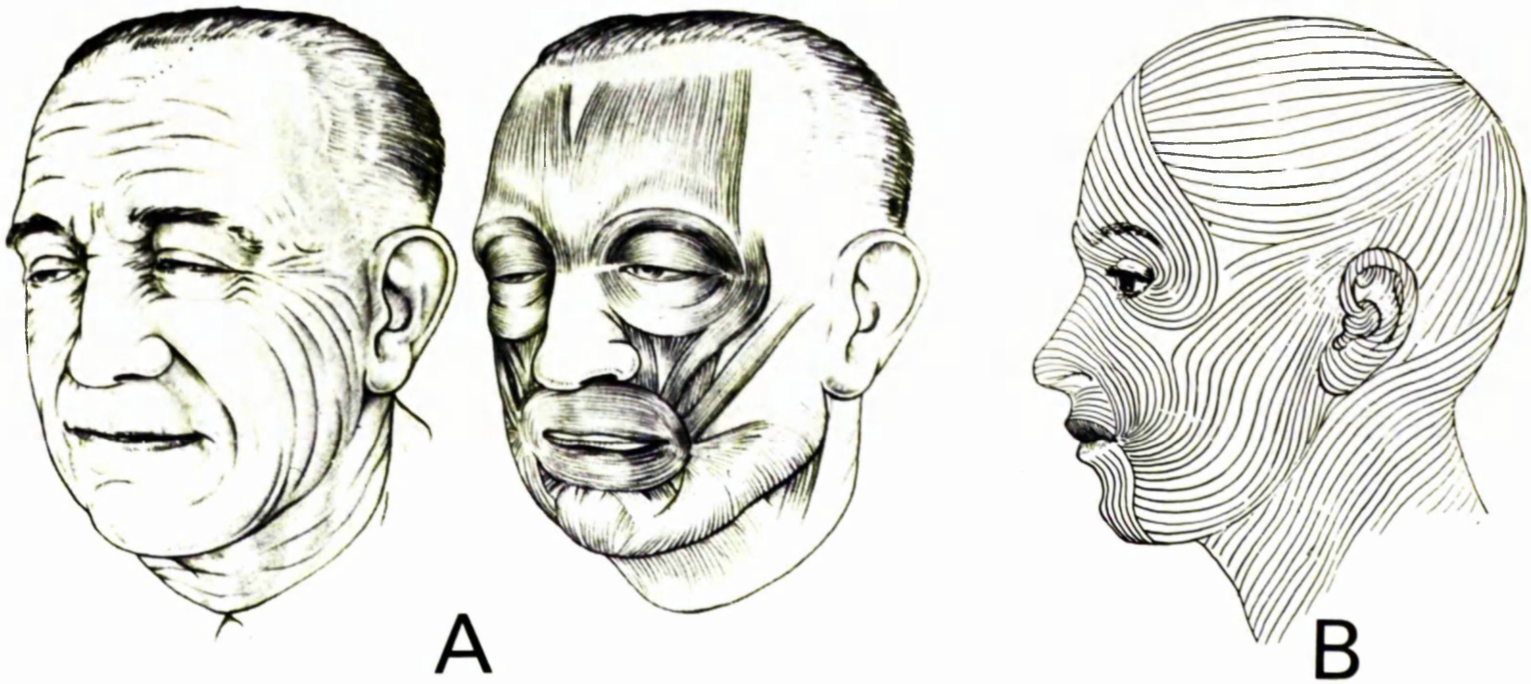

Fig. 14 : The pattern of wrinkling and its relationship to the underlying facial muscles (A), compared with Langer's lines (B), in the face.

fact, though Le Gros Clark had pointed it out in 1939, that the wrinkle pattern is actually related to the underlying muscles of facial expression. Wrinkles run at right angles to the pull of the muscle whose contraction has produced the wrinkle. There is little doubt of course that prior to 1951 many surgeons planned their elective incisions in the face exactly as we do to-day but in the mistaken belief that in so doing they were using Langer's lines.

This pattern of wrinkles is clearly visible in the older patient but in the young, before the loss of elasticity has developed in the skin, it is not yet established and we have to content ourselves by thinking of them as lines of election for scars. For simplicity, the term line of election will be used both for the line in young and the wrinkle in the adult, since for practical purposes they coincide.

The greater the angle between scar and line of election the less acceptable cosmetically the scar tends to be. The problem of acceptability of a scar which is otherwise satisfactory arises where the scar is more than 30° off the line of election. When a Z-plasty is used in the context of scar surgery it breaks the line of the scar and (Fig. 15) changes the direction of what in contracture surgery is called the contractural axis but which in scar surgery might better be called the longitudinal axis. When the flaps of the Z-plasty are transposed this longitudinal axis is converted into a transverse limb. It is found that the desirable result is achieved by getting this limb to lie post-operatively in a line of election. The problem is to design the Z-plasty in such a way that the post-operative transverse limb lies along a line pre-determined by the surgeon.

In working out the lengthening with various angle sizes in relation to contractures, it had become apparent on examining the geometrical figures that alteration of angle size had the incidental effect of altering the direction of the transverse axis post-operatively (Fig. 16). At the same time, working with the classical 60° angled Z-plasty, a method was developed (McGregor, 1960) of siting the Z-plasty so that its transverse limb could be placed in a predetermined site (Fig. 17), recognising, of course, that using a 60° Z-plasty the transverse limb would lie at right angles to the scar line.

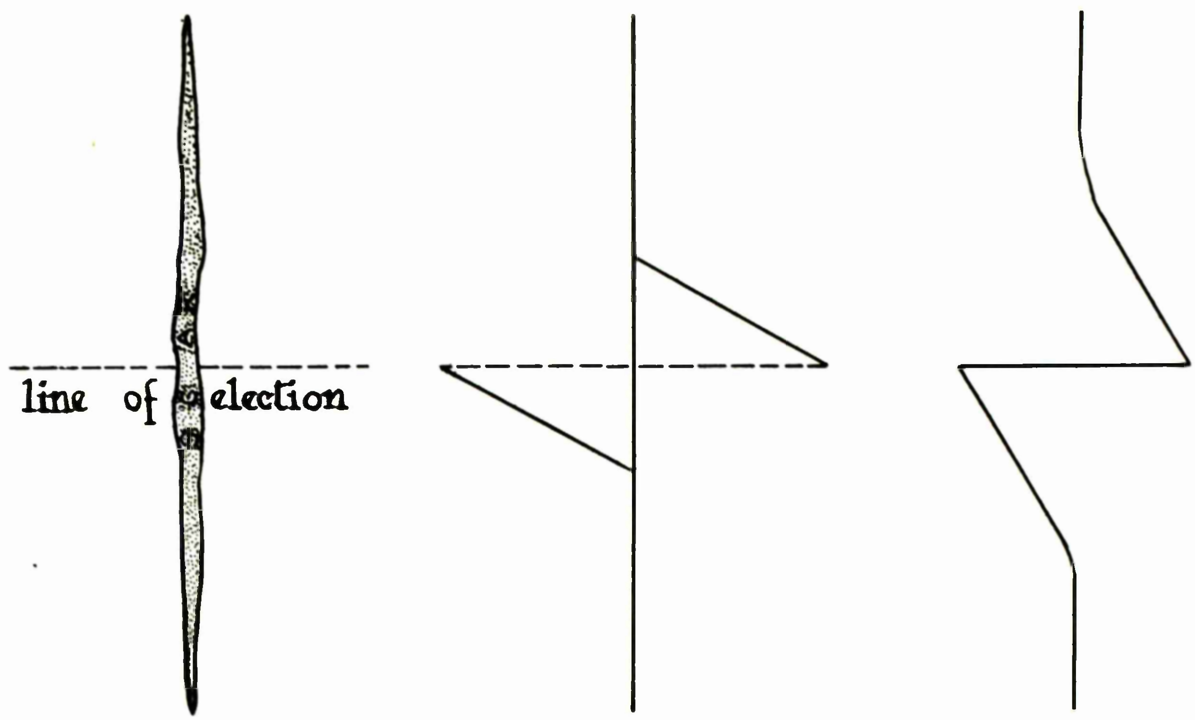

Fig. 15 : The effect of a Z-plasty placed in a line of election in breaking a scar line.

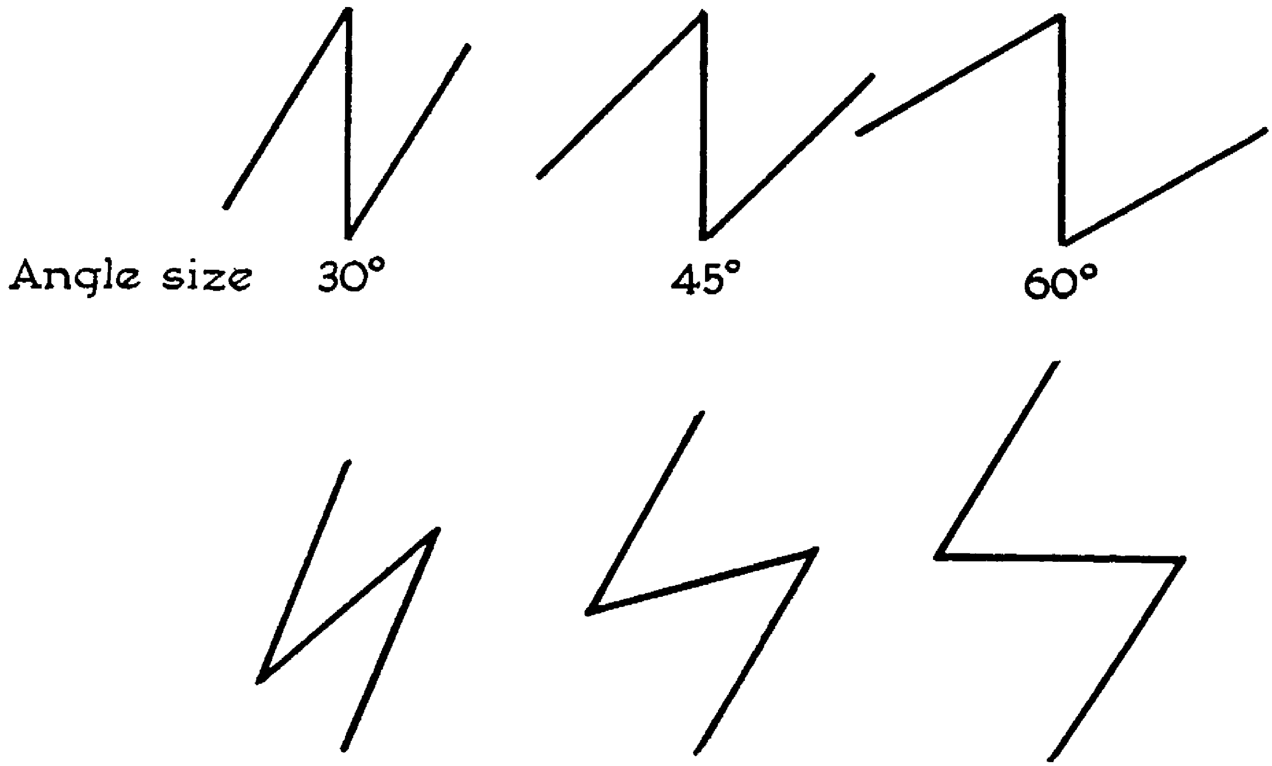

Fig. 16 : The changes in direction of the common limb of the Z with different angle sizes.

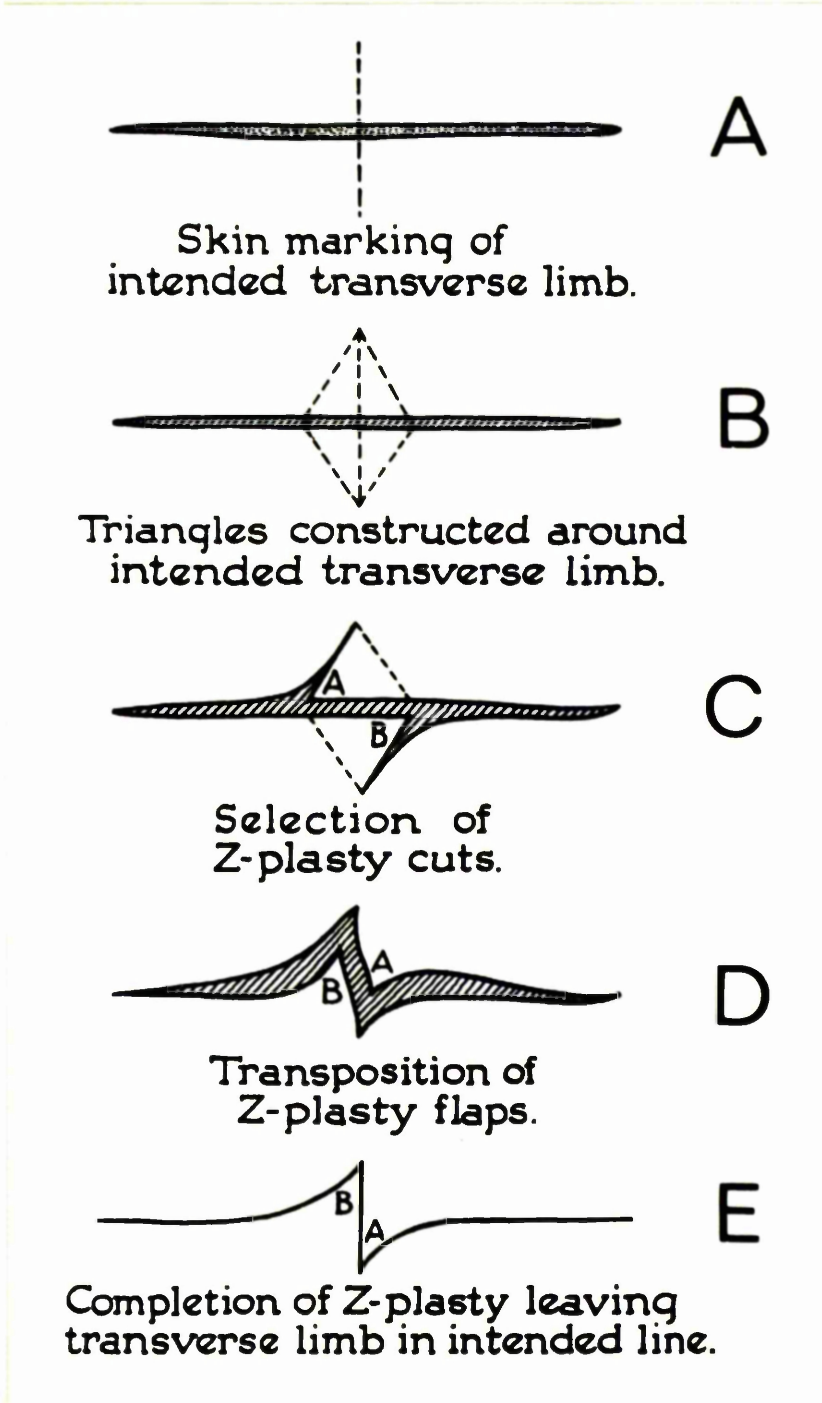

Fig. 17 : The method of siting a 60° angled Z-plasty.

A 60° angled triangle was constructed on both sides of the scar (Fig. 17B) and the selected Z-plasty cuts were made (Fig. 17C), each ending on the predetermined transverse line. Transposition of the flaps (Fig. 17D), left the transverse limb lying along the selected line as planned (Fig. 17E).

This method was adequate for the transverse limb at right angles and, as will be seen in its application in Hand Surgery, was extremely valuable. But in the face, the line of election all too seldom lay at right angles to the scar. What was required was an extension of the method which would allow the transverse limb to be placed in any direction.

It was apparent that with an oblique transverse limb the Z-plasty angle would not be 60° but search for a solution was at first sidetracked by a misguided concentration on angle size as the variable, change in which would determine obliquity of the transverse limb, not altogether surprisingly since it had been initially noted that change in obliquity occurred with change in angle size. In fact, the problem was readily solved once full use was made of the observations that :

1. If a particular transverse line is selected and the Z-plasty cuts can be designed to end up on this line, transposition of the flap will in all circumstances leave the transverse limb lying along this selected line.

2. The limbs of the Z-plasty are equal in length.

The Method (Fig. 18)

The steps are more easily illustrated than described. With the scar outlined (Step 1), the line along which the transverse limb of the completed Z-plasty is meant to lie is drawn out on the skin (Step 2). This will naturally be in a line of election. The size of the Z-plasty is determined (Step 3) by measuring out the length of the intended transverse limb along the line of the scar.

In the initial development of the method, this length was equally proportioned on each side of the line drawn in Step 2 to represent the line of the transverse limb of the completed Z-plasty. This was found to produce a Z-plasty with equal angles. Subsequently a way of producing a Z-plasty with unequal angles has been found but meantime the equi-angled Z-plasty alone will be discussed.

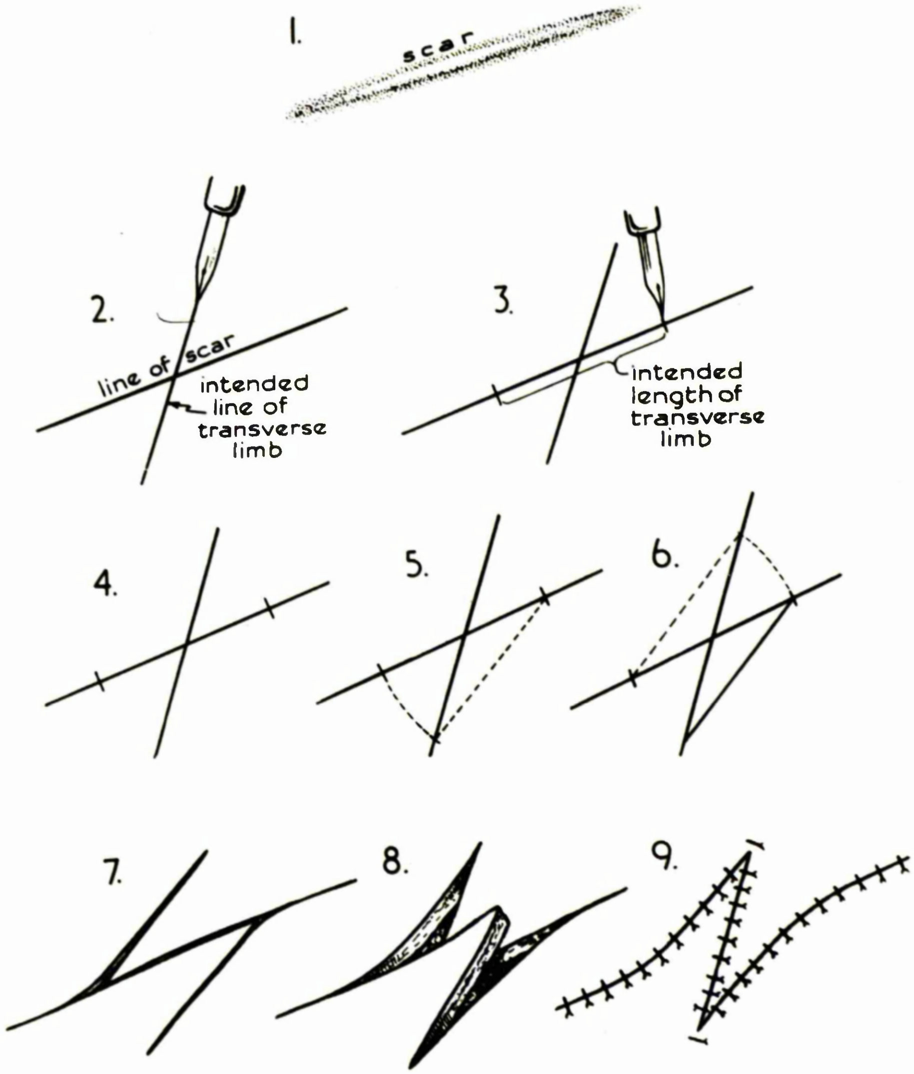

Fig. 18 : The steps used in planning and executing an equal angled Z-plasty designed to be of the length intended, and having its transverse limb in the direction desired, by the surgeon. The significance of each step is described in the text.

For the equi-angled Z-plasty then, an equal amount of the limb length is marked out on each side (Step 4). From each extremity of this length, a line of similar length is measured out to meet the line of the intended transverse limb - one on each side (Steps 5 and 6). These two lengths are equal to the Z limb already marked out and together the three make the Z-plasty flaps (Step 7). Transposition (Step 8) of necessity brings the transverse limb into the required line (Step 9) and this is true regardless of its direction. Altering its obliquity merely has the effect of altering the size of the Z-plasty angle. Increase of obliquity reduces the angle and decrease of obliquity increases the angle - to a maximum of 60° at which point the transverse limb becomes perpendicular to the line of the scar.

It will be apparent that the 60° angled Z-plasty with perpendicular transverse limb is in practice a limiting situation beyond which obliquity of the transverse limb in the opposite direction begins and the Z-plasty arms are transferred to the opposite direction (Fig. 19). It is because of this fact that two Z-plasties can be constructed at the limiting angle of 60°.

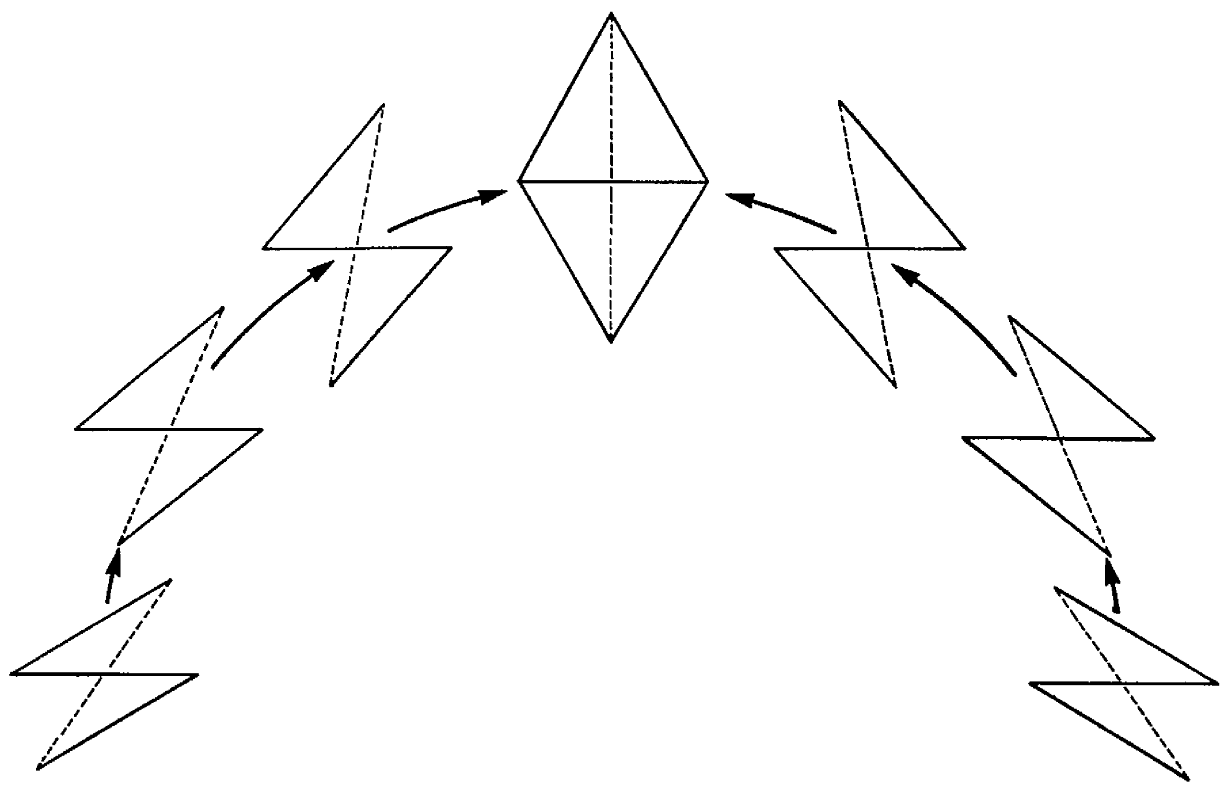

Fig. 19 : The change in transverse limb obliquity with increase in angle size up to the 60° angle when the transverse limb becomes perpendicular, showing how the 60° angle is in practice a limiting situation which can be approached from both sides, and how two pairs of angles and consequently two separate sides can be chosen in constructing a Z-plasty at this limiting angle size.

It should be appreciated that the oblique Z-plasty just described is a particular example of a more general type. It is the example in which an equal amount (Fig. 18, Steps 3 and 4) of the transverse limb length is marked out on both sides of the intended post-operative line of the transverse limb. The effect of marking it out symmetrically in this way (Fig. 20A) is to produce a Z-plasty with equal angles but there is no reason why this length should not be marked out in an asymmetrical fashion (Fig. 20B).

The effect of marking it out asymmetrically to either side of the selected line (Fig. 21) is to produce a Z-plasty with dissimilar angles, but it is one in which the transverse limb after transposition of the flaps still lies in the line selected in the pre-operative design.

This asymmetrical construction has no particular advantage in general use but it might be desirable depending on adjoining scars or lines of election. Certainly, to be able to construct it with pre-operative accuracy and complete it with absolute certainty does add an extra dimension of flexibility.

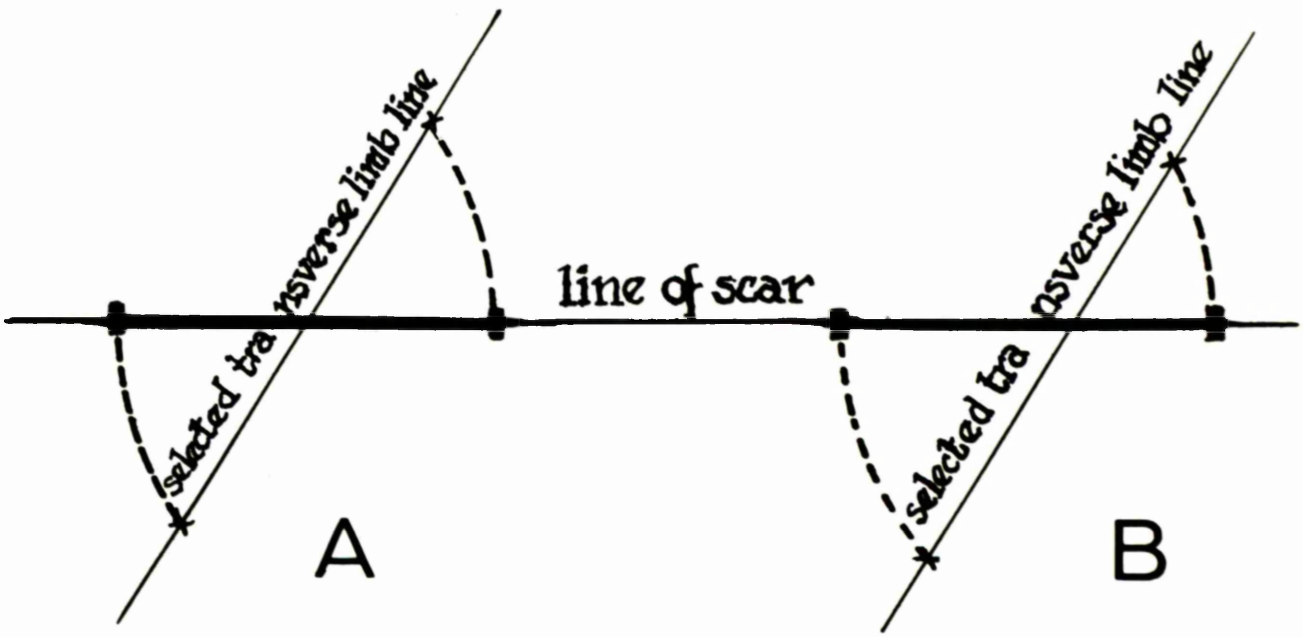

Fig. 20 : Equal proportions (A) and unequal proportions (B) of transverse limb length marked out on each side of the selected transverse limb line on the line of the scar, showing how the result is either (A) a symmetrical Z-plasty with equal angles or (B) an asymmetrical Z-plasty with unequal angles, but with the same final transverse limb line in each case.

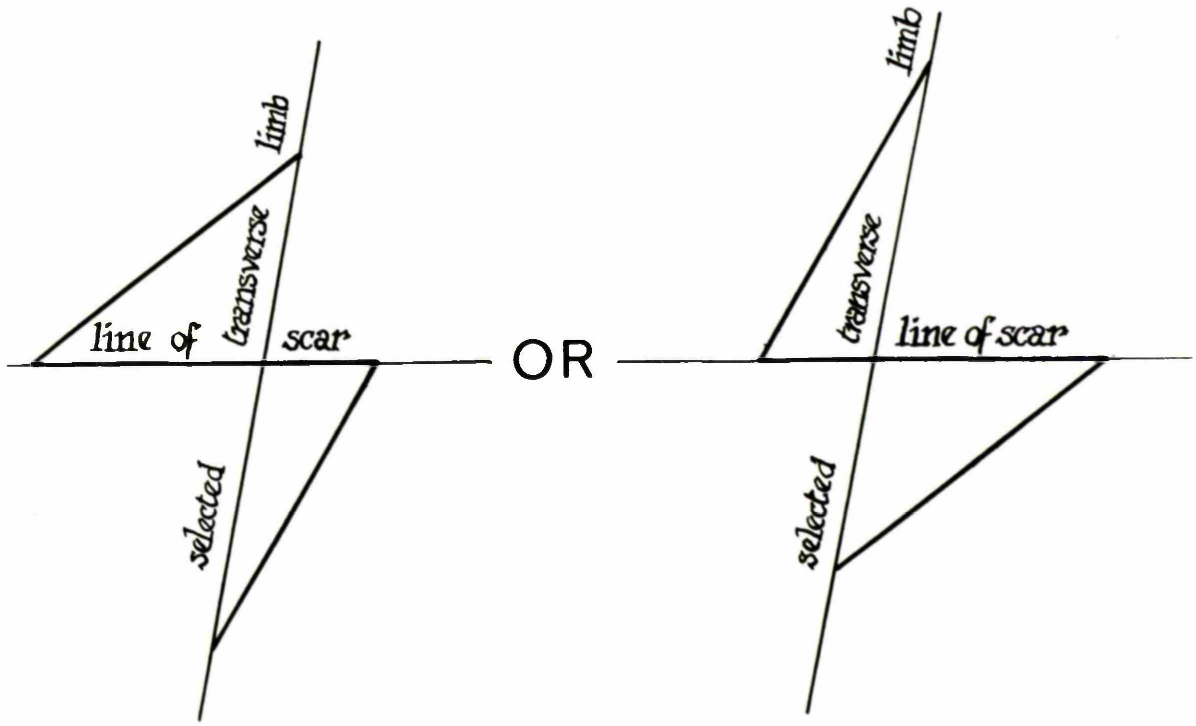

Fig. 21 : The effect of varying the proportions of transverse limb length on each side of the selected transverse limb line on the shape of the Z-plasty.

When such an oblique Z-plasty is being constructed, whether it be with equal or unequal angles, the main limiting factor results from the fact that as the transverse limb departs from the perpendicular, the flap becomes narrower with all that this means in terms of the effect on its blood supply. The oblique Z-plasty, being a technique used in scar surgery, is generally confined to the face and facial skin with its excellent blood supply is more tolerant of narrow flaps than skin elsewhere on the body surface. Nevertheless in the face too there is a limit to permissible narrowness. Fortunately the precise narrowness can in any case be predicted at the planning stage before any incision is actually made.

In using a Z-plasty in scar surgery, it is usual if the scar is of any length to break its line with more than one Z-plasty. When a multiple Z-plasty is used in this way the effect is to convert a single linear scar into a series of smaller scars joined by transverse limbs in lines of election, even in actual wrinkle lines if wrinkles are present. In the ideal situation, each transverse limb would be concealed in the wrinkle, in the less ideal the transverse limbs are less noticeable even if they are still visible. Several small scars connected by transverse limbs are in any case less conspicuous than a single long scar. It is also found in practice that the large Z-plasty does not give as good a cosmetic result as the smaller Z. In planning therefore, the estimated length of the transverse limb should be kept fairly small.

When a scar is being broken up by several Z-plasties in this way (Fig. 22), the lines of election are liable to run in different directions in different parts of the scar and the transverse limb in each Z-plasty may have to vary its direction to suit. This is no problem since each tansverse limb can have its direction and length independently planned in the manner described. Examples are shown in the cases illustrated (Figs. 23 and 24).

When a multiple Z-plasty is used to break up a scar, problems resulting from the simultaneous lengthening can occur (Fig. 25). A Z-plasty with the usual angle sizes between 30° and 60° produces a significant amount of

Fig. 22 : A scar of face, broken up by three Z-plasties, showing how the transverse limb of each Z-plasty has been made to vary its direction to suit the direction of the line of election in the particular part of the face.

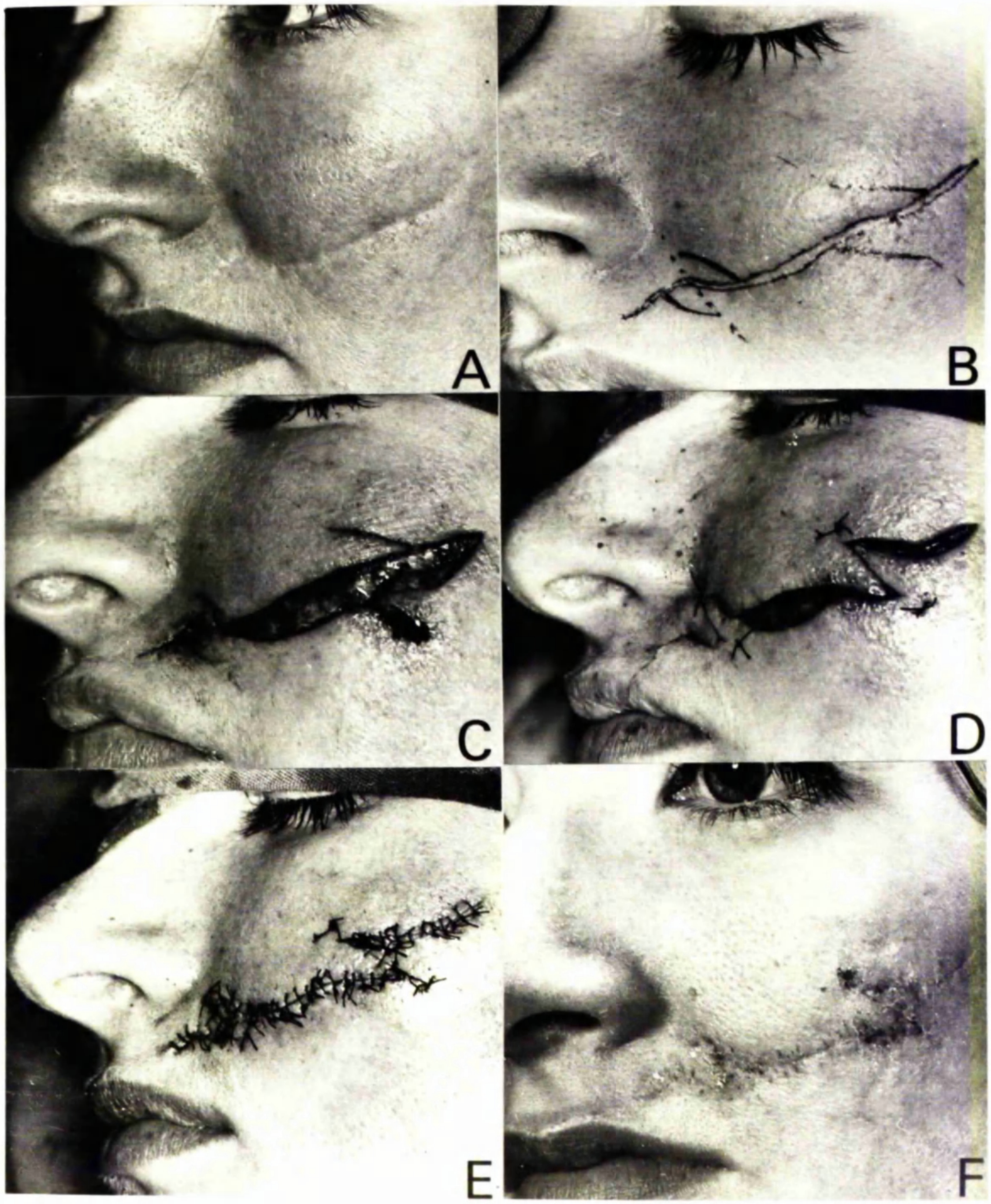

Fig. 23 : A scar of face, showing the stages of excision, incorporating two Z-plasties, in each instance placed in the line of election. The scar (A), with the lines of excision and the two Z-plasties placed to lie in the appropriate line of election (B). The scar excised and the Z-plasty incisions made (C). The Z-plasty flaps transposed (D), showing how the transverse limb lies in the line of election as planned in (B). The scar sutured (E), and the appearance immediately after removal of the sutures (F).

Fig. 24 : A trap-door scar of angle of mouth excised, incorporating four Z-plasties in such a way that the resulting transverse limbs lie along a curving line of election. The steps of the manoeuvre are shown, carried out according to Fig. 18. The lines of the transverse limbs, planned in (B), are similar in direction to the post-operative limbs, after the Z-plasty flaps (F) have been transposed.

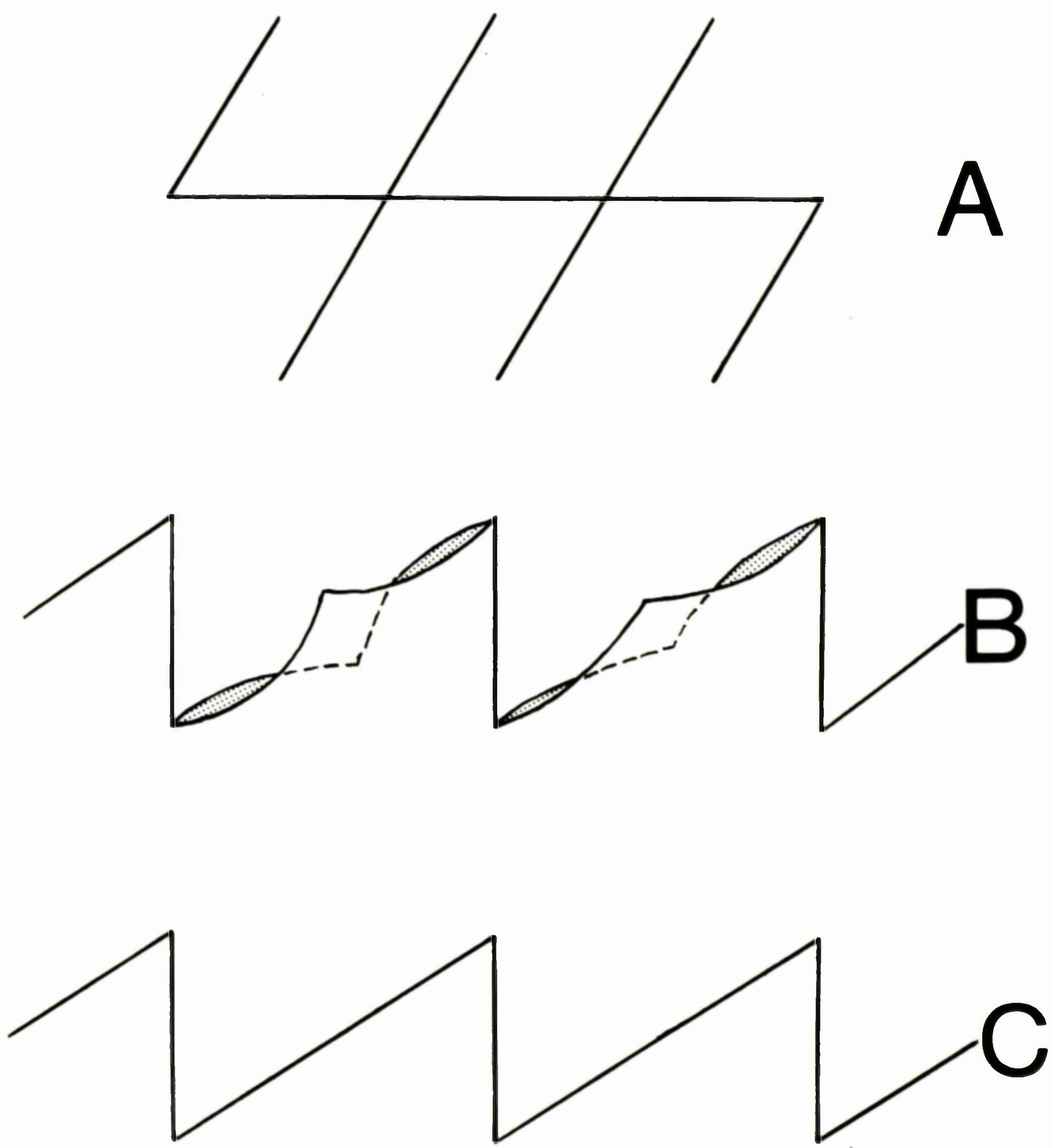

Fig. 25 : The multiple Z-plasty (A) where the full amount of lengthening cannot be accommodated by the tissues, showing how overlapping from one Z to the next develops (B), treated by trimming the excess on each flap (C), as seen in Fig. 26.

lengthening, 25% to 75%, as an automatic and inevitable consequence of the flap transpositions. This lengthening can usually only be accommodated partially without causing distortion which shows as an overlapping of the flaps as they pass from one Z to the next (Fig. 25B). The overlap on each flap is usually excised (Fig. 26). Excision of the overlap has the effect of reducing the overall lengthening and consequently the bulk of the distortion.

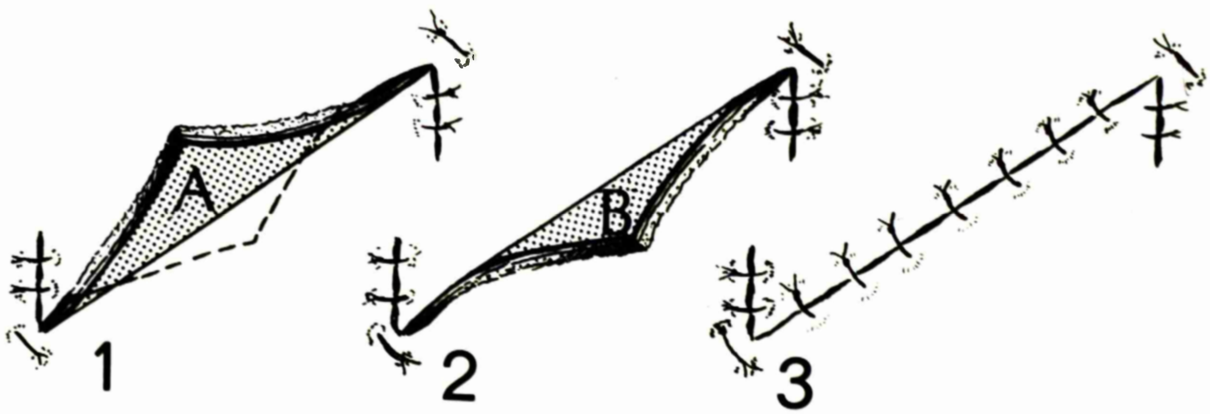

Fig. 26 : The stages in removal of the excess as indicated in Fig. 25, to reduce the overall lengthening.

CHAPTER 5

THE CURVING Z-PLASTY

"But the new and important problem which now emerges is to correlate the deformation or transformation which we discover in one plane with that which we have observed in another: and at length, perhaps, after grasping the general principles of such correlation, to forecast approximately what is likely to take place in the third dimension when we are acquainted with two, that is to say, to determine the values along one axis in terms of the other two."

D'Arcy Wentworth Thompson,
On Growth and Form, p. 323.

Until now consideration of the Z-plasty has concerned its use mainly in a single plane, and it has proved possible to interpret the observed phenomena adequately even although the discussion was limited to two dimensions. It has been found empirically over many years, however, that the method is also effective in certain common problems involving curves where a third dimension is involved. In this situation it can conveniently be called a curving Z-plasty.

The problems are notching of the lip, bridle scarring, i.e. scarring which bridges a concavity, congenital ring-constrictions of the limbs (Dingman, 1955), and those which arise in deepening finger clefts. It is true that other related problems can be solved by the Z-plasty but the relationship to one of these basic situations is sufficiently obvious to obviate the need to discuss each individually, at least from a theoretical point of view. It is also true that the curving Z-plasty has potential uses in other fields of surgery. Some of these will be discussed in the section headed Discussion and Conclusion.

A further finding is that the curving Z-plasty can be used "in reverse" to shorten where it usually lengthens and lengthen where it usually shortens. This admittedly is rarely required, in fact virtually only in relation to finger webs. It will be discussed in that context.

Using the knowledge of the Z-plasty already acquired, it is possible to explain the rationale of the curving Z-plasty in these situations despite the added dimension. The fact that the Z-plasty is not being used on a reasonably plane surface but on a series of curved surfaces does modify its effect very considerably but the observed phenomena, particularly as they relate to its mode of action, can still be explained in terms of lengthening and shortening in the two axes which take place when Z-plasty flaps are transposed (Fig. 27). It is not a change in the fact of lengthening and shortening but rather a change in the effect.

To appreciate the effect of lengthening and shortening when the curving Z-plasty is used in this context it must first be appreciated there may be no contracture involved and the surrounding tissues may be relatively fixed in position as a

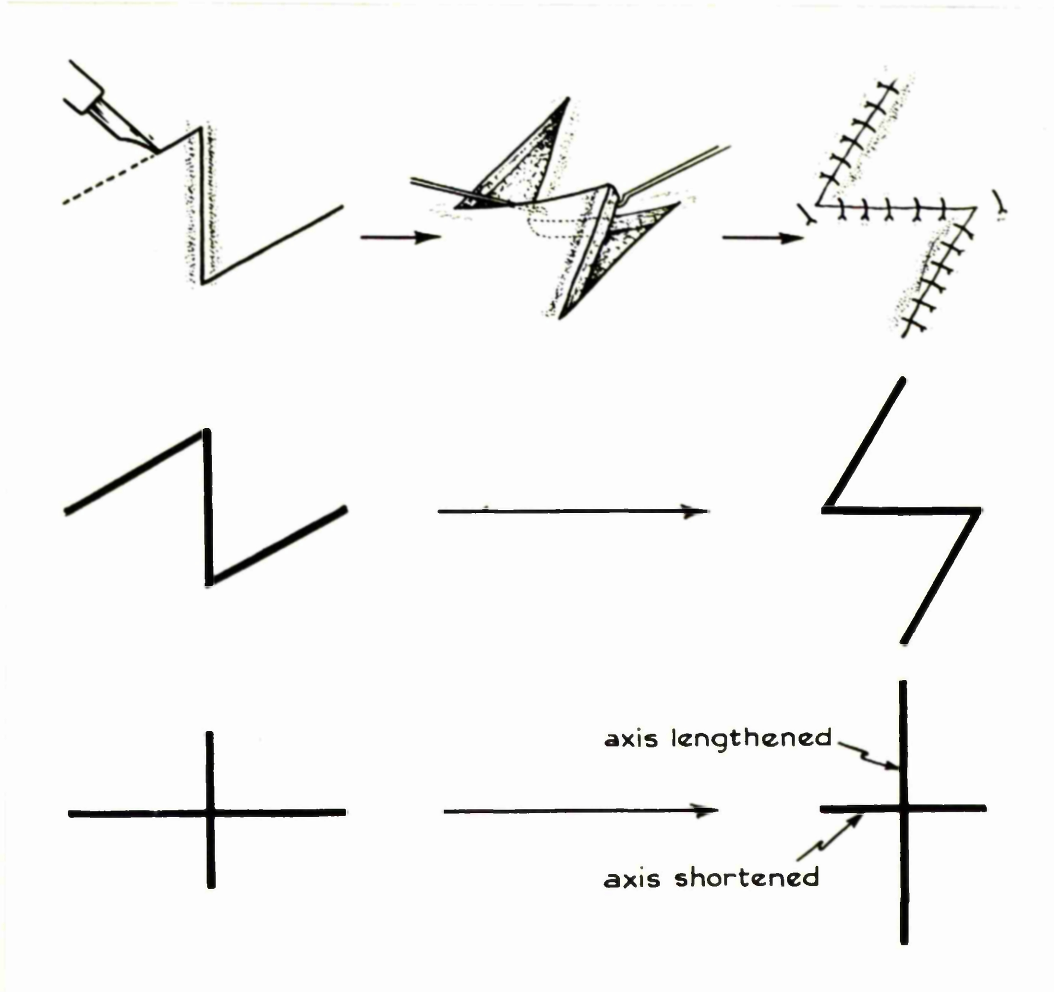

Fig. 27 : The 60° angled Z-plasty showing how its effect is to lengthen and shorten in the perpendicular axes.

result. Furthermore the lengthening and shortening is taking place along the line of a curve whose ends are virtually fixed in position.

If we consider such a curve, AB (Fig. 28), with end points A and B fixed in position, the effects of lengthening and shortening can readily be observed. As lengthening occurs, the curve becomes greater in depth (A^1B^1 and A^2B^2). As shortening occurs, the curve becomes shallower (A_1B_1) until a limit is reached and it becomes a straight line (A_2B_2), a straight line being the shortest possible distance between A and B.

Accepting the fact then that if a 60° Z-plasty is carried out in these circumstances lengthening and shortening in the two perpendicular axes will occur, its effect on the various curves concerned will be of the nature discussed above. The remaining point is to see where the axes should be in each of the clinical situations.

Notching of the Lip

The axes here are the line of the notch itself and the line of the lip margin, and as can be seen they lie at right

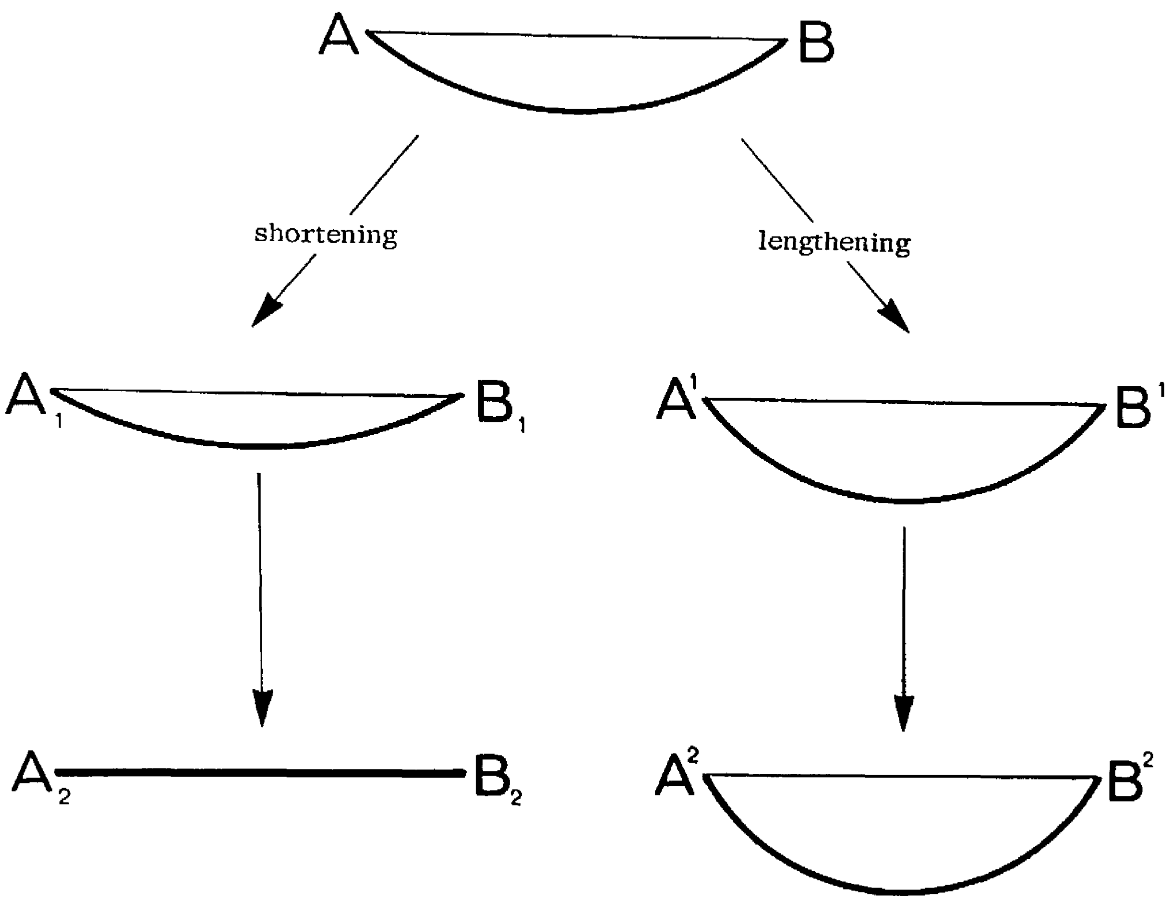

Fig. 28 : The effect of lengthening and the effect of shortening a curve, the extremities (A, B) of which are fixed in position.
Lengthening deepens the curve, AB $\rightarrow$ A^1B^1 $\rightarrow$ A^2B^2.
Shortening makes the curve shallower, AB $\rightarrow$ A_1B_1, finally making a straight line, A_2B_2.

angles to each other (Fig. 29).

If we consider the line of the notch which is the curve BB, any manoeuvre which has the effect of increasing its length will tend to reduce the notch, finally eliminating it altogether when the curve has become as long as the curve of the adjoining normal lip. We wish therefore to lengthen this axis. Considering the line of the lip margin as it dips into the notch and down again into the normal lip margin (AA), any manoeuvre which has the effect of shortening its length will reduce and finally eliminate the notch completely. We wish therefore to shorten this axis: As has already been shown, the Z-plasty simultaneously lengthens and shortens its axes and in this way eliminates the notch (Figs. 30 and 31).

The Bridle Scar

Such a scar, in relation to the hollow it bridges, can either be deep, i.e. comparatively short in relation to the depth of the hollow, or shallow, i.e.comparatively long in relation to the depth of the hollow. The use of the Z-plasty differs in these two situations in that the deep scar is corrected by using one large Z-plasty (Fig. 32) while the

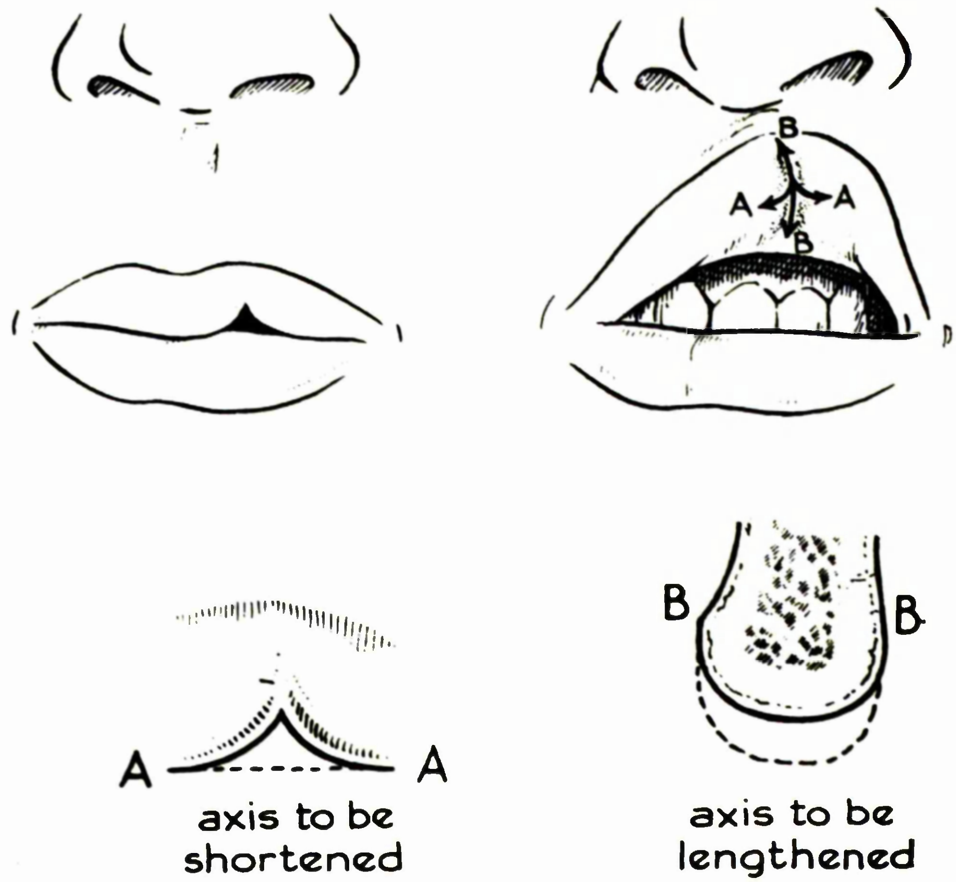

Fig. 29 : The use of the Z-plasty to correct notching of the lip, showing how the effect is achieved by lengthening the B - B axis and shortening the A - A axis.

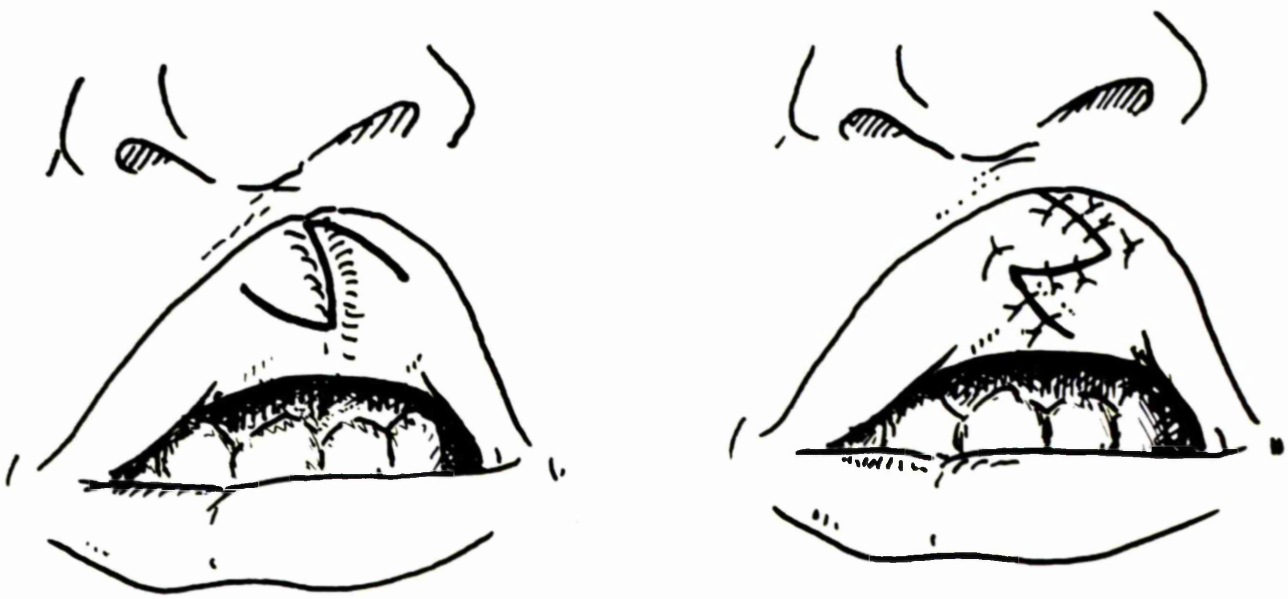

Fig. 30 : A diagram of the Z-plasty placed to correct notching of the lip.

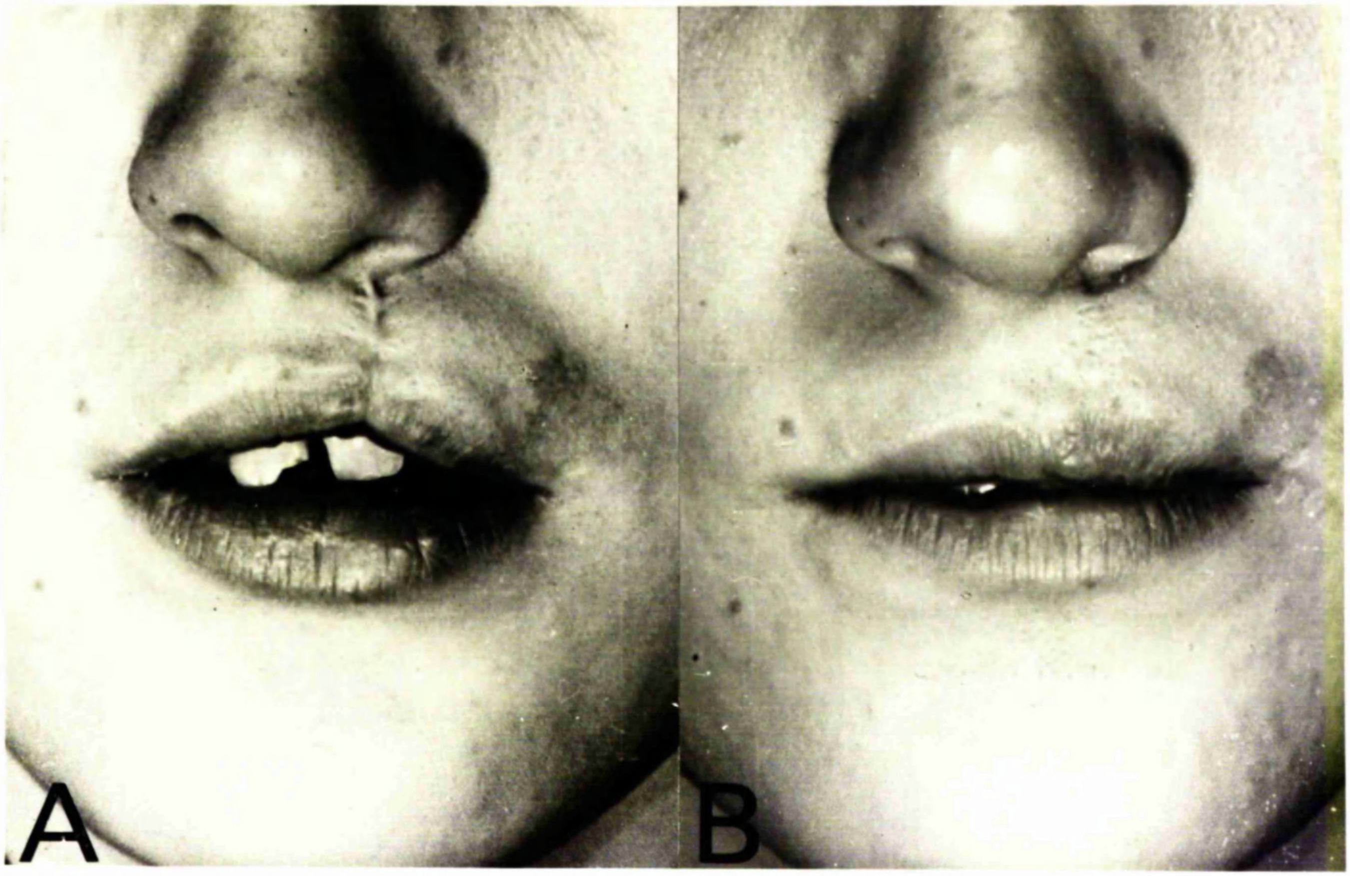

Fig. 31 : The appearance (A) following an unsatisfactory primary repair of a cleft lip, with notching of the lip as part of the deformity, and (B) the appearance following secondary repair, showing the effectiveness of the Z-plasty, incorporated as part of the procedure, in correcting this aspect of the deformity.

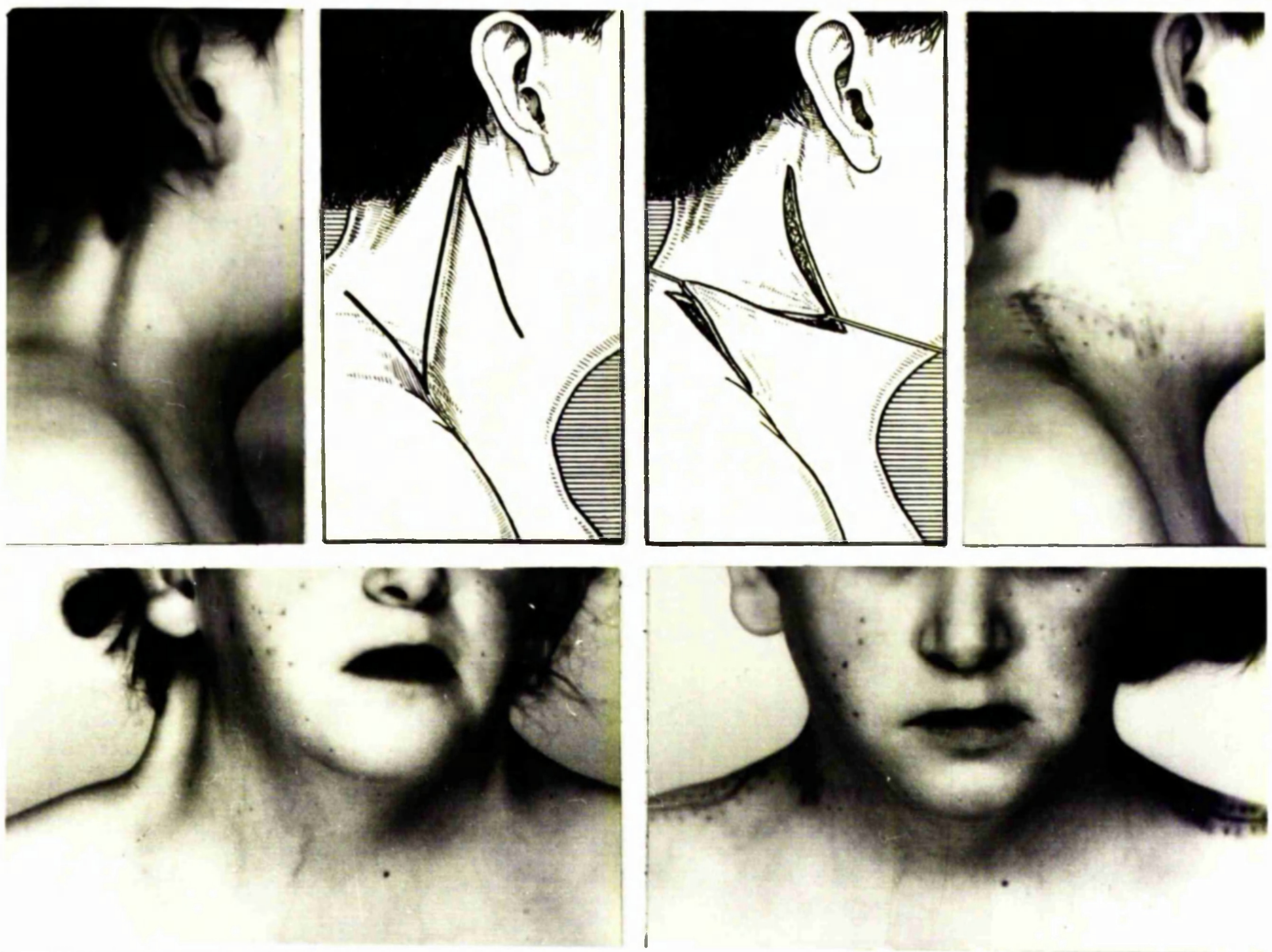

Fig. 32 : An example of a single Z-plasty used in a condition akin to the deep bridle scar, namely the neck webbing component of Turner's syndrome.

shallow scar requires a multiple Z-plasty (Fig. 33). Before discussing the different handling of these two scar types, deep and shallow, it is appropriate to discuss in terms of lengthening and shortening of axis curves why the Z-plasty works at all.

If we consider the axes to be lengthened and shortened, they are the <u>line of the scar</u> itself and the <u>line drawn from its centre at right angles to it</u> (Fig. 34). Since the points marked at A, B, C and D in Fig. 34 are as already stated fixed points, lengthening of AB, the line of the scar, will translate it into the line of the hollow and eliminate its bridle element. At the same time, the line CD rising up from the hollow on each side to the scar will by shortening become the straight line which would result if the bridle scar were eliminated. The Z-plasty with axes along the lines AB and CD will produce this effect by lengthening and shortening.

With the axes thus established the different practice when the hollow is deep and shallow in relation to the scar remains to be explained (Fig. 35). The short scar with deep hollow and the long scar with shallow hollow are the extremes

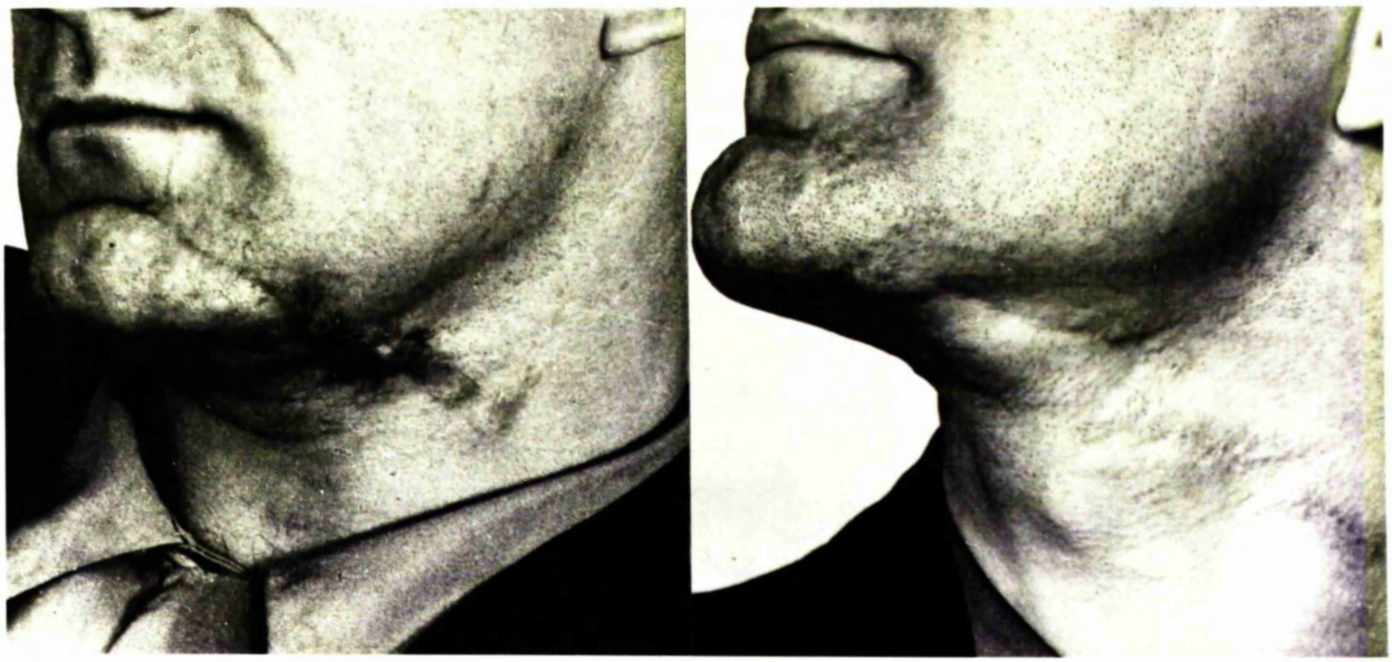

Fig. 33 : An example of the multiple Z-plasty used in a shallow bridle scar.

It should be noted that it has been possible to place each transverse limb in a line of election using the method shown in Fig. 18.

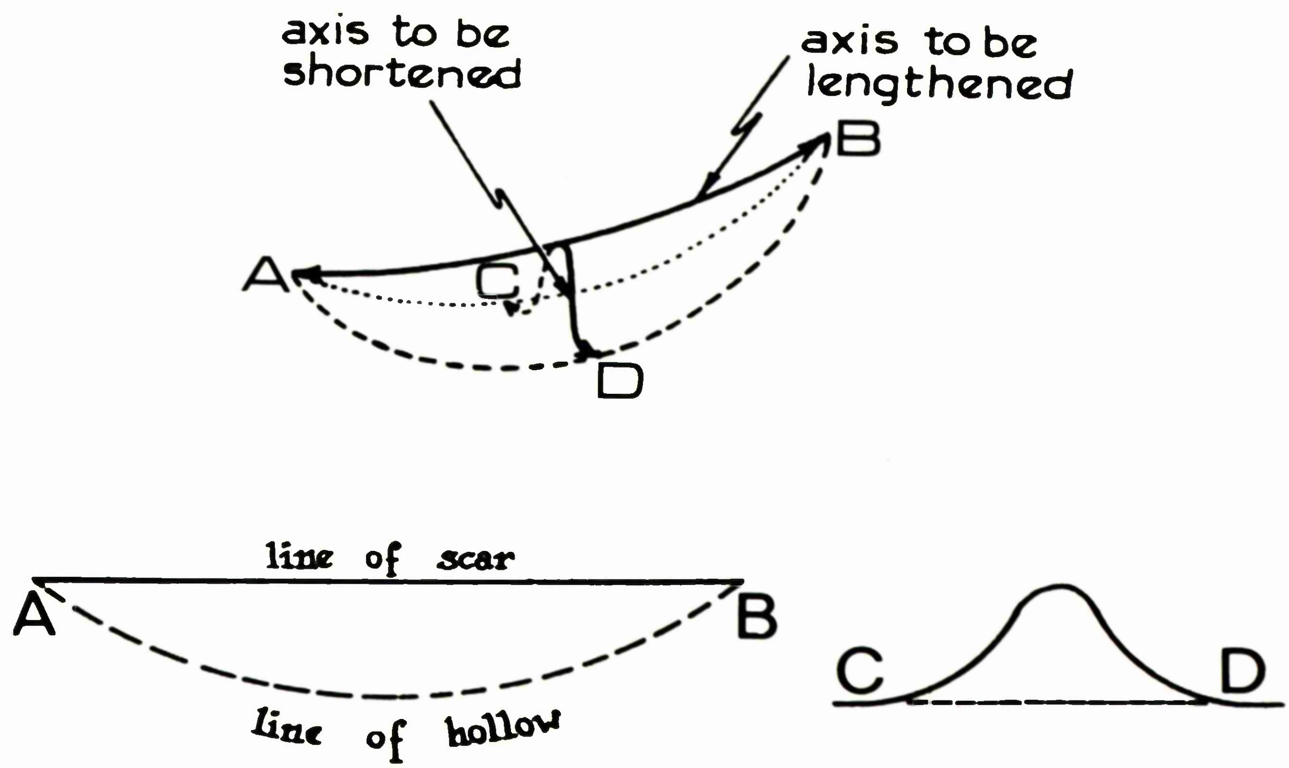

Fig. 34 : The appropriate axes, AB and CD, when the Z-plasty is used to correct a bridle scar.

Lengthening of AB and shortening of CD together have the effect of making the bridle scar sit into the hollow.

but from discussion of the extremes the rationale of the intermediates follows readily.

In the deep hollow (Fig. 35) with axes labelled $A_1B_1C_1D_1$ the amount of lengthening required of A_1B_1 is nearly similar to the amount of shortening required of C_1D_1 to eliminate the bridle element of the scar. This means that the situation would best be served using one large single Z-plasty since with a single Z-plasty lengthening and shortening in the two axes is equal.

In the shallow hollow (Fig. 35) with axes labelled $A_2B_2C_2D_2$ the single large Z-plasty would be inappropriate as only enough shortening is required in one axis to straighten out C_2D_2 and a Z-plasty designed to do this would accomplish far too little lengthening along the axis A_2B_2. In addition shortening of C_2D_2 is required all the way along the scar. Nevertheless, considering the overall lengthening required to correct A_2B_2 the same amount may be needed as was required in A_1B_1, the short scar with deep hollow. The problem can be solved by using a multiple Z-plasty where the overall lengthening being in series is equal to that of the equivalent

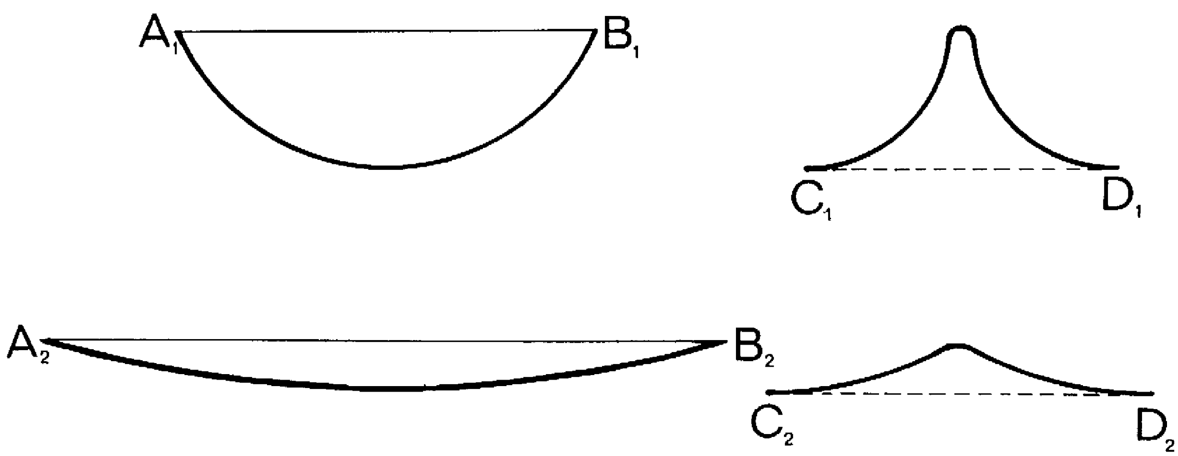

Fig. 35 : Comparison of the deep bridle scar ($A_1B_1 - C_1D_1$) and the shallow bridle scar ($A_2B_2 - C_2D_2$).

In $A_1B_1 - C_1D_1$, the lengthening of A_1B_1 required equals the shortening of C_1D_1 required, and consequently the single Z-plasty is appropriate.

In $A_2B_2 - C_2D_2$, the lengthening of A_2B_2 is much greater than the shortening of C_2D_2, though the shortening needs to be repeated at each transverse limb along the length of the scar, and so the multiple Z-plasty is appropriate.

large Z-plasty (Fig. 12), but the transverse shortening is reduced by a factor equal to the number of Z-plasties, assuming them to be all of the same size.

Between these extremes the appropriate Z-plasty or Z-plasties would vary in size according to the local amount of shortening required. When a multiple Z-plasty is required there is a temptation to make all the Zs of the same size but of course this is not essential. If the hollow is deeper at one point the shortening in the transverse axis required at that point will be greater and the Z-plasty in this segment of the scar can be increased in size appropriately. Even allowing for the fact that transverse shortening can be made to vary in this way overall lengthening will be unaffected if the Z-plasty is of the multiple continuous type and the angles have remained at 60° since it will still be a 75% increase on the original length.

It is not always possible to estimate pre-operatively the precise shortening and more important the precise lengthening required in a given bridle scar but the design of the flaps as it relates to limb length is fortunately only the coarse adjustment of lengthening. Lengthening tends if anything to be overdone and as already indicated (Fig. 25) this shows as overlap as one Z passes to the next. Excision of these provides a final fine adjustment of the length (Fig. 26).

Congenital Ring-Constriction

The situation in this condition has similarities to that of the lip notch if one imagines the notch continued around the circumference of the limb or finger; the main change in Z-plasty construction is the use of a continuous multiple Z-plasty (Fig. 36) instead of a single Z.

In one axis we wish to lengthen the circumference of the limb at the deepest part of the constriction until it equals that of the adjoining normal limb.

In the other axis, which is at right angles, we wish to eliminate the dip into the constriction. The dip can be eliminated by shortening its line from a curve dipping into the constriction to a straight line running across it.

With both of these achieved simultaneously the constriction would be eliminated. A multiple Z-plasty

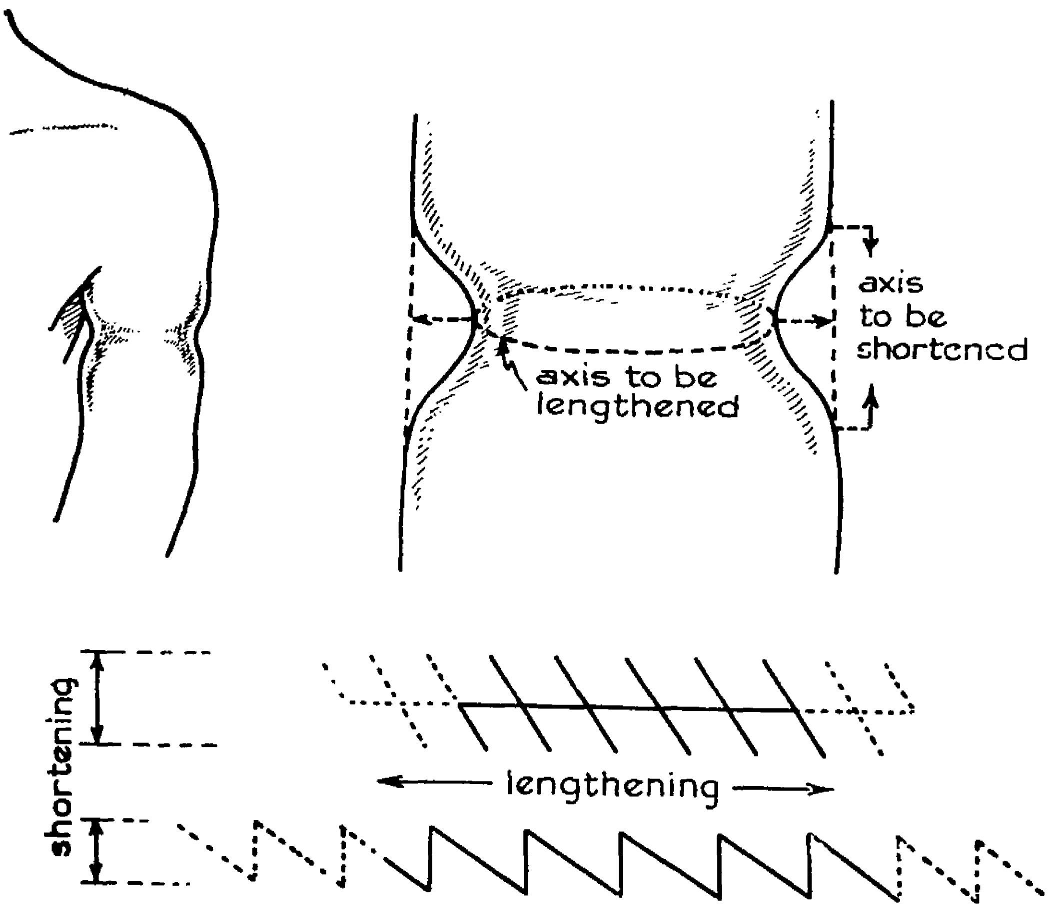

Fig. 36 : The use of the multiple Z-plasty in congenital ring-constriction of the limb showing the axes to be lengthened and shortened, and the way in which the multiple Z-plasty achieves this. The multiple Z-plasty encircling the limb has been drawn opened out to show more clearly how lengthening and shortening still occur in the relevant axes.

continued around the limb circumference will produce the desired lengthening in the circumferential axis so that the total circumference is increased until it equals the adjoining normal limb. At the same time shortening in each transverse axis eliminates the dip into the constriction (Fig. 37).

The beneficial effect of the multiple Z-plasty shows especially well in this situation for the required circumferential lengthening is very large compared with the transverse shortening. The desired comparatively small amount of shortening, repeated all the way round the limb, is the result which the multiple Z-plasty selectively achieves.

A related problem is the circumferential stricture in a hollow tube or, more often, of the entrance to a hollow tube, e.g. the contracted external auditory meatus or the post-vulvectomy constricted introitus. If we regard the ring-constriction as the "positive" then these problems are the corresponding "negative". With the problems essentially similar the multiple Z-plasty is equally effective and for precisely the same reasons. The same principles have also been employed in the treatment of the stenotic colostomy stoma (Lyons and Simon, 1960).

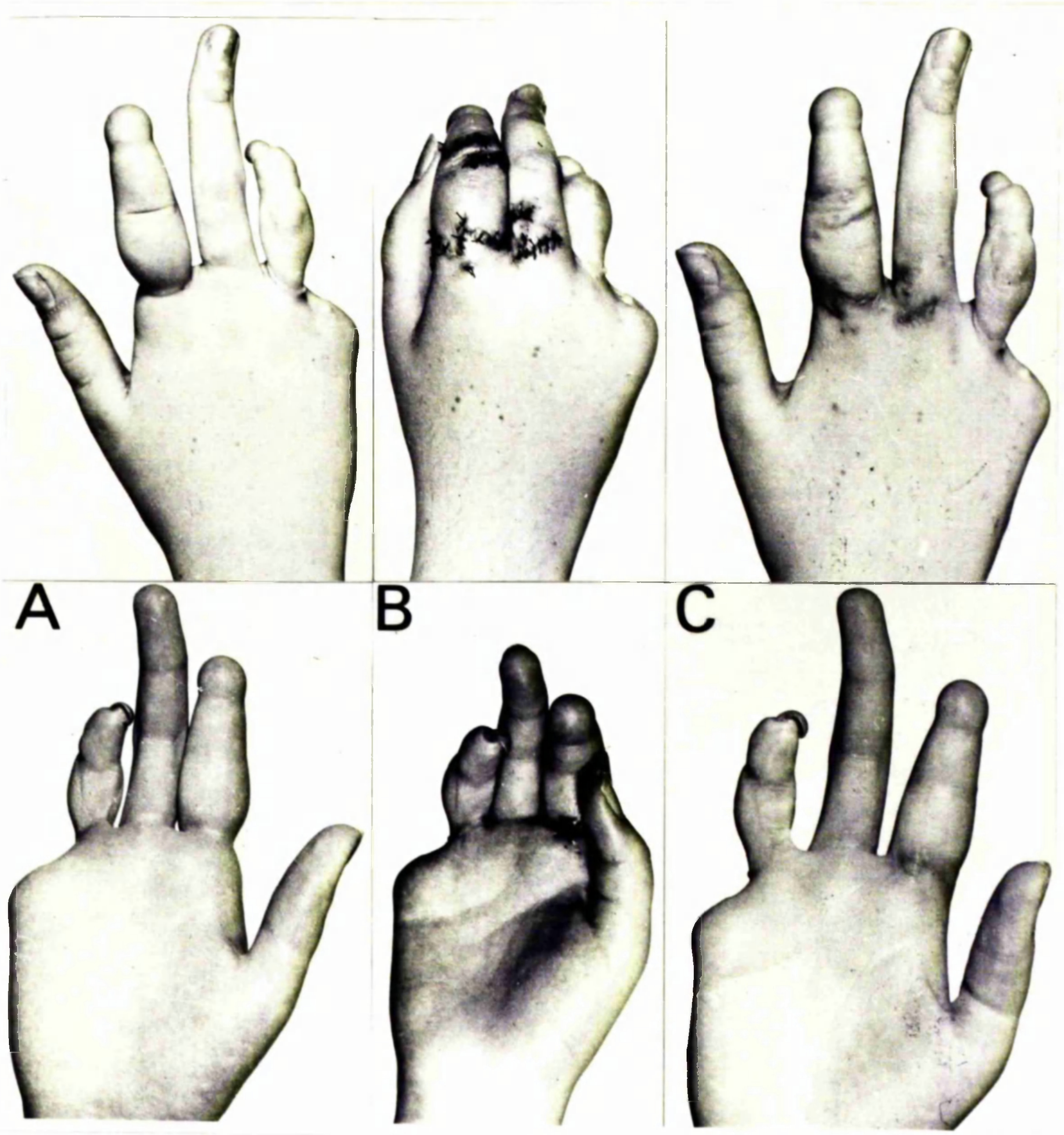

Fig. 37 : An example of the multiple Z-plasty used to correct congenital ring-constrictions of the fingers, showing (A) the pre-operative appearance, (B) the immediate post-operative appearance, and (C) the final result with complete correction of the ring-constrictions.

The Finger Web

In deepening such a web the axis requiring to be lengthened lies along the line of the curve of the web. Increasing the length of this curve must of necessity deepen the web. Shortening of the axis passing up and over the web at right angles will similarly deepen the web (Fig. 38). The Z-plasty accomplishes both (Fig. 39).

It is found in practice that if the web is not reasonably broad before the deepening procedure the Z-plasty does not work well. This is so because a Z-plasty of reasonable limb length cannot be constructed in the narrow web (Fig. 40). With an excessively short initial limb length, lengthening and shortening as already shown would be correspondingly small, and render the procedure pointless.

The Reverse Z-plasty

If the Z-plasty can be used to deepen a web, the converse should also be possible, namely that a "reverse Z-plasty" should be effective in making a web more shallow. Clearly it is not a procedure called for often but in the case of the

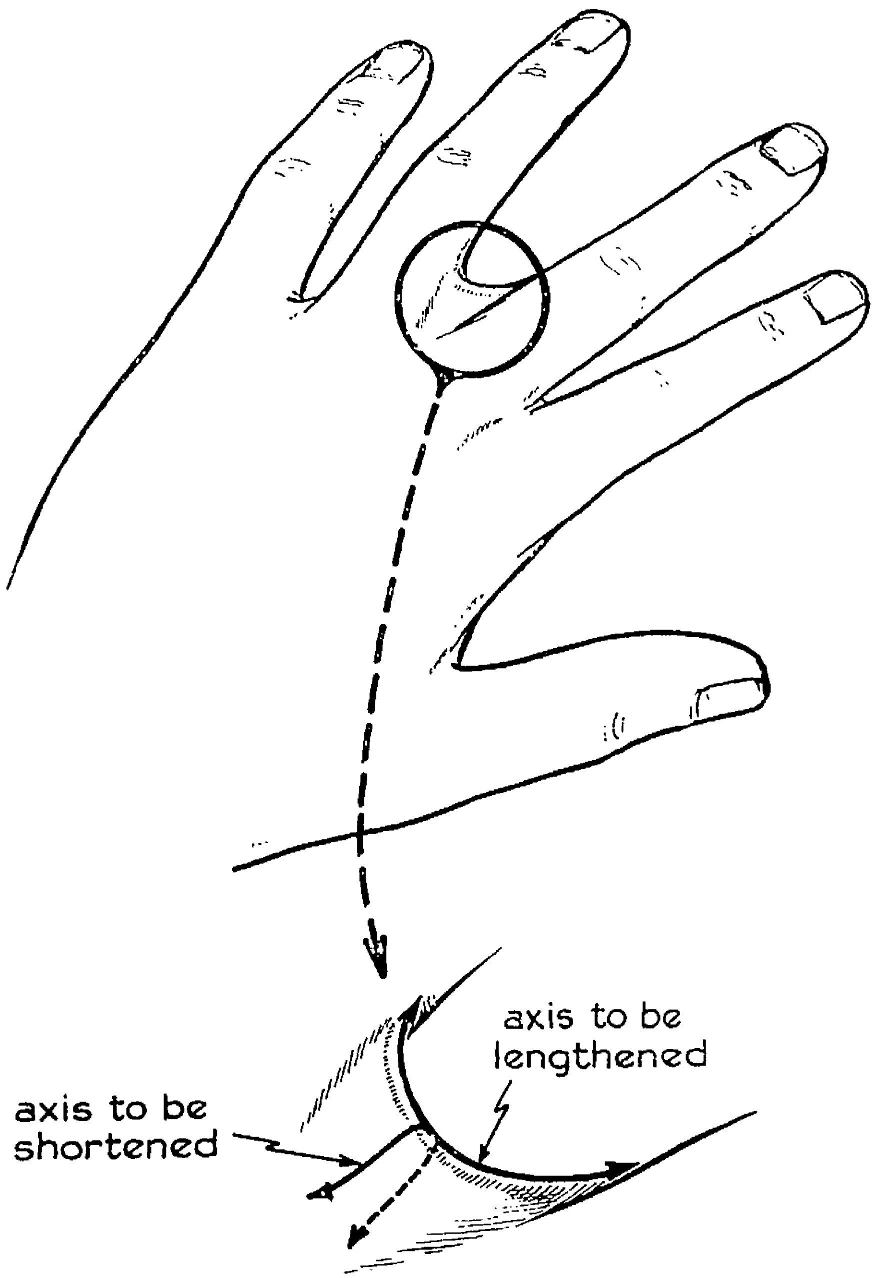

Fig. 38 : The axes in which lengthening and shortening takes place when a Z-plasty is used to deepen a finger cleft.

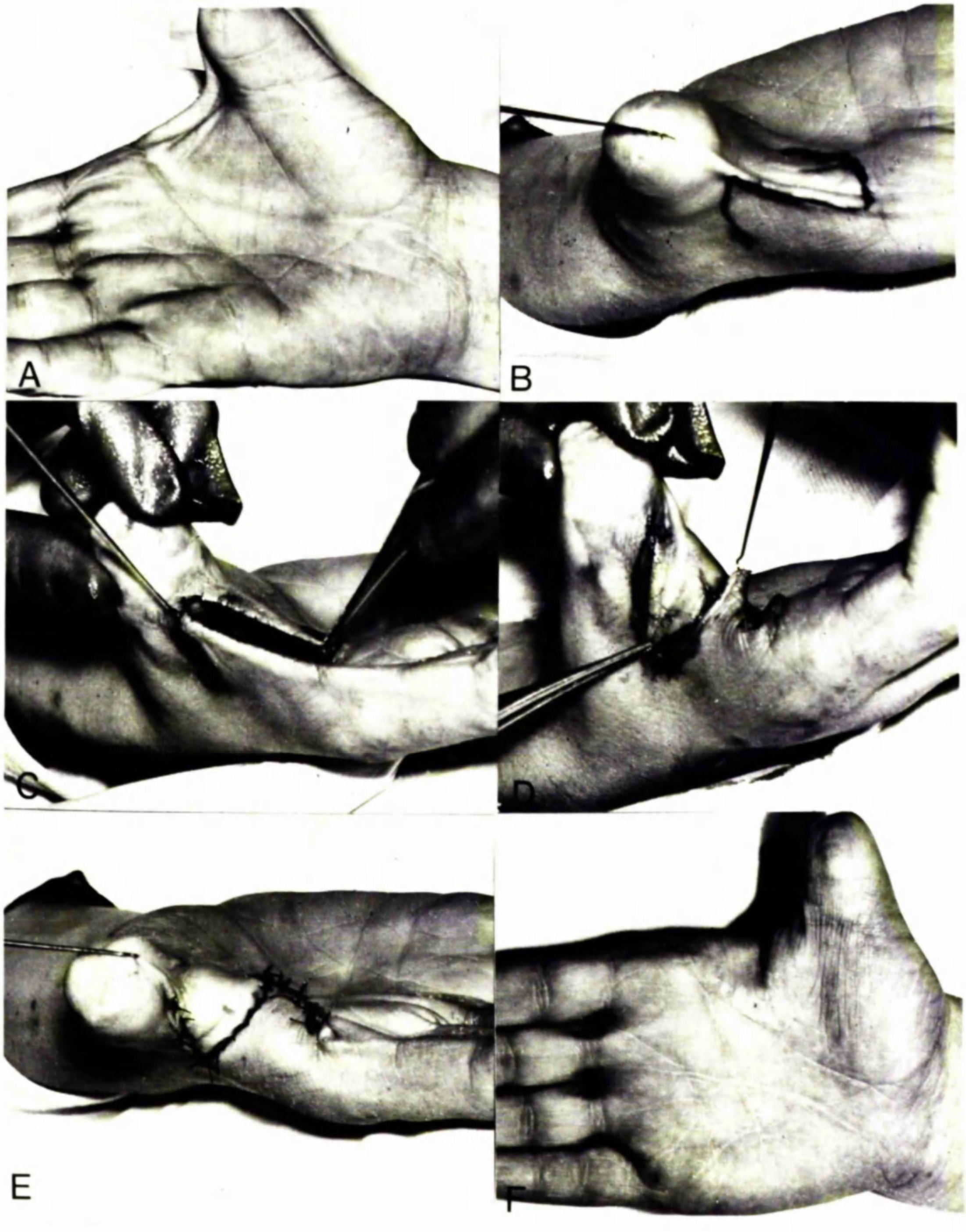

Fig. 39 : The cleft between thumb and index finger deepened using a Z-plasty, showing the several stages. The pre-operative state (A) and the Z-plasty drawn out (B). The flaps cut (C) and transposed (D and E). The final result (F).

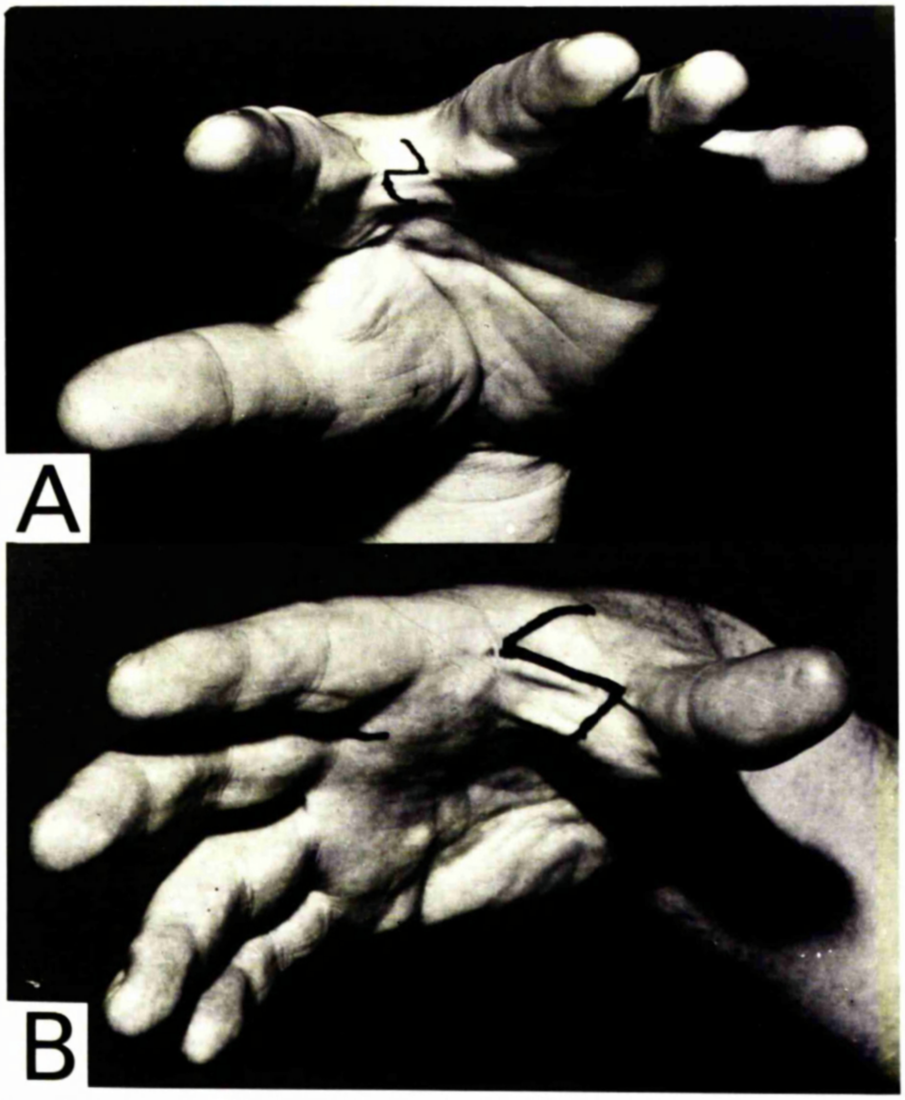

Fig. 40 : The difference in the Z-plasty in narrow and broad webs.

The broad web (B) permits a Z-plasty of long limb length to be constructed while the narrow web (A) permits only a Z-plasty with short limb length.

lobster claw or the corresponding anomaly of the foot, the method can be used to advantage, the steps being shown in Fig. 41. In effect the surgeon starts with the completed Z-plasty and works back to the pre-operative state. Reversing the reasoning used for web deepening (Figs. 38 and 39) the web is made more shallow (Fig. 41).

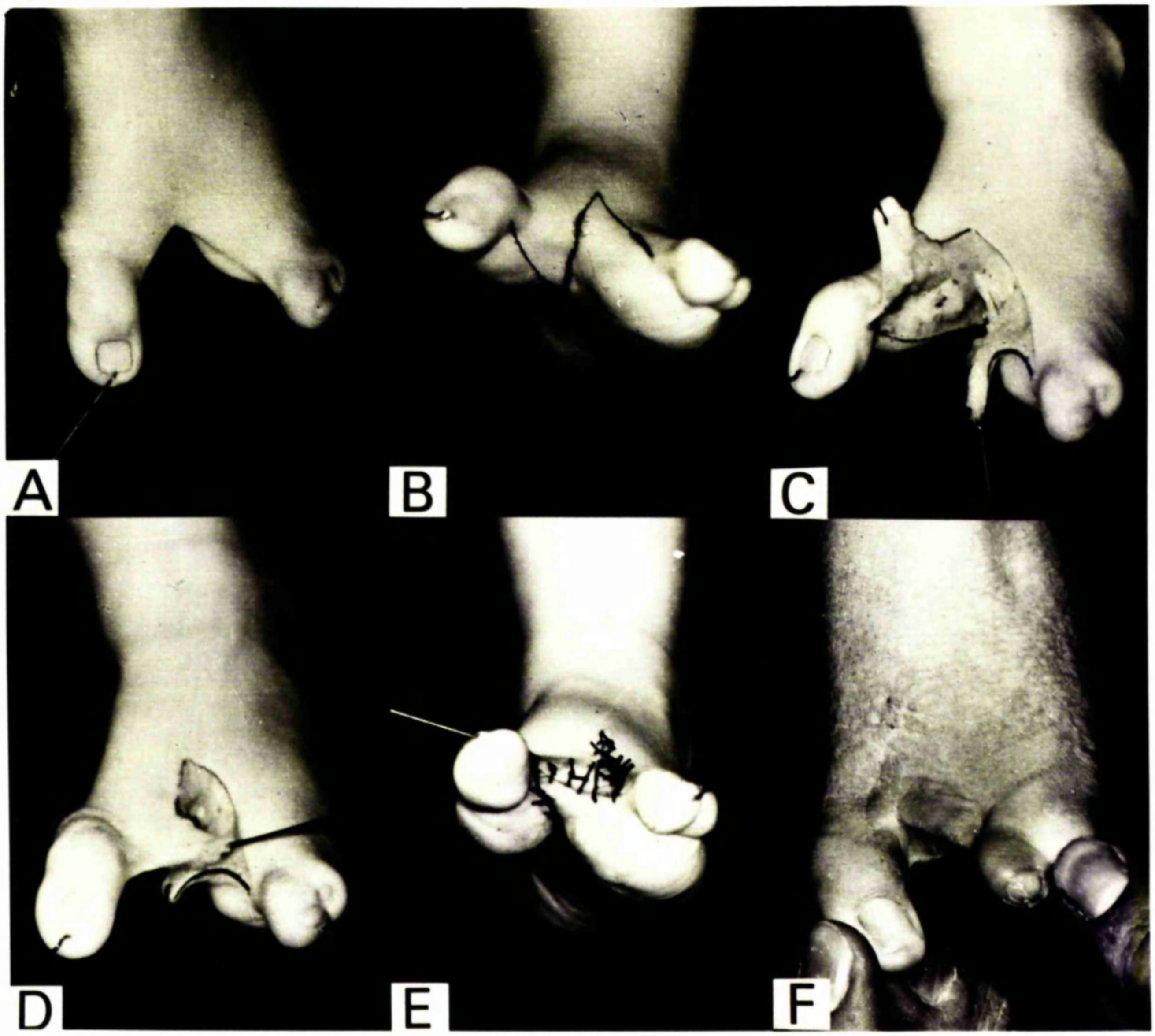

Fig. 41 : The reverse Z-plasty, used to make a web more shallow in "lobster claw" congenital anomaly of the foot.

The cleft between the hallux and the adjoining toe (A) is reduced in depth using the reverse Z-plasty, drawn out (B), with flaps raised (C), transposed (D), and sutured in position (E). The end result is shown (F).

CHAPTER 6

THE Z-PLASTY IN THE HAND

"It is clear, I think, that we may account for many ordinary biological processes of development or transformation of form by the existence of trammels or lines of constraint..."

D'Arcy Wentworth Thompson,
On Growth and Form, p. 287.

In discussing the Z-plasty, especially as it relates to contractures, the limiting factors have been fully described but nowhere in the body do these limiting factors exact a fuller quota of respect than in the hand because of its anatomical peculiarities. In fact, modifications of design primarily intended for use in the hand have proved their value in other sites.

The sites of the body where the Z-plasty has something to offer concern concavities rather than convexities - it is in the popliteal fossa, not over the patella, that the Z-plasty is used. In the same way the Z-plasty is used on the palmar surface of hand and finger, not on the dorsum.

Characteristically, palmar skin shares with plantar skin a marked lack of extensibility and also a very firm attachment to the underlying fascia. These attributes, in the context of the Z-plasty, mean that palmar skin neither moves easily nor does it turn readily. When a Z-plasty is used in other parts of the body (if one excludes its rather special use in facial scars) a good index of design and execution is that, once cut, the flaps should literally fall into their transposed position. It should be difficult to return them to their pre-operative position. In the hand, with its inextensile skin reluctant to move and turn, this is seldom true, and with this reluctance to move and turn is coupled the fact that there is little if any skin to spare either in the palm or in the fingers. Clearly this is a situation where maximal lengthening coupled with minimal shortening is desirable and consequently in the hand the multiple Z-plasty is almost universally used.

In keeping with the recognition of the fact that scars in the palm should parallel flexure lines, the Z-plasty should be so planned that its transverse limb after transposition lies in a flexure line. Wood Jones (1941) stressed that such lines mark the site of what he called a "skin joint" brought into action by the movement of an underlying bony joint, and he pointed out that they constitute lines of comparative skin rest. The advantages, when a joint has to be crossed by the Z-plasty, of having the transverse scar in the corresponding flexure line scarcely need to be emphasized. The method of siting a transverse limb has already been demonstrated (Fig. 17) and the same method is entirely applicable in the hand.

All that need be done in planning is to bring the transverse limb into the flexure line - a fact more readily seen from illustration than description (Fig. 42).

The Z-plasty then can be designed so that the resulting transverse limb will lie along the flexure line, but the question remains of how large each Z-plasty can be made. The palm differs slightly from the fingers in the factors which limit size though the final limits themselves are virtually the same in both. A good working rule is that a Z-plasty of a size which would fit into the adjoining phalangeal segments will give rise to shortening in the transverse axis acceptable to the local tissues. This is certainly the largest size which should be used and on occasion a smaller one may be preferable.

One would expect the problem of factors limiting size of the Z-plasty to arise most acutely in the fingers for it is here that the least tissue appears to be available. In the palm, however, the availability of skin for transverse shortening is more apparent than real. The expanse of skin is admittedly much greater than in the fingers, but the skin itself is more

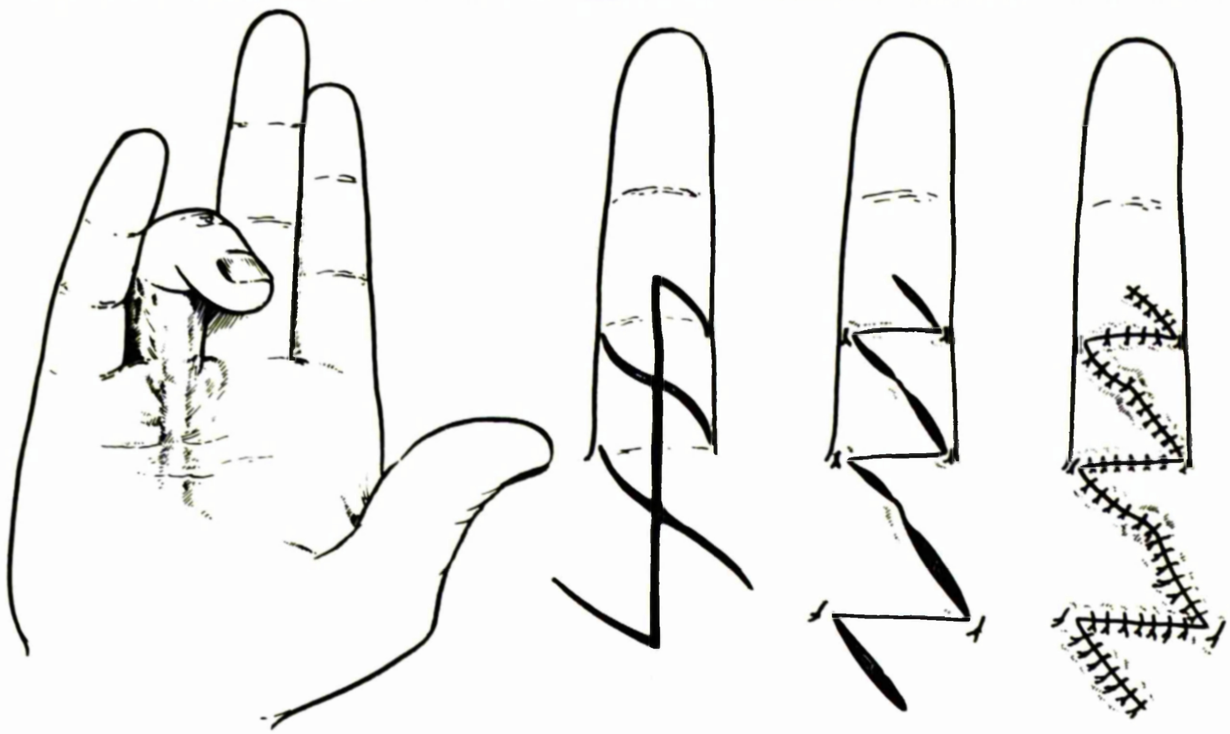

Fig. 42 : The multiple Z-plasty as used in the hand as for example in the treatment of Dupuytren's contracture, showing how by applying the technique shown in Fig. 17 the transverse limb of each Z-plasty can be made to lie in a flexure line.

firmly fixed to the underlying palmar fascia and this in turn is anchored to the metacarpals by its vertical septa. These factors impair its mobility enormously and put strict limits on its availability for transverse shortening as well as reducing its capacity to turn readily in transposition of Z-flaps. Furthermore the skin in the region of the proximal and distal palmar creases has a poor blood supply in comparison with the palmar skin elsewhere (Conway and Stark, 1954) and this is the area of the palm where the Z-plasty tends to be most oftan required. These factors combine to place a very strict curb on the size of Z-plasty which it is safe to construct in the palm. It should certainly not be larger than the Z-plasty which would be considered appropriate for the proximal phalangeal segment and is often better made smaller.

The lack of available tissue for transverse shortening is much more obvious in the fingers and the actual size of the possible Z-plasty diminishes from the proximal to the distal phalangeal segments. There are three separate factors which can be responsible for this, one or more of which may be operative at a time in each of the fingers. Firstly, the distance between flexure creases tends to diminish from the proximal to the distal end, and the Z-plasty which can be constructed consequently becomes smaller. Secondly, the finger narrows from the proximal to the distal end, and in consequence the tissue available for transverse shortening becomes less. Thirdly, the mobility of the dorsal tissues becomes less from the proximal to the distal end, reducing the slack available for transverse shortening.

The experienced surgeon is usually able to take these factors into account and design a continuous multiple diminishing Z-plasty (Fig. 43) but this is rather a refinement and by no means obligatory. An equally good result will be obtained by making a series of discontinuous Z-plasties linked by the single line running proximo-distally along the fingers and palm (Fig. 44).

It was previously pointed out (Fig. 25) that with a multiple Z-plasty lengthening tends sometimes to be greater than the tissues can accommodate and this gives rise to

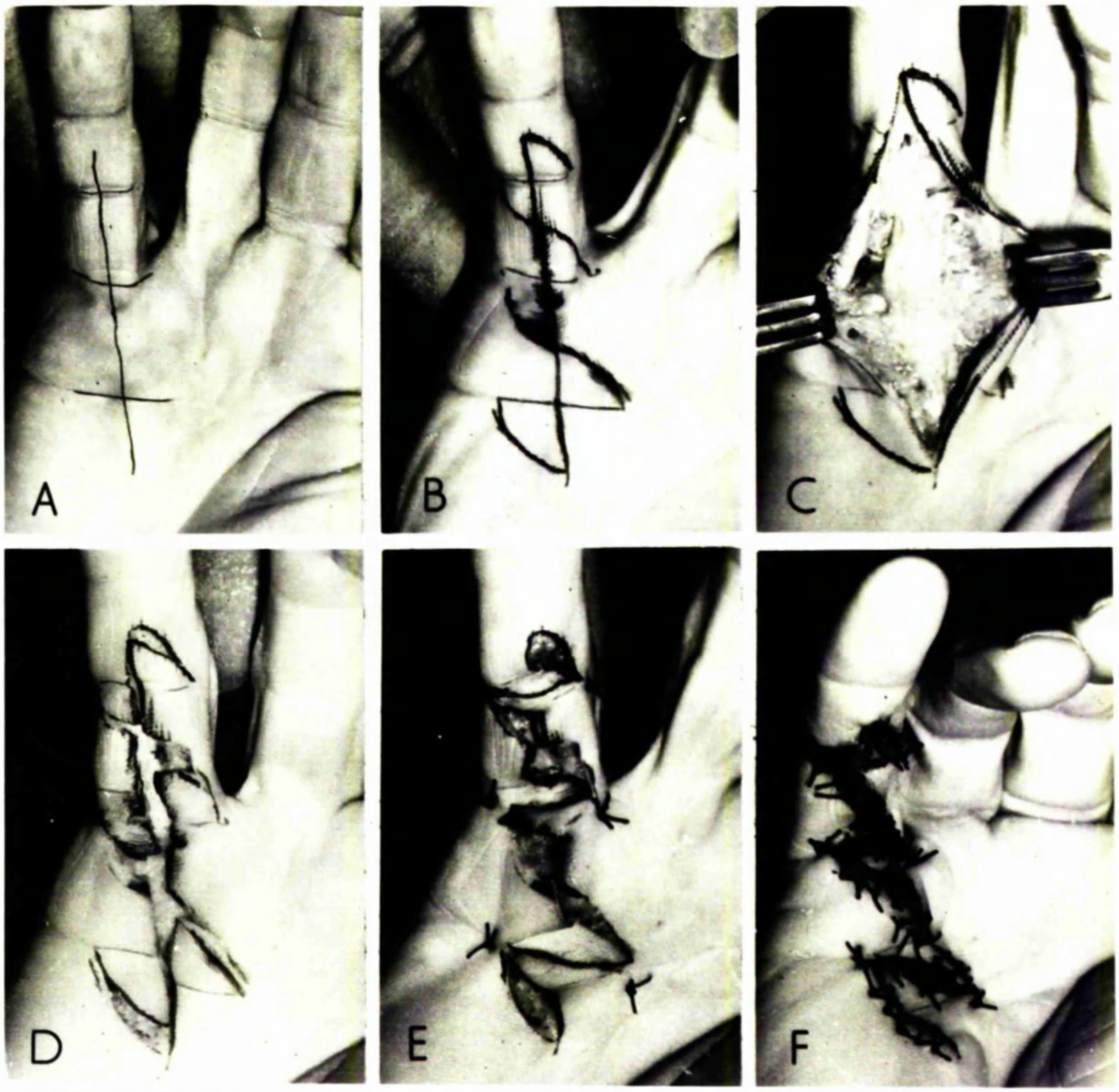

Fig. 43 : The multiple Z-plasty used in the treatment of Dupuytren's contracture involving the little finger.

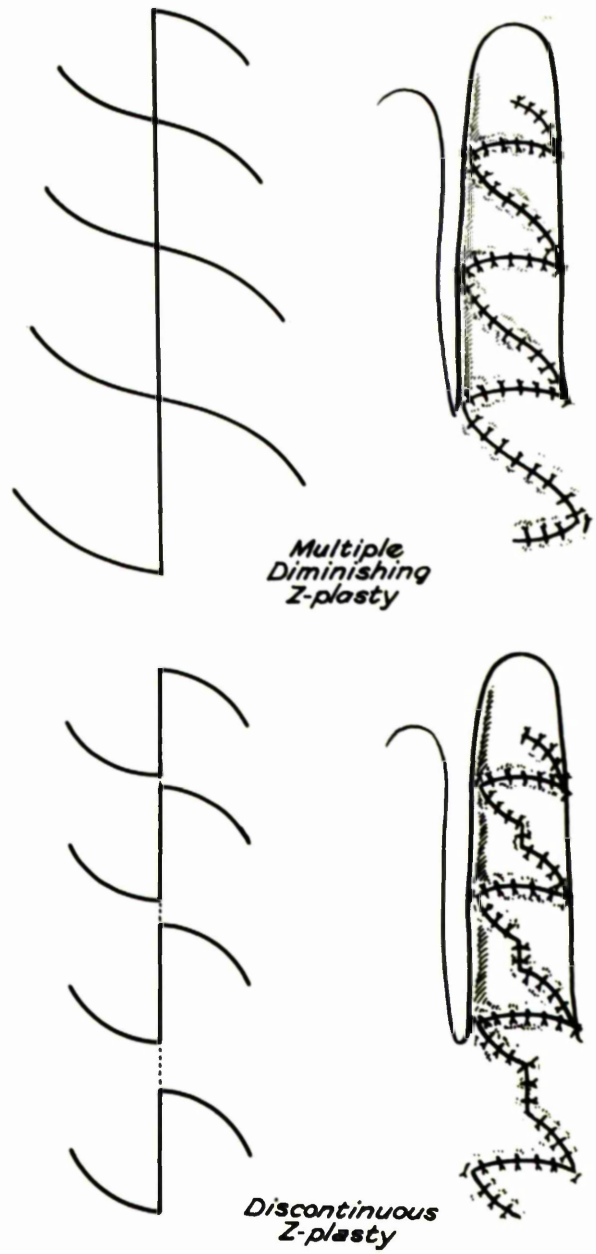

Fig. 44 : The design of the multiple diminishing Z-plasty and the discontinuous Z-plasty showing how the two produce virtually identical results.

overlapping of the flaps as they pass from one Z to the next. This happens almost invariably when a multiple Z-plasty is used in the hand. While it may be appropriate in other sites to trim the excess this should not be done in the hand. With the transverse limbs placed in flexure creases the excess develops between the creases, particularly in the middle of a phalangeal segment (Fig. 43). There is a natural bulk in this part of the normal finger and the redundancy settles with time to a normal and natural looking bulkiness.

The method was initially used to correct the linear scar running along the length of the finger which was giving rise to a flexion contracture. The success of the multiple Z-plasty in this has led to its use in Dupuytren's contracture despite the fact that the skin is not primarily involved by the pathological condition. In Dupuytren's contracture it allows use of the obvious and logical surgical approach - abhorred in the past with good reason by so many surgeons - namely the longitudinal incision along the length of the involved finger and into the palm as far as needed. Such a linear incision gives excellent exposure, there is no blind area in the difficult segment just proximal to the web, and the neurovascular bundles can be visualised throughout their length. In this field too the Z-plasty though primarily being used for exposure does in addition positively eliminate any tendency to subsequent scar contraction.

CHAPTER 7

DISCUSSION AND CONCLUSION

Recent issues of "Plastic and Reconstructive Surgery", the Journal of the American Association of Plastic Surgeons, have contained a series of reprints of classic texts in Plastic Surgery, each followed by an authoritative commentary and discussion from a modern viewpoint. Recently John Staige Davis' paper on the Z-plasty, originally published in 1931, was reproduced. In the subsequent illuminating commentary by Bradford Cannon (1966) the aspects of Davis' paper which would be unacceptable in modern practice were discussed, with an explanation of why views have changed in the interval.

Davis' contention, unacceptable to-day, was that in diffuse scar contractures the scar tissue could be used in the Z flaps. His main use for the method was in fact in post-burn contractures and it is striking that in his paper he does not mention once the question of where the lengthening is coming from or discuss simultaneous shortening. As Cannon states and as has been amply proved in the foregoing text, "the tight web can be relaxed by a Z-plastic but only at the expense of slackness in the axis at a 90° angle to it." The point which Davis does not make and which explains why the method is unsatisfactory in most burn scars is that the burn scar which has contracted, has contracted in all directions simultaneously. In effect all axes are contractural axes and, if one is more obviously contracted than another, this is purely relative (Fig. 45) and does not mean that the other is capable of providing slack for lengthening. It explains incidentally why it is preferable to replace the missing skin by grafting rather than by local tissue shifts. At the time of Davis' paper, of course, the technique of split-skin grafting had not been developed and Davis naturally had to rely on second best, in this instance the Z-plasty. In fact, most plastic surgeons do attempt on at least one occasion to correct a narrow contracted burn scar with a Z-plasty because it looks as though the contracture is only in one axis. The experience is usually a disappointing one in that correction is found only to be partial; incomplete because the skin loss has really been multi-axial. Burn scars are seldom if ever <u>totally</u> correctable by the Z-plasty.

Fig. 45 : An axillary contracture resulting from a burn, showing how although the contracture appears to be in one axis it is on closer inspection really multi-axial.

In plastic surgery, particularly in the last 20 years, the Z-plasty has increasingly pervaded the specialty as application after application has been found for it. In all of these it is possible to see the operation of one or more of the principles already discussed. In general I have confined myself in this thesis to considering particular clinical situations which led me to the discovery of the underlying principle or which seemed to illustrate the principle particularly effectively.

It is also of interest to consider possible ways in which the Z-plasty might be of use in abdominal and other fields of surgery. Some such uses have been described already, in hollow cylinder anastomosis (Blocker et al., 1949; Holman and Hahn, 1953), to the anastomosis of the common bile duct (Singleton and Moore, 1950), in urethral stricture (Dingman, 1955). It is clear that despite these papers the method has not caught on. Why should this be so? My own experience of the Z-plasty, though an extensive one in plastic surgery, is limited to this specialty and I can only speculate. It is possible nonetheless to venture reasonable guesses, apart from the obvious one of isolation of specialties and a lack of cross-fertilisation of ideas from one specialty to another.

The first relates to flap cutting. In the skin Z-plasty, the vulnerable segment of the flap is its tip, though a way to broaden the tip (Fig. 46) and reduce this vulnerability has been described (McGregor, 1960) which is now standard (Converse, 1964; Grabb and Smith, 1968). Tip necrosis, though a nuisance, is seldom catastrophic in any case with a Z-plasty used in the skin. In gut, bile duct, ureter, etc. such loss would be disastrous since it would result in leakage from the line of anastomosis.

The second, not unrelated to the first, concerns the factor of blood supply. Without an accurate knowledge of the vascular pattern and general viability of Z-flaps cut in gut, etc. one can only speculate on the safety margin but it might well be small. The problem of blood supply can be unexpectedly relevant as a personal experience of tracheostomy following pharyngo-laryngectomy showed. Having previously encountered the not uncommon problem of

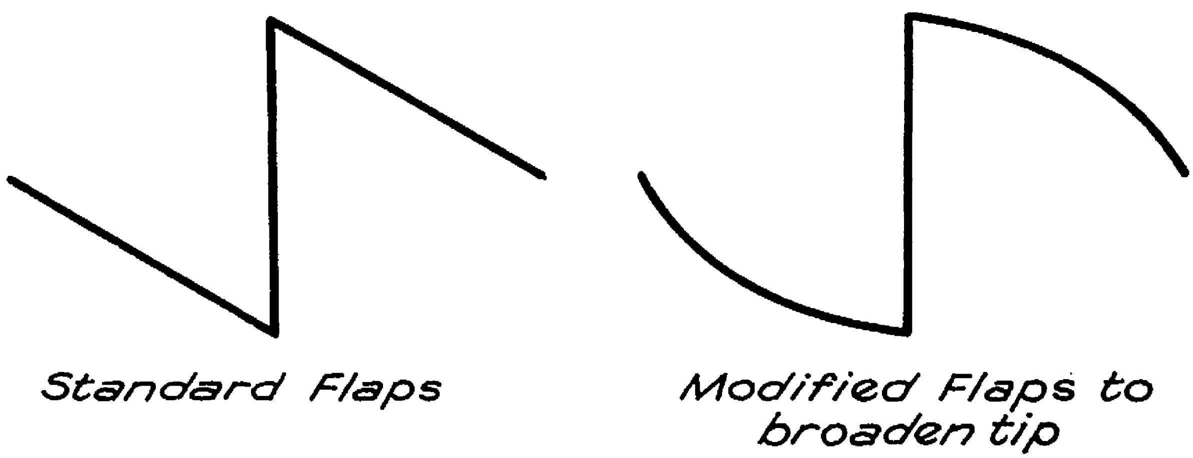

Fig. 46 : The standard Z-plasty flaps and the flaps modified to broaden the tips.

delayed stricture formation at the tracheostome I made a multiple Z-plasty around the stoma at the time of making the tracheostome in the hope of preventing the subsequent development of a stricture. The blood supply of the tracheal flaps was inadequate and all necrosed. Preliminary investigation of this factor in all the potential applications would certainly be required before any use was made of the method in man.

The third refers to surgical technique. The demands on standards of suturing, fineness of technique, suture materials and instruments would be exacting in a way more in keeping with the operating microscope than with the general style of abdominal surgery, especially when anastomosing one of the narrower tubes. Admittedly it is a technique which could be learned, but before setting out to learn it the advantages would need to be very clear-cut - and they are not. One feels further that to show the method to be technically feasible would scarcely be enough; that abdominal surgeons would remain to be convinced that it was worthwhile.

It is certainly true that despite these forays into the abdomen, the method has stubbornly remained limited to the skin. But there its popularity and uses have steadily increased both in the standard ways described in this thesis and in other more exotic though less frequently required fields.

The Z-plasty has applications in most parts of the body surface and modifications are required to suit local anatomical conditions and pathological circumstances. Nonetheless, the basic theory remains valid at all times and its effects can always be described in terms of this theory. Furthermore, with a knowledge in depth of the theory, we can see with greater clarity why the modifications are not merely desirable but often essential and why even the Z-plasty in reverse may have a use. As D'Arcy Thompson says on page 370 of his classic "On Growth and Form" :

> "Growth and Form are throughout of this composite nature; therefore the laws of mathematics are bound to underlie them, and her methods to be peculiarly fitted to interpret them."

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ACKNOWLEDGEMENTS

I wish to thank Mr. Ian McKie, Department of Dermatology, Glasgow University, for the time, care and skill he has expended on the production of the illustrations and Mr. Robin Callander for the line drawings previously reproduced in the publications of my own listed in the references.