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Prosthetic Fitting after Finger and Hand Amputations

Prosthetic Fitting after Amputations in the Area of the Fingers or Hand
State-of-the-art according to the “Quality Standard for Upper Limb Prosthetics”

Amputations in the area of the fingers and the hand can lead to significant limitations of the motor, sensory and gesture-related tasks of the hand. The

loss of length and volume not only limits the opposition function and the hand's functional grip parameters, but also reduces the sensory feedback of the tactile and sensory organ called hand. Amputations of fingers and hand areas reveal in a frightening manner the various impacts a hand has. The fact that in almost all medical as well as concomitant therapeutic and technical measures in the rehabilitative process after finger and partial hand amputations, compensation for the loss of parts of the hand is very incomplete, shows how important the functional, sensory and expressive organ called hand is in the life of humans. The following contribution is intended to explain further the variants of prosthetics after finger and partial hand amputations and depicts the technological possibilities of a functional and aesthetic finger and hand replacement.

Parallels to the contents of the „Quality Standard for Upper Limb Prosthetics“, created by experts of the Association for Quality Assurance in Upper Limb Prosthetics and which will soon be distributed by the German Association of Orthopaedic Technology, are intentional.

Key words: finger prosthesis, partial hand prosthesis, myoelectricity, silicone socket technology, quality standard

Aesthetics and Function in Finger and Hand Prosthetics

In the daily work with finger and hand amputees, a hand and finger prosthetist can clearly see which different needs can be present after a finger or partial hand amputation.

The importance placed on functional and aesthetic aspects can differ not only from user to user, it also depends heavily on the clinical situation and the extent of functional and physical deficits.

Especially in the post-operative phase, amputees perceive the loss of their hand to be very stressful and they suffer from the visible defect. Unlike amputations of the lower limbs, amputation defects of the hand cannot simply be concealed by wearing suitable footwear – once summer arrives, everyone would notice if gloves were worn. The suffering, especially of patients who are often “among people”, can be attributed to this permanent visibility of the amputation.

While the level of cosmetic restoration is already very high with today's technical advances in prosthetics, the loss of function can generally never be completely restored [1]. There can be different requirements of a suitable prosthesis depending on the type of the prosthesis and the user's requirements in daily life. Most of the persons affected have the understandable wish for maximum functionality coupled with a simultaneous wish for a realistic-looking, inconspicuous restoration of their body image. Both needs therefore have to be present in the arm prosthetist's technical repertoire and can affect the design of the prosthesis in various ways. The fact that the finger or partial hand pros-

thesis also has to withstand the enormous demands regarding strength and wear and tear placed on it in everyday use poses a huge challenge for orthopaedic technology. In the last two decades, silicone has become increasingly important as a material in the technical implementation [2, 3] and it is no longer possible to imagine doing without it for these indications.

Aesthetic aspects of finger and hand prosthetics

Different factors affect the needs of the affected individuals for the least conspicuous restoration of the limb. While there are some individuals who, for example, come to terms with a narrowed hand and the corresponding changes in their everyday lives extremely well and do not feel the need for any prosthesis, it can be a catastrophe, e.g. for a multi-instrumentalist who operates several instruments with his or her 10 fingers if just the distal phalanx of the small finger is amputated. Both reactions must be recognised and treated with understanding. A number of other influencing factors such as the personality of the affected individual, the job situation, the family situation, hobbies and interests, and religious and cultural background can also have a sustained effect on the treatment process. Catching up with non-amputees, reintegration into social life, and avoiding psychological stress and stigmatisation are key tasks of physical restoration with a prosthesis. In “Qualitätsstandard im Bereich Prothetik der oberen Extremität“ [Quality Standard for Upper Limb Prosthetics], these aspects of participation are specifically addressed in sections 1.1 and 2.1, where rehabilitation goals are defined.

To fulfil the aesthetic demands placed on a prosthetic restoration of



Fig. 1 Features of an aesthetic restoration – imitation of shape, colour and structure using a silicone hand prosthesis as an example

the body image, it must be possible to design the shape, colour, and surface texture of the prosthesis freely (Fig. 1). Materials that are processed using an addition-vulcanising polymeric process have become well established for this purpose because colour pigments of various shades can be added before vulcanisation or when they are already in the vulcanised state.

All shades of the three basic colours red, green, and blue as well as black and white tones can be created. The additional use of many different natural brown tones that approximate those of human skin has proven successful in practice. Structures on the surface of the skin can be achieved using shapes formed with structure templates.

The design of the fingernail is of particular importance in restorative prosthetics. The fingernail can be made in all conceivable combinations of colours and as a highly visible feature at the tip of the finger and the prosthesis, it is particularly noticeable to other people. Fingernails can be made of cold polymerising acrylic or high-temperature vulcanising silicone with 4 to 8 colours to imitate the colour and shape of the nails on the remaining fingers. Dispensing with a fingernail in a finger or partial hand prosthesis, as is increasingly requested by cost carriers, does not make sense, especially considering the function of restoring the appearance, and should therefore be considered only when merely restoring function when there is no expectation of restoring an inconspicuous shape.

Functional aspects after finger and hand amputations

From the biomechanical perspective, the hand is the most complex organ of the human body [4]. If the main

goal is restoring hand function, all possible approaches for improving function from the various disciplines (medicine, therapy, and orthopaedic technology) must be brought together when discussing and determining the treatment goals and the optimal procedure must be considered on a case-by-case basis. While from a therapeutic aspect, early functional post-operative mobilisation and training residual function units can preserve the major functions of the hand, surgical measures to improve function can also often be considered even after a final amputation of fingers or parts of the hand. These measures include narrowing the hand, repositioning tendons for functional stabilisation of the hand situation and preservation of muscle balance, and local flaps for preserving the limb and its function.

A toe transfer can also be a surgical measure for improving function if suitable underlying conditions are present [5]. However, in many cases, a toe transfer does not meet the demand for an aesthetic restoration of shape and inconspicuous appearance. The surgical procedure of a toe transfer is therefore usually performed with the goal of improving hand function, mainly in individuals with congenital deformities. The decision to perform another amputation on the foot is usually decisively rejected by most patients after a traumatic amputation. One exception is a toe transfer to replace the thumb, which can have an acceptable functional as well as an aesthetically pleasing result.

There can be no differentiation of functional considerations in comparison with a prosthesis. A prosthesis must also take the assessment of a functional benefit into considera-

tion. In the life of a finger or partial hand amputee who uses a prosthesis, a functional benefit means that the prosthesis enables him or her to perform recurring activities of daily life that would not be possible without the prosthesis.

This can be evaluated using different criteria [6], for example:

- Increase in gesticulating functions
- Restoration of the hand's holding and guiding functions
- Support for bimanual work processes
- Restoration and increase of finger length, grasping surface, and grip strength of the hand
- Adding grasp and grip types in daily living (Fig. 2). The classification of grasp types described by Kapandji [7] into static grasps, grasps primarily using the force of gravity, and dynamic grasps is recommended for this.

Factors that have a decisive effect on the functional outcome with a prosthesis can be the underlying clinical situation (skin condition, remaining muscle functions, remaining joint functions) and the available technical options for the prosthesis.

Pre-prosthetic measures

To prevent the postoperative loss of remaining movements and muscle strength and to ensure an optimal rehabilitation process, an early functional postoperative treatment plan should be implemented by experienced hand therapists immediately after the amputation and removal of sutures. The major components of this treatment must always be coordinated with the specialist physician and depending on the amputation situation may include the following [8]:

- Scar treatment, prevention of keloids and scar care (massage)
- Oedema treatment and initiation of compression therapy to consolidate the residual limb situation
- Mobilisation of remaining joint functions in the fingers and hand
- Desensitisation of the amputation area (sensitivity to pressure, touch, and temperature; toughening up)
- Pain therapy (trophic pain, neuroma pain, phantom limb pain)

A prosthesis with elastic silicone full-contact socket technology, which has been the state of the art after finger



Fig. 2 Additional grasp types with a finger (left) and a partial hand (right) prosthesis



Fig. 3 Use of silicone compression elements to consolidate the residual limb after finger and hand amputations

and hand amputations for years, leads to changes in shape and reduction of volume in almost all amputation situations – even when the surgery of the residual limb was performed years previously. This is due in part to the compressible and decongestive effect of the elastic socket bed, but also due to the increasing force exerted during routine use of the prosthesis. This is why compression therapy should be initiated in early functional treatment. If it is already clear at this point that the amputee will require a prosthesis, he or she should receive compression therapy with customised silicone compression elements. These elements help reduce pain in the sensitive postoperative phase and support functional use of the hand in daily routine due to their resistance to dirt and moisture (Fig. 3). Systematic compression therapy is applied depending on the situation of the residual limb for a period of around 3 to 6 weeks in addition to other therapeutic measures.

Prosthetic fitting after finger amputations

The classification of prosthetic fittings after finger amputations compiled by Schäfer in 2002 and supplemented in 2008 [3, 9] has been established in daily routine for years and is based on the length of the residual finger and the resulting requirements for the design of a suitable finger prosthesis (Fig. 4). The function and development of strength in remaining structures and structures adjacent to the residual finger (joints and muscles) have a major impact on the functional outcome. The length and condition of the residual limb also have a considerable effect on the functionality and aesthetics of the final result.

Using the classification of the prosthesis according to length of the residual limb and function of remaining joints, the prosthetic fitting of the finger can also be systematically illustrated according to the “Quality Standard

for Upper Limb Prosthetics”. The design standards described above for the classification of finger prostheses [3, 9] are not repeated here, but important design features of finger prostheses are presented to demonstrate the quality standard:

Socket shapes and socket design variants in finger prosthetics

Circular full-contact compression socket (Fig. 5, top left)

The circular full-contact compression socket made of HTV silicone is the most common socket design used for finger prostheses.

Flap socket technique for fixating the finger prosthesis (Fig. 5, top right)

This socket technique is used only for very short residual fingers or disarticulations in the MCP, i.e. when adhesion cannot be achieved with circular compression. In this case, adhesion is achieved using a medical skin adhesive, which avoids the need for a larger socket volume with circular fixation of the metacarpus.

Circular metacarpal socket with one finger (Fig. 5, bottom left)

This design variant is used primarily for a thumb-opposition prosthesis when there is no or only an extremely short residual limb.

Variable ranges of hardness in socket design (Fig. 5, bottom right)

The strength and adhesive properties of the prosthetic socket can be additionally controlled using the Shore hardness of silicone (Shore hardness range A 20-50). Experience has shown that it is useful to select a higher Shore hardness for sockets when the residual finger is soft, while hard and sensitive



Fig. 4 Schäfer classification of silicone finger prostheses

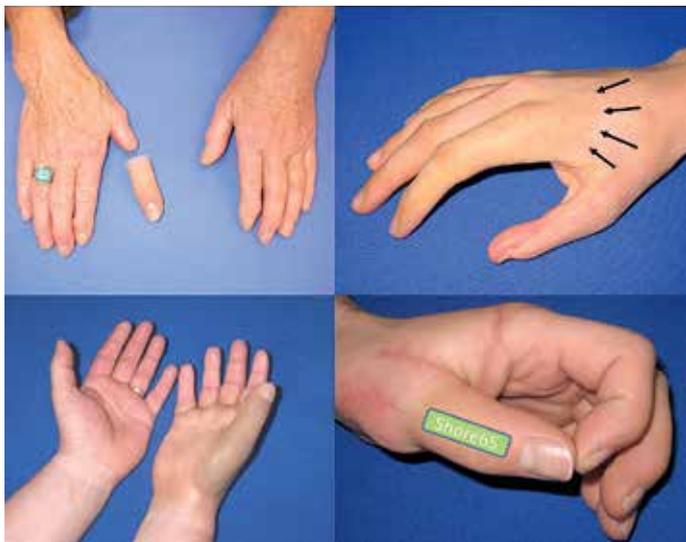


Fig. 5 Socket design variants in silicone finger prosthetics



Fig. 6 Additive fixation options: side-by-side coupling (left), ring fixation (right)

residual fingers are preferably bedded in softer silicone. When greater strength is needed, for example to build up thumb gripping strength, the integration of bilateral high-Shore silicone stabilisers has proven effective.

Bedding techniques, adhesive mechanisms, fixation

Integration of partial relief zones and gel beds

Partial relief zones in the form of gel beds are used at the residual limb end of finger prostheses. This is needed when the residual finger has little tissue cover and tapping on a hard surface is painful.

Integration of hollow cavities

The integration of hollow cavities is useful only for a type IIIa+b silicone finger prosthesis because only this prosthesis length has enough internal space available. One thing the cavity is useful for is to increase adhesive properties. For this, a fine connecting channel is created between the prosthetic socket and the cavity. A cavity is also often integrated to reduce the weight of the prosthesis to a minimum when the residual finger is extremely short in order to ensure good control and stable finger position when using the prosthesis.

Side-by-side coupling of a silicone finger prosthesis (Fig. 6, left)

This variant can be used for a multiple-finger prosthesis if one residual finger is too short for sufficient fixation of the prosthetic socket. In this case, the prosthesis can contain a hol-

low cavity and be connected to the adjacent finger with a “silicone bridge”.

Ring fixation of a prosthesis (Fig. 6, right).

Fixation of a prosthesis to a ring on the adjacent fingers is another method of supporting fixation when other options are not sufficient. In addition to ring fixation, a medical adhesive can be applied in the socket control area for better adhesion.

Prosthetic fitting after partial hand amputations

A partial hand amputation means that individual fingers are still present after an amputation and the amputation defect extends beyond the fingers to the metacarpal and/or carpal area. Prosthesis designs generally include the metacarpal and carpal area. Based on the work by Beasley at the beginning of the 1980s, the established classification for clinical differentiation includes transverse hand amputations (Fig. 7, top left), central or mid-line hand amputations (Fig. 7, bottom left), longitudinal ulnar hand amputations (Fig. 7, top right), and longitudinal radial hand amputations (Fig. 7, bottom right) [10, 11].

The prosthetic fitting of partial hand amputations can be described as the greatest challenge in hand prosthetics because it is essential to take remaining functionality, digital rays and arches into consideration, as the prosthesis should not impair any of these remaining functions. Following the motto “form follows function”,

in a best-case scenario, the prosthetic sockets are made of silicone and prepreg with the aim of giving the remaining hand maximum freedom of movement and flexible bedding zones that allow sensory perception. Based on the functional properties, it is useful to classify partial hand prostheses in 4 categories [11]:

Cosmetic partial hand prostheses (Fig. 8, top left)

Cosmetic prostheses are passive prostheses whose purpose is to restore the appearance, position, and external shape of the amputated limb.

Unfortunately, the term “passive” is often associated with non-functional. However, a modern cosmetic prosthesis has nothing in common with an old-fashioned “PVC zipper decorative prosthesis”. After the “German Prostheses List” was finally shelved, this neither functional nor aesthetic variant of earlier partial hand prostheses should also be eliminated. By contrast, the design elements of a cosmetic prosthesis make the best possible restoration of shape and appearance possible. However, passive cosmetic prostheses also facilitate many tasks of bimanual activities of daily living such as holding, guiding, and moving objects.

Additional joint systems can allow lockable, movable, and partially locked finger positions in cosmetic prostheses, which can be easily manoeuvred into different positions using tension and/or pressure mechanisms (Fig. 9), thus giving even a “passive” hand more function. However, active grasping is not possible with this type of prosthesis.



Fig. 7 Different types of partial hand amputations



Fig. 8 Types of prostheses used in partial hand prosthetics

Partial hand work prostheses (Fig. 8, bottom left)

Partial hand work prostheses are designed solely for function and loading. Restoration of body image usually plays a subordinate role in this prosthesis type. A sturdier, more robust design is frequently required for the prosthesis structure.

Partial hand work prostheses can be used to carry heavy objects and play sports and they require multifunctional features and fixation options.

Since work prostheses frequently come into contact with dirt and moisture, it is also advisable to use silicone for some parts of them. However, the silicone selected for this purpose often has a very high Shore hardness to withstand mechanical stress and is not used for the supporting socket structure, instead being used for moisture-resistant covering of the sturdy socket structure, often applying carbon, stainless steel, and nylon components.

To allow the use of various kinds of occupational tools, the prostheses can be equipped with multifunctional adapters that can accommodate many different tools (Fig. 10).

Body-powered partial hand prostheses (Fig. 8, top right)

Body-powered partial hand prostheses enable the user to perform active gross motor grips using existing body functions. When the wrist is used as the source of power, a forearm-length prosthesis must be designed. The most functional results are achieved with direct control of movement. The constructional grip elements must

include a rigid structure because the loss of strength when gripping would otherwise be too great. Body-powered partial hand prostheses with tension or lever controlled movement mechanisms (e.g. the M-Finger, X-Finger) allow articulating finger units to be powered [11], but these systems develop only limited grip strength, which means that they often do not achieve the level of a functional prosthesis. Today we look back somewhat wistfully at the body-powered Sauerbruch prosthesis, which in addition to adjustable functional feedback, could also transport sensitive information and we ask where this technology might be with today's technical possibilities.

Externally powered partial hand prostheses (Fig. 8, bottom right)

Externally powered partial hand prosthetics is the field in which the functional prosthetic treatment of partial hand defects currently receives the most attention from the various parties of technical orthopaedics, research and development, and the orthopaedics sector. The possibility of controlling voluntary active movement with proportionate grip strength behaviour using a partial hand prosthesis gives it a big advantage in the functional assessment. Users do not have to depend on a large range of movement of existing joints or on muscle strength to control fingers that can grip actively. There are currently two systems on the market: the Prodigit system from TouchBionics and the Vincent Finger system [12] sold by the German start-up company Vincent Systems. Both systems can be used only after intensive

training and certification of an experienced arm prosthetist, which makes sense given the complexity of this part of the body. While the Prodigit system is sold in a purely functional condition with silicone caps to protect the fingers, Vincent Systems has adopted a complete cosmetic solution. In addition to transparent and coloured cosmetic coverings which, due to the different shapes and structures of the externally powered partial hand prostheses, are fabricated only after a custom impression or scan of the prosthesis is made, aesthetic silicone cosmetic coverings with coordinated shapes and colours are also available. Lower structural heights and a slimmer design allow them to be used even with longer residual metacarpal limbs and give experienced arm prosthetists a number of different fitting options.

Teams of experts have been formed around the world that have worked intensively with fitting patients with these systems [11, 13, 14]. As a result of seven years of experience in fitting patients with myoelectric finger systems, the following statements can be made today:

Preserving the size and shape of the hand
Preserving the size and especially the shape of the hand is an absolute "must" for externally powered partial hand prostheses (Fig. 11). An Internet search of this topic turns up many prostheses in which neither the lengths of fingers nor analogous hand sizes (compared with the contralateral side) were selected. Slightly greater volumes cannot always be avoided due to the design. But length-



Fig. 9 Different finger joint systems used in partial hand prostheses

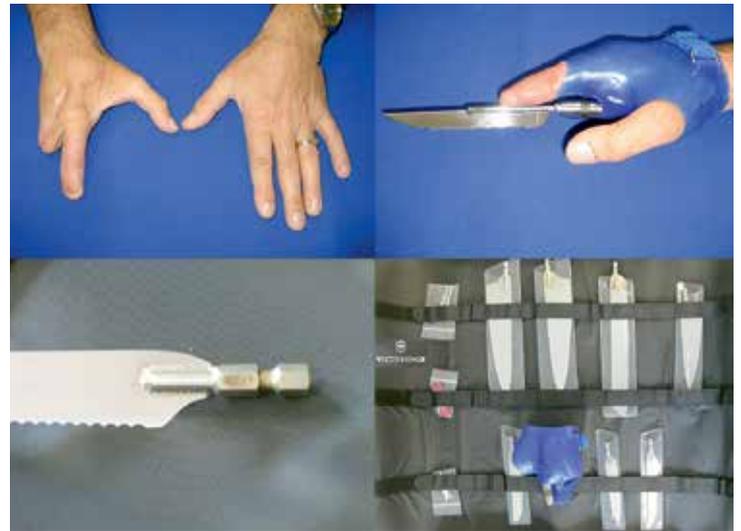


Fig. 10 Work prosthesis with multifunction adapter for inserting different tools

ening the individual hand is acceptable only when all 5 fingers are to be replaced by a prosthesis and the geometry of the grips is preserved. Especially considering that individual digital rays with a full range of movement may still be present in externally powered partial hand prostheses, the failure to take the shape of the hand into consideration and excessive length of the prosthetic fingers are not acceptable from an orthopaedic perspective.

Selection of suitable sensor technology

In externally powered partial hand prosthetics, different sensors can be used to control hand functions. The preferred method is with electrodes that utilise the action potentials of muscles and convert them to controlled hand movements via controllers. For this, it is important that the myosignals selected can be clearly defined and compensatory triggering from accompanying movements of

remaining joints (in the fingers and wrist) can be ruled out. Since such unambiguous signal behaviour is not present in all residual partial hands, other options are FSR sensors (touchpads) or flexion sensors.

Battery management

The selection of battery size depends mainly on how the wearer will use the prosthesis in everyday life and the number of the fingers to be controlled. Generally, lithium ion or lithium polymer batteries that have been approved for use in medical devices are used. The battery capacity should be at least 1900 mAh for externally powered partial hand prostheses with 4 to 5 fingers. If there are fewer myofingers, the battery capacity can be reduced accordingly.

Externally powered forearm-free partial hand prostheses

For partial hand amputations with longer remaining residual limbs and

for small hand sizes, the technology, i.e. the controller and battery management, must be placed in the forearm. Technical cuffs made of silicone, neoprene and nylon that provide protection to the battery, are resistant to tension and can be flexibly connected with the socket of the partial hand prosthesis are suitable for this purpose.

If the amputation level makes it possible to integrate the technical components (controller, battery, electrode, charger plug) within the hand and this can be implemented technically, this type of prosthesis should always be preferred (Fig. 12). This arrangement allows the full range of movement of the wrist and keeps the technical components all in the hand.

Protectors and cosmetic gloves for externally powered partial hand prostheses

Designing cosmetic gloves for these prostheses poses a great challenge. On the one hand these protectors must restore the appearance of the hand and prevent dirt and moisture from entering, but on the other hand, they must allow a large range of movement in the finger and metacarpal joints. Due to the different shapes of the prosthesis designs, these requirements can be met only with custom-made, especially shaped and highly elastic gloves. Areas of prosthetic finger elements that are sensitive to pressure are protected with additive protectors made of silicone. The gloves should seal the proximal edge of the prosthesis; for complete hand variants without a forearm element, it is advisable to use a silicone lip to seal this area (Fig. 13).

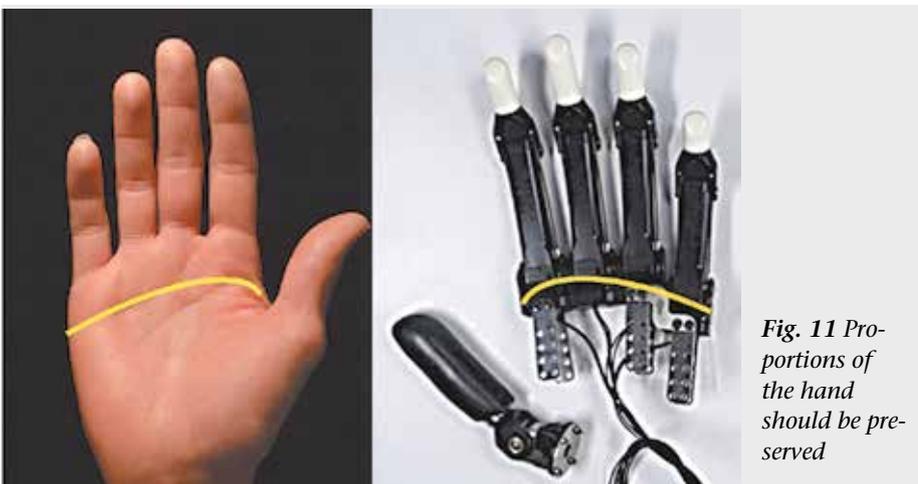


Fig. 11 Proportions of the hand should be preserved



Fig. 12 Structure of a myoelectric partial hand prosthesis with all the technology integrated into the hand



Abb. 13 Individuelle formadaptierte HTV-Silikonkosmetik zur myoelektrischen Partialhandprothese.

Fitting process, service and maintenance, quality assurance

A trial prosthesis should always be made before the definitive prosthesis is fitted. The trial prosthesis is used to determine the length and volume of the finger or partial hand prosthesis as well as its functional position. The trial prosthesis should be made using the material to be used for the definitive socket so that any material intolerance, the skin's sensitivity to pressure and the patient's wearing comfort can be assessed during the trial fitting. Only after these conditions are met and after an extensive testing phase with the trial prosthesis should the definitive finger or partial hand prosthesis be produced.

The prosthesis should be assessed at yearly intervals. The functionality must be checked, worn areas such as the residual limb bedding and finger replacement parts must be repaired or replaced if necessary. Externally pow-

ered partial hand prostheses require more attention because of their complexity, the high level of wear and the fact that long-term experience is not yet available. Therefore, especially in the initial years of this type of prosthesis, any additional manufacturer warranties for the electrical components are recommended.

For the initial prosthetic fitting, a follow-up appointment should be arranged soon after the definitive prosthesis is fitted to ensure the proper fit and use of the prosthesis. Quality assurance includes documentation of the clinical data, prosthesis planning, fitting procedure (trial and definitive prosthesis) and approval protocols using the "Quality Standard for Upper Limb Prosthetics" forms [15], section 1.15 and 2.15.

Conclusion

Prosthetic fitting after a partial or total finger or hand amputation places high demands on a trained arm prosthetist. Aesthetic aspects as well as

functional requirements must be assessed and implemented. Innovative functional improvements and electronic components are just as important as the implementation of minimalist, custom-designed beddings for the residual limb.

The new "Quality Standard for Upper Limb Prosthetics" supports these efforts and specifies a fitting process with all the associated qualitative parameters for ensuring a suitable, modern prosthesis. This will benefit the affected individuals in their everyday lives.

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