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CLINICAL REPORT

Optimal circumference reduction of finger models for good prosthetic fit of a thimble-type prosthesis for distal finger amputations

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Abstract—The prosthetic fit of a thimble-type esthetic silicone prosthesis was retrospectively reviewed in 29 patients who were fitted following distal finger amputations. The aim was to correlate prosthetic fit with the magnitudes of circumference reduction in the finger models used to produce the prostheses and to identify the optimum reduction for the best outcome. A good fit is achieved primarily by making the prosthesis circumferentially smaller than the segment of the residual finger (residuum) over which it "cups". The percentage reduction in circumference of the finger model against the residuum model was calculated by dividing the difference in circumference between the residuum model and the finger model by the residuum model circumference and multiplying the result by 100.

The computed percentage circumference reduction in the finger models ranged from small (1–3), moderate (5–7), to large (8–9). Twelve of 15 patients whose finger models had between one to three circumference reductions had a loose prosthetic fit. Only two of 14 patients who had a larger model circumference reduction of between five to nine had loose-fitting prostheses. Two of five patients who had eight to nine model circumference reduction had an uncomfortably tight prosthetic fit. A 5–7% circumference reduction in the finger model was shown in this study to best translate into good fit of a thimble-type prosthesis for distal finger amputations.

Key words: *esthetic silicone prosthesis, distal finger amputations, finger model, model circumference reduction, prosthetic fit, residuum model.*

INTRODUCTION

For many patients, the psychological impact following a traumatic loss of digits in the hand can be out of proportion to the extent of the mutilation (1,2). Frequently, the loss of even the tip of a digit can be so emotionally disturbing to the patient that it deserves serious attention. For distal finger amputations, the provision of a distal cap or thimble prosthesis made of silicone rubber has been advocated (3–5). Leow, et al. (5) recommend fitting a thimble prosthesis over a full-length finger prosthesis when the residual length distal to the mid-shaft of the middle phalanx is more than 5 mm. In such a case, a thimble prosthesis is fitted on the residual finger (residuum) such that its proximal edge

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terminates distal to the proximal finger joint but proximal to the mid-shaft of the middle phalanx (**Figure 1**). Fitting a thimble prosthesis offers two important advantages (5) over a full-length finger prosthesis: i) it avoids fitting across and thus allows unobstructed mobilization of the proximal interphalangeal joint (PIPJ); and ii) it minimizes coverage and thus allows maximum sensibility of the intact skin. The proximal edge of the prosthesis is made thin and translucent using a fabrication technique to achieve a good visual blend with the surrounding skin.

A constraint confronting the choice of fitting a long finger residuum with a thimble prosthesis lies in the short residual length—distal to the PIPJ—that is available for a suction-type fit and the associated higher probability of an accidental slipping off of prosthesis from a suction loss. The problem is compounded by the fact that a suction-fitted prosthesis acts very much like a pressure garment and when worn for a protracted period, can shrink the residuum via soft tissue compression. The challenge in fitting thimble prostheses is to achieve a good prosthetic fit despite these constraints. In these suction-fitted prostheses, the elastic and nonporous silicone rubber allows an airtight "cupping" of the residuum such that an incipient slippage of the prosthesis is immediately followed by an internal vacuum effect that checks further displacement. To ensure a secure prosthetic fit, the proximal segment of the prosthesis is made circumferentially smaller than the segment of the residuum over which it "cups." This is done primarily through prior circumference modification of the finger models after which the prosthesis is modeled.

In this retrospective study, the authors reviewed in 29 patients the prosthetic fit of thimble prostheses that were fabricated from finger models made circumferentially smaller than the positive models of the residuum in varying magnitudes. The aim was to correlate the magnitudes of model circumference reduction with the outcome and to identify the optimum that best translates into good prosthetic fit.

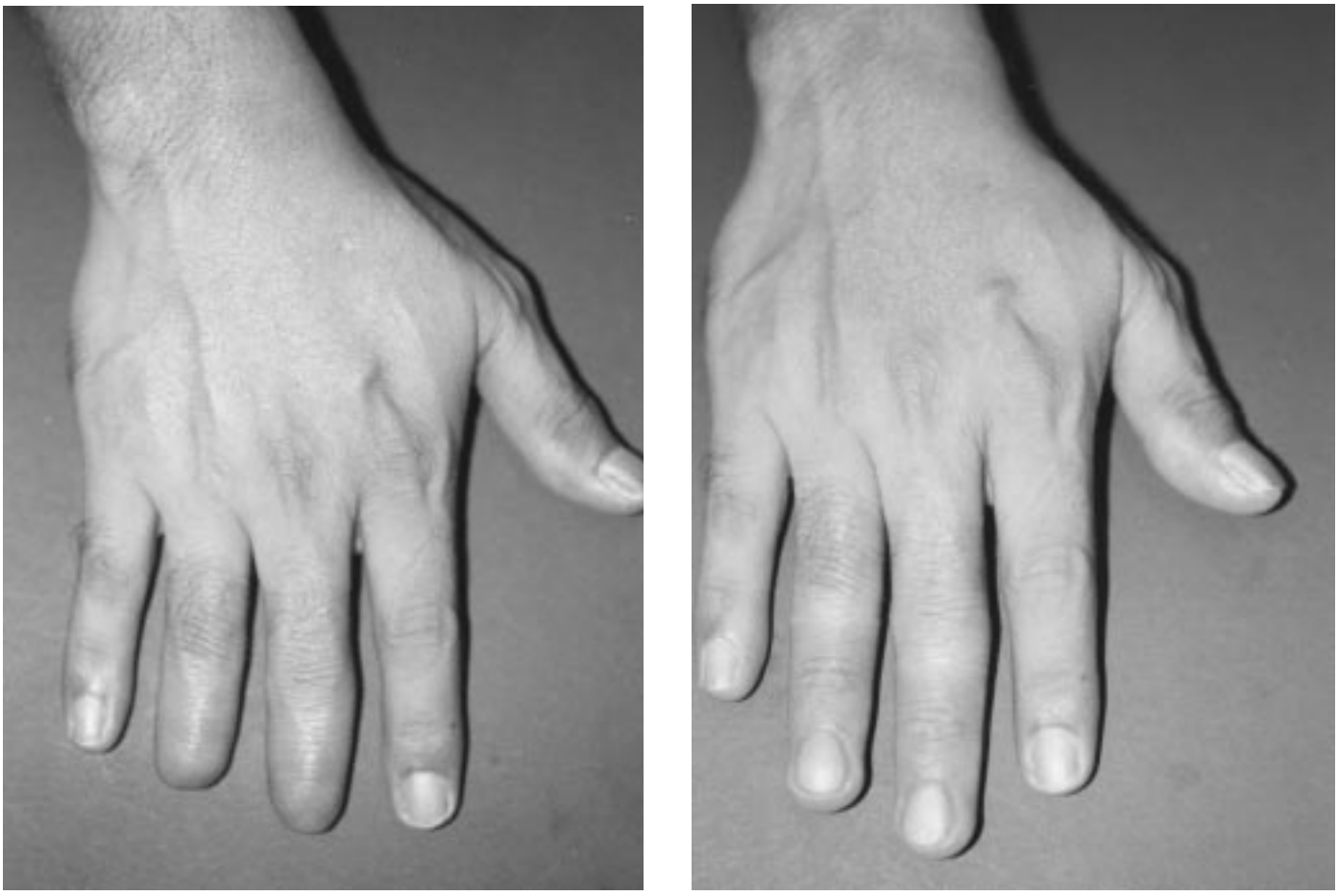

Figure 1:
One of the patients (Case 20) with distal amputations involving the right middle and ring fingers (a) before fitting (b) after fitting with thimble prostheses.

MATERIALS AND METHODS

Data Collection

The prosthetic records of 258 patients who were fitted with a variety of esthetic silicone prostheses between 1990 and 1998 were reviewed to identify those cases that had a thimble-type prosthesis. Additional procedures that were documented to have been done at the time of fitting to achieve a good prosthetic fit were noted and recorded (**Table 1**). The measures that were taken to improve prosthetic fit at follow-up reviews and at subsequent patient visits concerning loose-fitting prostheses were also noted and recorded.

The circumference of the positive models of the residuum and of the corresponding contralateral fingers that were used to produce the prostheses in each case was

Table 1.
Patient profile, percentage circumference reduction of finger models against residuum models and outcome of prosthetic fit

Patient No.	Gender/Age (yr)	Amputated digits (Affected hand)	Time span between amputation and fitting (yrs)	Assessment of the amount of soft tissue cover of the residua	% circumference reduction of finger models against residuum models	Measures taken to rectify a loose fit	
						Were silicone layers added?	Was skin adhesive used?
1	M/29	1 (R)	1/2	Good	1% (small)	Yes	Yes
2	F/44	R (R)	4	Poor	1% (small)	-	-
3	F/47	M (L)	1/2	Good	1% (small)	Yes	Yes
4	M/23	M (R)	1/2	Good	1% (small)	Yes	-
5	F/38	M (L)	32	Good	1% (small)	Yes	-
6	F/32	M (L)	31	Good	1% (small)	Yes	Yes
7	M/46	I, *M (R)	1	Poor	2% (small)	Yes	-
8	M/40	M, R (L)	1/2	Good	2% (small)	Yes	-
9	F/20	I (R)	1/2	Good	2% (small)	-	-
10	M/26	R (R)	1/2	Poor	2% (small)	-	-
11	F/32	1 (R)	28	Good	2% (small)	Yes	-
12	F/43	M (R)	1/2	Good	2% (small)	Yes	-
13	#M/47	I, M (R)	1/2	Poor	3% (small)	Yes	Yes
		*T, *I, M, L (L)	1/2	Poor			
14	F/40	M (R)	1/2	Poor	3% (small)	Yes	Yes
15	F/17	M (R)	3/4	Good	3% (small)	Yes	Yes
16	F/22	R (L)	20	Good	5% (moderate)	-	-
17	F/16	M (R)	14	Good	5% (moderate)	-	-
18	M/44	M (R)	1	Good	6% (moderate)	-	-
19	F/37	M (R)	1/2	Good	6% (moderate)	Yes	-
20	M/42	M, R (R)	1	Good	6% (moderate)	Yes	-
21	M/27	M (L)	1/2	Good	7% (moderate)	-	-
22	M/25	I, M (L)	1/2	Good	7% (moderate)	-	-
23	M/29	I (R)	1	Poor	7% (moderate)	-	-
24	M/40	*M, R, (R)	1	Poor	7% (moderate)	-	-
25	M/32	R, L (R)	1/2	Good	8% (large)	-	-
26	M/19	R (R)	1/2	Good	8% (large)	-	-
27	M/21	I (L)	1/2	Good	8% (large)	-	-
28	F/41	M (L)	1/2	Poor	8% (large)	(Prosthesis expanded)	
29	F/38	I (R)	18	Good	9% (large)	(Prosthesis expanded)	

Bilateral involvement.
* Finger residua that were fitted with a full-length finger prothesis due to insufficient length for fitting a thimble prosthesis.
T - Thumb; I - Index; M - Middle; R - Ring; L - Little; (R) - Right; (L) - Left.

noted. The difference in circumference between the residuum model and the modified finger model was calculated. The percentage circumference reduction in the finger model against the residuum model was computed using the following equation:

$$\% \text{ Circumference Reduction (of Finger Model)} = \frac{\text{Residuum Model}_{\text{Circumference}} - \text{Finger Model}_{\text{Circumference}}}{\text{Residuum Model}_{\text{Circumference}}} \times 100\ \%$$

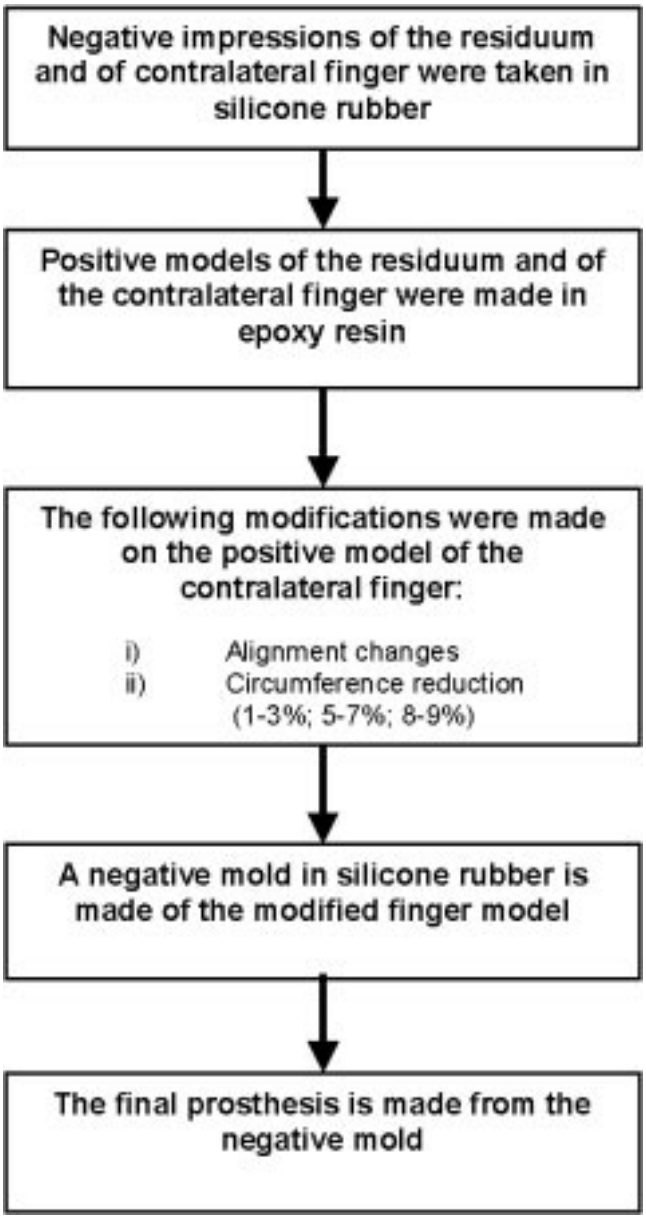

Figure 2:
A flow chart showing the sequential procedures involved in producing the custom-molded prostheses.

Production and Modification of Finger Models

All prostheses were custom-made to be identical to the size, shape and skin details of the lost segment. The sequential procedures involved in producing the prostheses are depicted in the flow chart shown in **Figure 2**. A positive model of the finger was first made in epoxy resin (Chemi R77N, Chemicrete Enterprises, Singapore) from a negative impression in silicone rubber (Zerosil-light, Dreve-Dentamid, GmbH, Germany) taken from the corresponding finger of the patient's contralateral uninjured hand (**Figure 3**). A positive model of the residual finger was similarly made. The impressions of the residua were taken at least 4 months post-amputation and after application of pressure garment or Coban™ bandage to bring down edema. Two important modifications were done on the finger models before they were used to fabricate the prostheses. These included alignment changes (6) to match the mirror orientation of the digits on the opposite hand, and circumference reduction against that of the residuum model (baseline circumference). The magnitude of circumference reduction in each case took into account two parameters: i) the circumference of the residuum obtained using a soft measuring tape; and ii) the adequacy of soft tissues in the residuum. In working out

Figure 3:
The finger models after which the prostheses shown in **Figure 1** were modeled and the respective models of the finger residua. The finger models were made circumferentially smaller than the residuum models around the "middle Phalanx" segment to achieve a secure prosthetic fit.

the final/target circumference for a finger model, between 0.5 mm to 4.5 mm was first subtracted from the residuum model circumference, depending on the size of the digit involved. An additional 0.5 mm was subtracted when the residuum is assessed as having a good soft tissue cover as contrasted to none when it is bony with poor soft tissue cover. The resulting circumference was used as the target circumference for the finger model. The excess material was ground off the finger model using a rotary electric grinder (Rotex™ 780, Dentamerica Industry, California). More material was taken off from the palmar side and less from the lateral aspects, leaving the dorsal aspect with the fine skin details intact. A negative mold in silicone rubber (7) was then made from the modified finger model from which the prosthesis was molded.

Layered Molding and Color-Matching of Prosthesis

The prostheses were molded in multiple layers of silicone rubber (Cosmesil™, Principality Medical Ltd., South Wales, UK) and matched to the color of the patient's skin using a color-matching technique based upon the multiplier anatomy and optical properties of the human skin (8–13). With this layered prosthetic design, a translucent outer layer and an opaque inner layer sandwich an intermediate layer of touch-up colors to reproduce the esthetic effects of the skin and impart a life-like appearance to the prosthesis. The thickness of the prosthesis was maintained at 0.2 mm to 0.3 mm around the edges, with a gradual increase in thickness towards the distal end in conformity with the tapering distal shape of the residuum.

Fitting Methodology

A good prosthetic fit is defined as being achieved when the prosthesis fits securely on the residuum without causing any pressure discomfort. To achieve a good suction fit, the inner circumference of the prosthesis was made smaller than that of the residuum. This was achieved through prior circumference reduction of the finger model against the circumference of the residuum model. The thickness of the prosthesis would further add to the circumference disparity. A loose prosthetic fit at the time of fitting or at follow-up reviews was first rectified by molding additional layers of silicone rubber onto the inner surface of the prosthesis. This was to reduce the inner circumference of the prosthesis and improve suction (**Table 1**). When this modification did not result in a satisfactory improvement, the use of a skin adhesive (Pros-Aide, ADM Tronics, Inc., New Jersey) was prescribed to augment the fit. The segment of the prosthesis that corresponds to the amputated part of the digit was packed with a material comprised of silicone and polystyrene beads.

A set of two prostheses were provided for each digit involved unless otherwise requested by the patient. The patients were advised to pay careful attention to their prostheses during the initial weeks and to return within the first month of fitting for rectification if they were to encounter a problem with a loose fit.

Statistical Methods

The Fisher's exact test and logistic regression were used for the statistical analysis.

RESULTS

Patients

Twenty-nine patients (15 males, 14 females) who were fitted with thimble-type prostheses were identified from the prosthetic records (**Table 1**). Their age at the time of fitting ranged between 16 to 47 years (mean, 33 years). Seven patients had multiple-digit loss with one involving both hands. Of a total of 40 finger residua that were fitted, 36 had sufficient length to allow fitting with a thimble prosthesis. A total of 67 thimble prostheses were made. In seven patients, the amputation was a result of an old injury with the post-amputation period at the time of fitting ranging from 4 to 32 years. For the remaining patients who had sustained a new injury, prosthetic fitting was completed at between 6 to 12 months after the date of amputation.

Magnitudes of Model Circumference Reduction *versus* Outcome of Prosthetic Fit

The finger models that were used to produce the prostheses for this series of patients were computed to have circumference reductions of between one percent to nine percent against the circumference of the respective residuum models around corresponding segments (**Table 1**). The results revealed a higher incidence of loose prosthetic fit in cases where the finger models were one percent to three percent smaller than the residuum model, circumferentially. Twelve of 15 patients who had circumference reduction in their finger models of between one percent and three percent had loose-fitting prostheses. In significant contrast, only two of 14 patients whose finger models were given a larger circumference reduction of

between five percent to nine percent had a problem with a loose fit ($p<0.001$, Fisher's exact test). For those 12 patients who had a one to three percent model reduction and had a loose fit, the adding of extra silicone layers to the prostheses alone sufficed in rectifying the loose fit for six patients, while for the other six, the use of skin adhesive had to be additionally prescribed (**Table 1**). For the two patients who were on a larger circumference reduction and still had a loose fit, the computed reduction was six percent. In another two cases—one with a nine percent and the other with an eight percent model circumference reduction—the patients had complained of an uncomfortably tight fit and their prostheses had to be expanded to relieve the discomfort.

DISCUSSION

Precise circumference reduction of finger models aimed at achieving good prosthetic fit constituted an integral procedure in the custom-fabrication of thimble-type prostheses for distal finger amputations. In the very few reports that were identified in the current literature that advocated the fitting of these prostheses, little mention was made concerning the model modification and fabrication techniques behind achieving a good prosthetic fit, given the constraint of a shorter length (distal to PIPJ) available for anchorage.

The method of adding layers of silicone on the inner aspect of the prosthesis should be an option for rectifying a loose fit only when the resulting thickened and hence, more conspicuous proximal edge of the prosthesis can be concealed, for instance, by wearing a ring such as in the case of fitting a full-length finger prosthesis. The use of a ring is, however, not an acceptable means for camouflaging the prosthesis-skin juncture when fitting a thimble prosthesis since it is not customary to have one worn anywhere distal to the proximal finger joint. A concern amongst the patients whose prostheses were thickened was the increased visibility of the prosthesis-skin juncture. The proximal edge of thimble prostheses must therefore remain thin and translucent to blend with the surrounding skin without any need for concealment. In this respect, fitting a thimble prosthesis calls for good prosthetic fit to be achieved from the outset, without having to subsequently resort to increasing the thickness of the prosthesis. This, in turn, demands that an exacting circumference reduction be made on the finger models before they were used to fabricate the prostheses.

When effecting a circumference reduction in a finger model, the authors had used the circumference of the model of the residuum rather than that of the residuum *per se* as the baseline. Circumference measurement of the residuum obtained using a soft measuring tape has the disadvantage of variability, as it is dependent on the tension in the tape around the residuum when taking the measurement. It has also been noted that the measured circumference of the finger residuum tended to be smaller than the measured circumference of a model of itself in epoxy resin. The difference that was observed from this study was 1–2 mm, depending on the size of the digit involved. This discrepancy is attributable to the different extent to which the measuring tape can be snugly applied around the hard epoxy model and the soft tissues of the residuum. The measured circumferences of the residua were referred to and checked against when modifying the finger models.

As a benchmark to facilitate future model modifications, the circumference reductions that were made on the finger models for this series of patients can be categorized into three ranges: small (1–3 percent), moderate (5–7 percent), and large (8–9 percent). Feedback received from patients about loose prosthetic fit during our initial experience with fitting thimble prosthesis had prompted us to experiment on a larger circumference reduction when modifying the finger models. The results of this retrospective study demonstrated that a larger model circumference reduction of between five percent to eight percent is necessary for achieving a secure prosthetic fit and for obviating a subsequent need for rectifying the prosthesis. The complaints in two patients—one with an eight percent and the other with a nine percent model circumference reduction—of an uncomfortably tight fit suggested that eight percent might be the threshold reduction beyond which an excessively tight fit may result.

The presence of residual edema in the residuum at the time of impression-taking is a factor that ought to be considered when deciding between a moderate and a large model circumference reduction. It should be emphasized that unlike transradial amputations where early fitting can be instituted by the provision of a temporary prosthesis before the residuum has matured, the relatively high cost of custom-produced silicone prosthetic fingers makes replacements expensive and early fitting prohibitive. Whereas in more definitive transradial fittings where the use of residuum socks can circumvent a loosened fit from slight volumetric reductions in the residuum, the same cannot be applied when fitting silicone prosthetic fingers. The addition of socks in this case will not only result in suction loss and a comprised prosthetic fit but will also distort the esthetic proportions achieved. For this reason, we routinely complete

prosthetic fitting for patients who had sustained a new injury at least 6 months after amputation when the residuum has largely settled. However, a further residuum shrinkage after fitting, either from waning residual edema or tissue atrophy or a combination of both changes, can commonly occur. When the presence of edema in the residuum cannot be unequivocally ruled out at the time of impression taking, erring on the larger circumference reduction during model modification procedure may better serve to prevent a subsequent loose fit. This was demonstrated in the two patients who had a moderate model circumference reduction of six percent and yet had a loose fit. The interval between fitting and amputation was 6 months for 1 patient and 12 months for the other. Records had shown that a further shrinkage in their finger residua had occurred. For both these patients, the molding of additional silicone layers onto their prostheses sufficed in addressing the loose fit. The problem could have been averted by a larger model circumference reduction of, for instance, eight percent. In another four patients who had a model circumference reduction of between one percent and three percent and whose prostheses required extra silicone layers in addition to the use of skin adhesive for improving the prosthetic fit, further residuum shrinkage was documented. This underlined the need for a larger model circumference reduction of five to eight percent when modifying the finger models to allow for potential late changes in the size of the residuum as it matures further.

The adequacy/amount of the soft tissue cover in the residuum may also be considered when contemplating between a moderate and a large circumference reduction. Of the three patients who had either a one percent or two percent model circumference reduction and yet had no problems with a poor fit, two had finger residua that were assessed as having inadequate/poor soft tissue cover (i.e., bony). None of the three patients who had bony residua and had a moderate to large model circumference reduction had a loose prosthetic fit. Although not proven statistically ($p=0.14$, logistic regression), this seems to suggest that for bony residua, a moderate model circumference reduction would suffice in achieving a good prosthetic fit, while residua having good soft tissue cover and therefore more susceptible to volumetric reduction from tissue compression may require a more aggressive model circumference reduction.

The influence of the variations in the tapers and lengths of the finger residua in excess of the minimum for fitting a thimble prosthesis was not considered in this review in relation to the outcome of the prosthetic fit. The principal aim of this study was to look at the optimum circumference reduction in the finger models that would translate into good prosthetic fit of a thimble-type prosthesis for all digital residua so long as adequate length remains to allow for such a fitting.

CONCLUSION

Exacting prior circumference reduction of finger models for producing thimble-type prostheses for distal finger amputations is crucial to achieving good prosthetic fit, given the shorter distal segment of the residuum available for anchorage and the problems of residuum shrinkage from donning the prosthesis or late tissue atrophy. A five to seven percent circumference reduction in the finger models against the respective models of the residuum was shown to best translate into good prosthetic fit of these suction-fitted thimble prostheses.

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