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Passive hand prostheses

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Despite major advancements in surgical techniques, including microsurgical revascularization and free composite tissue transfer, there are a large number of patients with hand mutilations who are best served with high quality prosthetics targeted to carefully determine the prime needs of each individual. Once defined, a master plan to optimize the meeting of these needs often includes preliminary surgical procedures. Logical conclusions require consideration of all alternatives, surgical and prosthetic. Hand surgeons should, therefore, be knowledgeable about the basic principles, potentials, and limitations of the various prostheses.

The pattern of hand injuries has been progressively changing, with total hand loss becoming increasingly infrequent and bilateral total hand loss extremely rare. Partial hand losses are more frequent and one may see several hundred hand mutilations with some remaining parts for each total hand amputation. Candidates for passive hand prostheses are those patients who have some remaining digits but could use a static complement to enhance the value of remaining natural parts (Fig. 1). One of the basic axioms of all limb amputations is as true today as it was in the past: the more distal the loss, the greater the sensory feedback essential for automatic or subconscious control and the greater the resulting improvement in physical capability.

Another prudent point is that the deformity constitutes a real socioeconomic handicap because of the rapid shifting of the work force from manual labor to service industries in which one's living is made by dealing directly with others. A passive prosthesis should not be considered a cosmetic device. Cosmesis is a term that should be discarded, as it can unjustly deprive patients of benefits to which they are entitled. Cosmesis means changing something normal to have a better appearance, in one's opinion. We are treating specific amputation deformities and passive prostheses can eliminate the stigma of disfigurement in partial or complete hand mutilations. Disfigurement can be a real socioeconomic handicap. In fact, the United States Supreme Court in the case of the School Board of Nassau County v Arleen, 490 US 273, 1987 has confirmed the extreme social and economic impact of deformity.

Goals and realistic expectations

First we must expand the concept of function beyond prehensile capacity to a global concept of acceptance of the individual in society. There should be clear understanding by everyone that no prosthesis is truly replacing missing parts. The purpose of passive prostheses is to minimize the physical, emotional, social, and economic consequences of deformities. Also, it is fundamentally necessary to appreciate the high level of specificity of all hand prostheses. The same patient may need a different type of prosthesis for different occasions. One prosthesis may be required for a factory job, whereas a different prosthesis may be needed for business or social affairs (Fig. 2).

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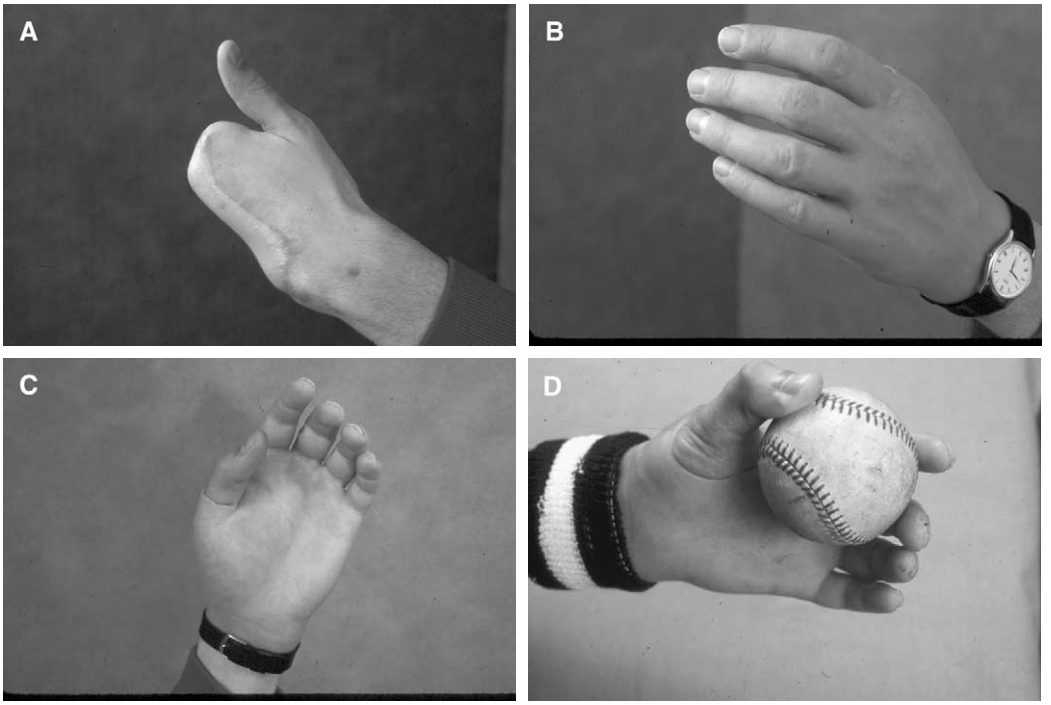

Fig. 1. (*A*) Mutilated hand closed with distant flap. The thumb is normal but virtually useless. (*B*,*C*) Fine custom partial hand prosthesis. (*D*) Prosthetic fingers fabricated with new micro-hinged passively adjustable armature greatly enhance capability.

Because it is not possible for the prosthetic device to restore all of which a normal hand is capable, time should be spent in determining the paramount goals for each patient. If this is done and an appropriate, top quality prosthesis is provided, a high success rate can be anticipated. Unrealistic expectations are fraught with noncompliance and failure.

Another basic axiom is that there is no relationship between the extent of physical loss and the emotional response to it. It cannot be assumed that a patient with partial loss of a single digit will make a rapid recovery and assign appropriate significance to the loss. It is crucial for every patient to understand the goals of the proposed prosthetics and their limitations. Again, the purpose of prostheses is to minimize the physical, emotional, social, and economic consequences of the deficiencies.

Aesthetic considerations

With the importance of social presentation in our society having been established, a word about our system of visual perception is in order. Basically our concern about the aesthetics of prosthetics is a practical one. What the patient considers to be a stigma is generally correct, because those people involved with the patient will, for the most part, also share the same attitudes and cultural values.

In this context there are two aspects of aesthetics to be considered. The obvious one is the artistic characteristic of size, shape, color, and texture that the artist can duplicate with great accuracy. A perfect color match is difficult because autogenous tissue changes color constantly with temperature, emotional state, and other factors modifying blood flow. The second aspect of aesthetics, however, comes into play and basically neutralizes the constant color changes. This factor is the extent to which ordinary tasks can be accomplished in the expected manner. Basically our visual perception is to see only that which we expect to see unless there is some unexpected event provoking a critical analysis of the situation. For example, if a person has an index finger ray amputation and takes a sip of wine and replaces the glass on the table, most observers will not recognize that a finger is missing. Thus, there is an important aesthetic contribution from motion and improving physical capability should be an important design criterion

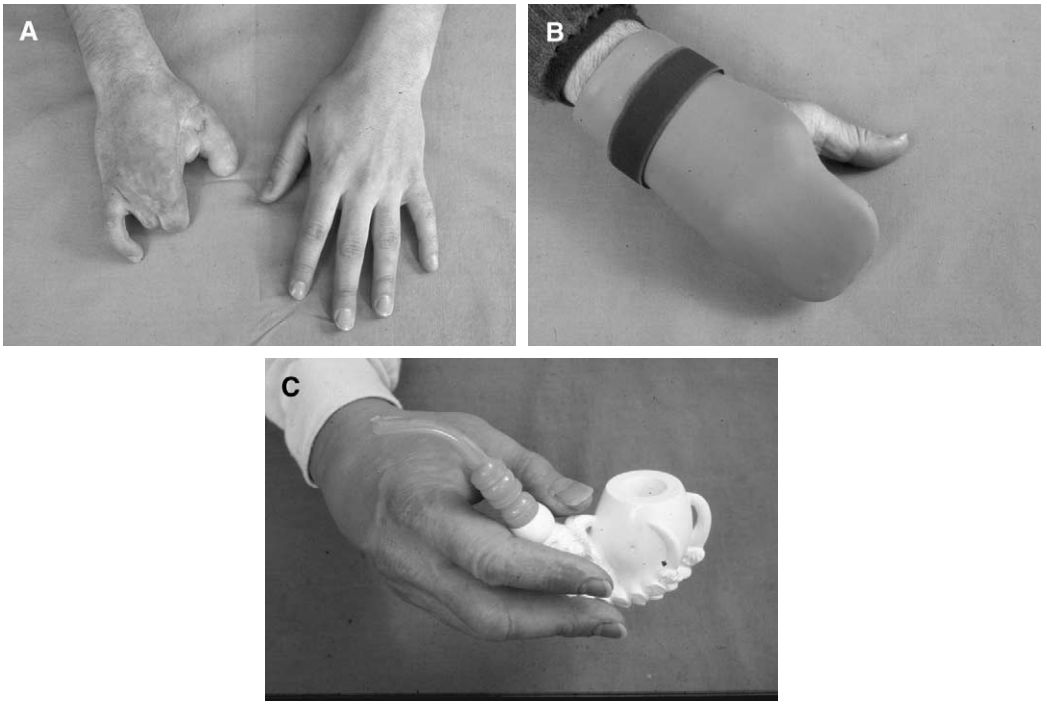

Fig. 2. (*A*) Severely mutilated right hand. (*B*) Strong and rugged, but not grotesque, fiberglass prosthetic device restores function of the normal thumb for work in a factory. (*C*) Fine custom silicone life-like prosthesis for business and social occasions.

for every prosthesis. It is a rare exception that an appropriately designed passive hand prosthesis fails to make a positive contribution to better physical capability. They enhance the usefulness of remaining parts, which in turn provide various degrees of sensory feedback for subconscious control of movements.

Master plan

In the treatment of a mangled hand, a master plan should be developed in the early stages of the patient's care. It can be modified, based on the patient's progress. Such a plan requires a thorough knowledge of surgical and reconstructive potentials as well as prosthetic fundamentals and possibilities. It is not wise to embark on long and complicated surgical procedures without having an eye on the long-term result with respect to global function. The hand surgeons should leave the parts in the best possible condition for complimenting their efforts prosthetically when appropriate. Even the closure of a finger amputation should be considered a reconstructive procedure, leaving the stump in the best form for prosthetic fitting. A finger amputation stump should be slightly smaller than normal so a prosthesis of normal finger size can fit over it. The end should be smooth and tapered.

There has been a progressive shift from the classic teaching of "ideal levels of amputation" that often led to elective shortening. It is safe to say that in almost every instant as much length as possible should be preserved, provided good and direct soft tissue closure is possible. Local or even occasional distant flaps may be indicated to save length. Contrary to previous recommendations, the flare of the radial styloid should be preserved with a wrist disarticulation. This permits fitting of a short suction-held socket hand prosthesis. Otherwise a long socket extending above the elbow is required because the forearm changes shape with pronation/supination. There are innumerable individual considerations, but the principle of initial length preservation is a fundamentally important concept with rare exception.

Types of prostheses

There are two categories of hand prostheses.

1. Active prostheses (also known as "carrier tool prostheses")
2. Passive prostheses

One should not refer to active prostheses as ''functional,'' as that implies incorrectly that passive prostheses are ''nonfunctional.'' Most patients with passive prostheses enjoy a substantial degree of improvement in physical capabilities because these prostheses use the critical sensory feedback through the remaining natural structures.

The passive prostheses are designed intentionally without mechanical clamping units in them. Passive and active prosthesis target different goals and needs. Passive prostheses enhance the function of the remaining digits of the hand and also restore good social presentation.

New material and technology

Silicone has proven to be the best material for hand prostheses. Two recent and significant technologic innovations have enormously improved the possibilities for digital and partial hand prostheses.

The first is the Bio-Chromatic® coloring technique for silicones. This technique mimics nature by depositing color pigments on the interior surface of the clear silicone prosthetic glove. The clear exterior layer is similar to the colorless epidermis of normal skin. This gives the prosthesis a similar translucency. The superiority of color matching with this technique obviates the need for the traditional ring or small bandage applied to the junction of the prosthesis with the normal skin. It also permitted the creation of digital prostheses for the thumb and fingers without the need to extend proximally over intact interphalangeal joints. The same technology led to the development of a ''sub-mini'' prosthesis for a mutilated distal phalanx or even for a lost or damaged fingernail.

The second major innovation relates to digital armatures. Armatures are structures built into prosthetic fingers to allow passive adjustment of their contour by the normal hand for various tasks. This allows more efficient function of the remaining natural parts. Copper and stainless steel armatures were flawed by oxide formation causing discoloration and metal fatigue with breakage. Also, wire armatures require secure anchorage of their proximal end to modify their contour. The development of stainless steel micro-hinged armatures has resolved all three of these problems. These prostheses do not require proximal anchorage to adjust for their configuration. The flexion/extension occurs along the entire length of the micro-hinged armature rather than at one point. This eliminates the problems of metal fatigue and need for anchoring the proximal ends of the armatures that often is difficult to achieve. The new armatures can be used to create prostheses for fingers amputated at the level of the proximal phalanx. The finger can be placed in basic extension for thumb opposition. Alternatively, the digit may be curved for typing or other activities (Fig. 3).

Specific prostheses

Passive hand prostheses can be conveniently divided into three groups: (1) thumb, (2) fingers, and (3) partial hands, the latter term reserved for mutilating injuries with loss of a major portion of the hand.

Partial hand

The goal of a partial hand prosthesis is to enhance the usefulness of the remaining natural parts while also providing a socially acceptable appearance. The design and development of the partial hand prostheses is the most challenging of all, and often the most rewarding; however, natu-

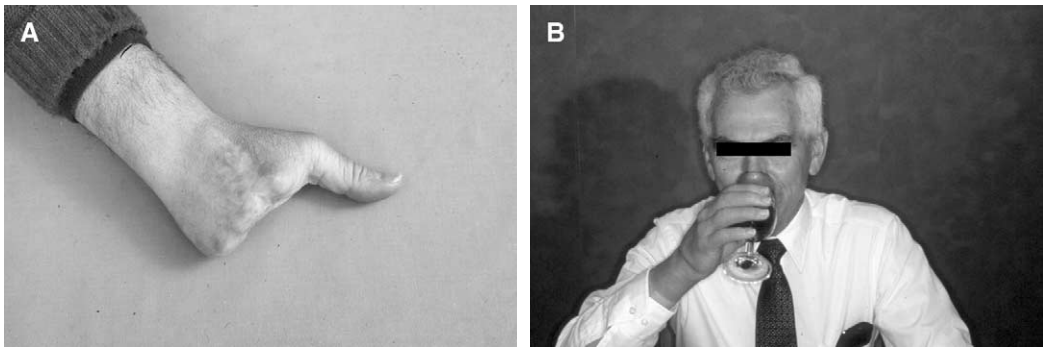

Fig. 3. (*A*) The common transmetacarpal amputation with a normal but almost useless thumb preserved. (*B*) Custom life-like prosthesis enhances use of the thumb.

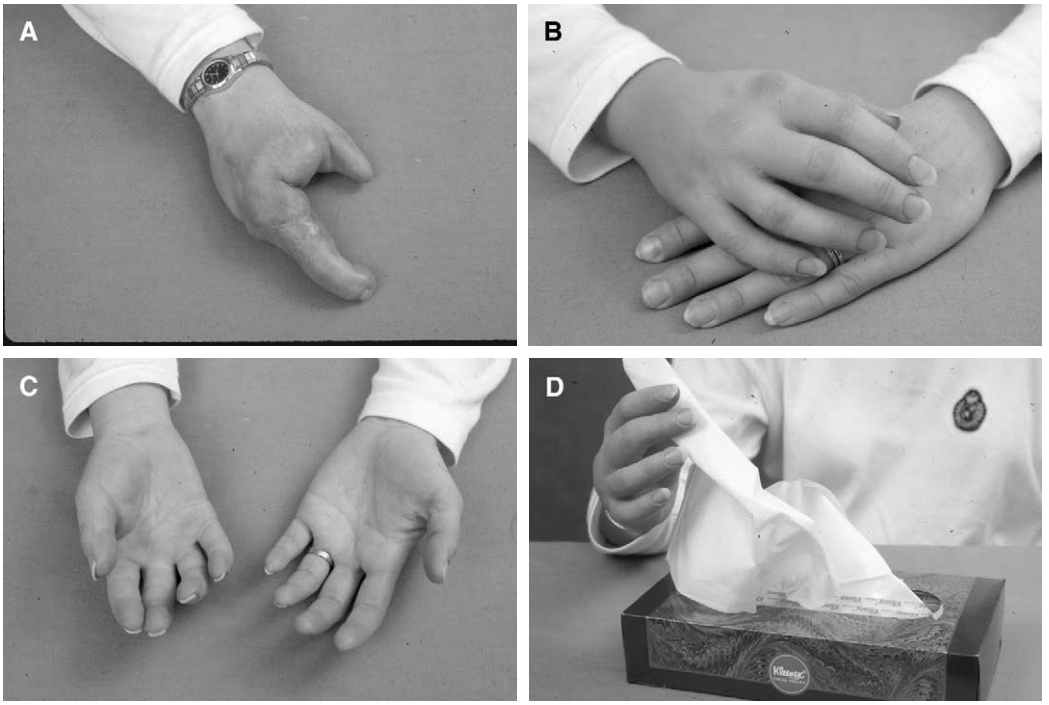

Fig. 4. (*A*) Mutilated right hand. (*B,C*) Fine custom, silicone, passive, partial hand prosthesis for which remaining parts provide active motion. (*D*) Intact sensory feedback for subconscious control improves capability to a degree no active prosthesis can approach.

ral parts with intact sensibility provide an advantage over any other device. A severe mutilating injury that illustrates the dramatic value of a top-quality partial hand prosthesis is loss of all four fingers through their distal metacarpals, with a normal thumb and palm preserved (Fig. 4). Before micro-hinged armatures, one would have to shorten the metacarpals to their neck levels in the case of MP disarticulations to have space for proximal anchorage of wire armatures.

Thumb

Fortunately, proximal thumb amputations are rare. There is really no satisfactory means of

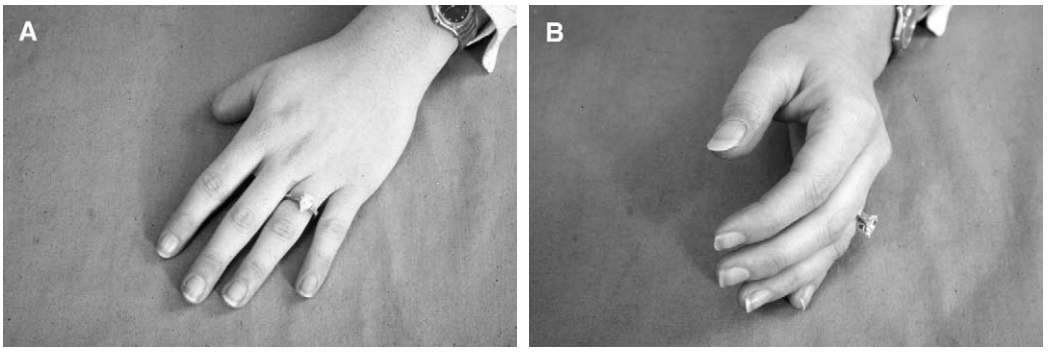

Fig. 5. (*A*) Thumb amputation through proximal phalanx. (*B*) Securely fitting digital prosthesis places the thumb pad where the brain expects it to be and sensory feedback is so good that capability is near normal. Social presentation was also simultaneously restored to normal.

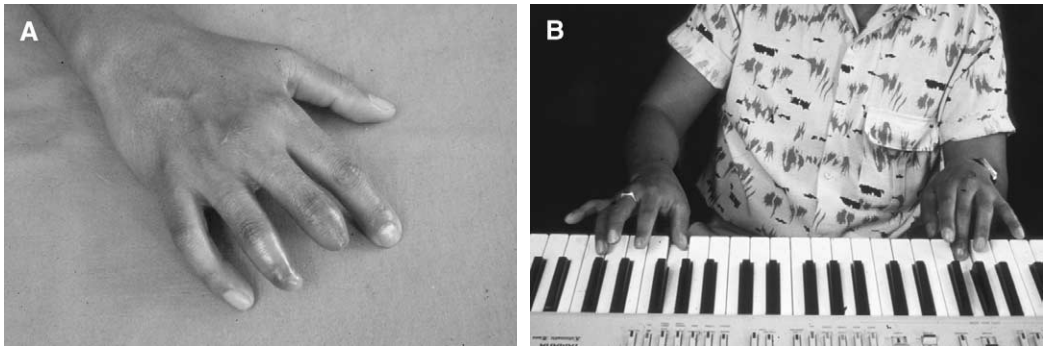

Fig. 6. (*A*) Mutilated hand with digital amputations and fused PIP joints. (*B*) Precisely fitting custom digital full-length prostheses provide excellent sensory feedback, and, fabricated with the passively adjustable micro-hinged armatures, a remarkable degree of fine functional rehabilitation.

securing the prosthetic attachment at this level of amputation. There were hopes that osseointegrated implants, so successful in the dental field, would resolve this situation, but this has not been realized.

Many thumb injuries are at the level of the proximal phalanx. In these cases, it is important to preserve maximum length, which may require wound closure with a flap. A minimal length of 15 mm of proximal phalanx is needed for securing a prosthetic suction attachment (Fig. 5).

For thumb amputations at the metacarpal-phalangeal (MP) joint level, slight deepening of the first web with tapering of the condyles and

Fig. 7. (*A*) Middle finger amputation at neck of middle phalanx. (*B*) The remarkable Bio-Chromatic® coloring technique permitted development of ''mini'' or short digital prostheses that leave the PIP joint uncovered and totally free. (*C*) The passive prosthetic fit provides sensory feedback, which with the finger's pad where the brain expects it to be, can give remarkable results. This has been a major technological breakthrough for prosthetics.

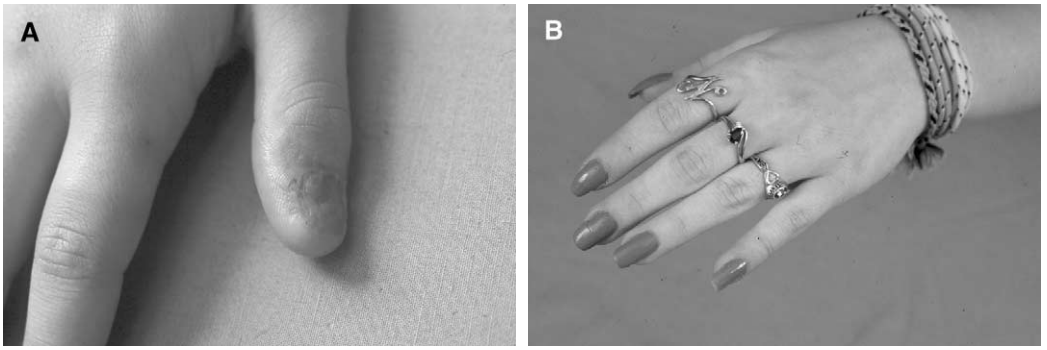

Fig. 8. (*A*) Partial amputation of only distal phalanx or even loss or damage of a fingernail can cause some patients great distress, and for this there is no satisfactory surgical treatment. (*B*) The same technology resulting in the "mini" digital prosthesis has been applied for a "sub-mini" prosthesis over the distal phalanx only, so both interphalangeal joints are free. As illustrated, it can be used for a fingernail alone.

removal of sesamoid bones makes secure fitting of the prosthesis possible. The deepening should not be more than 15 mm because further deepening would result in a cleft rather than a web. This will be aesthetically disturbing and will contribute to progressive damage to the thumb's adductor muscles.

Other cases of thumb amputation near the MP joint may be best treated by distraction osteotomy lengthening of the first metacarpal with bone grafting. The authors have gained additional lengths up to 34 mm with this technique.

Finger

Contrary to common belief, finger prostheses are not for appearance only. By placing fingertips where the brain expects them to be and because of the excellent sensory feedback to the brain necessary for subconscious or automatic control from their precision fit, finger prostheses can be among the most helpful.

When possible, finger amputations are much better treated with individual prostheses than a partial hand prosthesis that requires covering the hand with a glove (Fig. 6).

Proximal phalanx

Loss of both interphalangeal joints results in enormous reduction of finger dexterity. As prostheses are now available with multiple micro-hinged armatures that can be passively contoured without the need for proximal fixation, long finger prostheses can be useful for typing and similar activities. A length of 12–15 mm of finger distal to the interdigital web is required for secure suction attachment of finger prostheses. Occasionally, judicious deepening of the web can provide a critical additional 3–5 mm of length.

Middle phalanx

The traditional full-length prostheses for all levels of finger amputation covered the important proximal interphalangeal joint (PIP) compromising its mobility. The PIP joint provides the critical segment of the finger's flexion–extension arc of motion for most activities. With the advent of the short or "mini" digital prosthesis made possible by the Bio-Chromatic® coloring technique, no restriction is imposed on PIP joint mobility (Fig. 7).

Distal phalanx

The loss of a fingertip or even a deformed fingernail can be stressful to some patients. Using the new technology developed for middle phalangeal amputations, a "sub-mini" digital prosthesis has become available for the distal phalanx. There is no restriction of motion. The fingernail prosthesis is thin to permit transmission of sensibility from the finger. A perfect fit results in secure suction attachment and the acrylic fingernail, duplicated from the other hand, is always correctly positioned with no problems with skin irritation or cellulitis (Fig. 8).

Summary

For many mangled hands, appropriately designed passive prostheses now available, alone or in conjunction with surgical reconstruction, can offer the best available improvement, provided they are of high quality and backed by prompt and reliable after-delivery services. Invariably, there is improvement in physical capability along with restoration of good social presentation.