Experience With Electric Prostheses for the Partial Hand Presentation: An Eight-Year Retrospective

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ABSTRACT

This article provides a review of progressive partial hand prosthetic management as presented at the University of New Brunswick Myoelectric Controls Symposium in August 2008. This unique patient population allows an opportunity for further research and testing of upper limb principles, both historic and new. The prosthetic field is at the beginning of a paradigm shift of our current thinking as it relates to the treatment of individuals with partial hand limb differences. (*J Prosthet Orthot.* 2009;21:125–130.)

KEY INDEXING TERMS: upper-limb prosthetics, partial hand prosthetics, upper limb loss, electric prosthesis, amputation

Limb deficiency distal to the wrist is a common,[1] yet difficult level to treat with a functional prosthesis. Historically, the lack of acceptable electric options has limited prosthetic treatment. Not surprisingly, patients have been slow to embrace the meager prosthetic choices, which were often uncomfortable to wear, neither looked nor functioned like a natural hand, and provided no tactile sensation.[2] Michael[3] described the challenge in the early 1990s, stating, "The dilemma facing physicians and prosthetists is to determine when our admittedly limited prosthetic armamentarium will add a measure of function to diminish the substantial loss faced by the partial-hand amputee."

This gloomy outlook for partial hand amputees, however, is changing. The new research focus on upper limb prostheses promises to accelerate the transfer of technological advances from the research laboratory to the real world. These current and future prosthetic developments create both challenges and opportunities. With the growing attention to the partial hand level, variables such as residual limb presentation, surgical results, and anatomical stability point to the need for concise treatment parameters. This is fueling recognition of the need for a new specialization within upper limb prosthetics—that of partial hand level prosthetic management. As Cailliet[4] espoused nearly 15 years ago: "The hand is a precise dexterous mechanism that defies casually understanding. Its functional loss is a major calamity in all aspects of life. Early thorough evaluation ensures more complete recovery of function."

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UNIQUE OPPORTUNITY

Until recent years, individuals with partial hand deficiencies have been underserved, despite the prevalence of this amputation level.[1] In 2002, Dillingham et al. looked at the epidemiology and recent trends in the United States regarding limb amputation and limb deficiency. In his study, he found that each year approximately 18,496 individuals are either born without, lose an upper limb secondary to cancer or experience some type of traumatic insult that results in upper limb amputation. After further breaking down these numbers, Dillingham et al. discovered that the vast majority of cases involved trauma and, of significant interest, nearly 17,000 of these amputations were distal to the wrist. What this means from a clinical standpoint is that professionals in our field are focusing their efforts each year on the needs of fewer than 2,000 individuals who are at a high level of upper limb deficiency, and this minority of amputees comprises the bulk of our typical clinical experience. Meanwhile, there is a huge pool of partial hand level amputees who would no doubt appreciate and benefit greatly from effective prosthetic options if these options were only available to them.

PAST EXPERIENCE

Although partial hand level prosthetics are widely described in historical text and have been fit by many different adaptations to the robin aids type of hand components, it is not an amputation level on which researchers and clinicians have concentrated. My own exploration of electric partial hand prostheses began in 2000 and was inspired by the earlier work of Biden and Bush.[5] These researchers found that fitting a child with a partial hand prosthesis designed to actuate

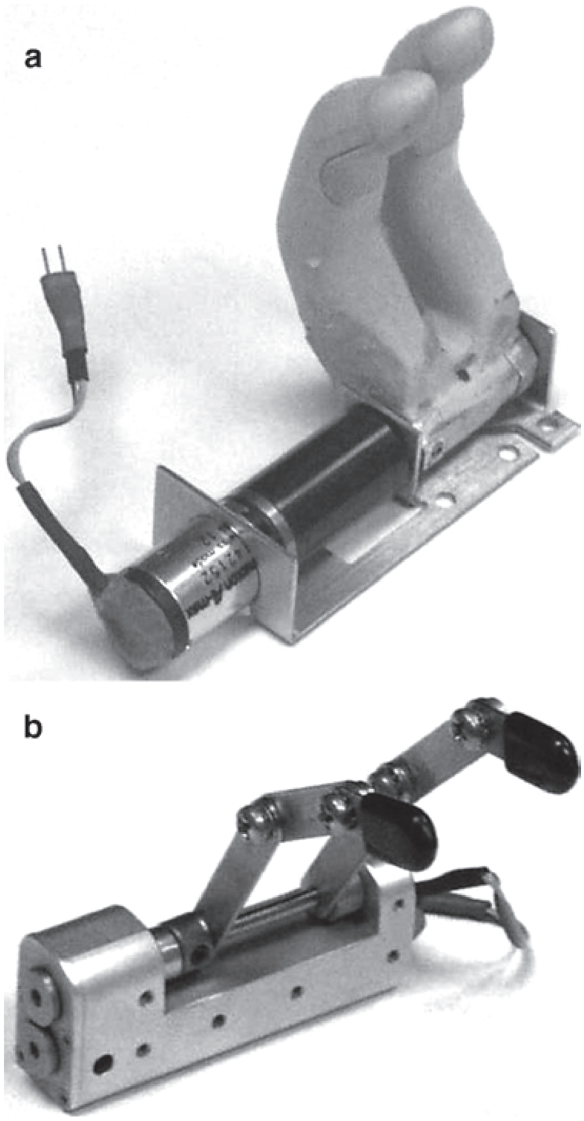

Figure 1. Evolution of the Advanced Arm Dynamics Partial Hand (a) design based on the work of Biden and Bush[5]; (b) Advanced Arm Dynamics Partial Hand Mechanism, patent pending.

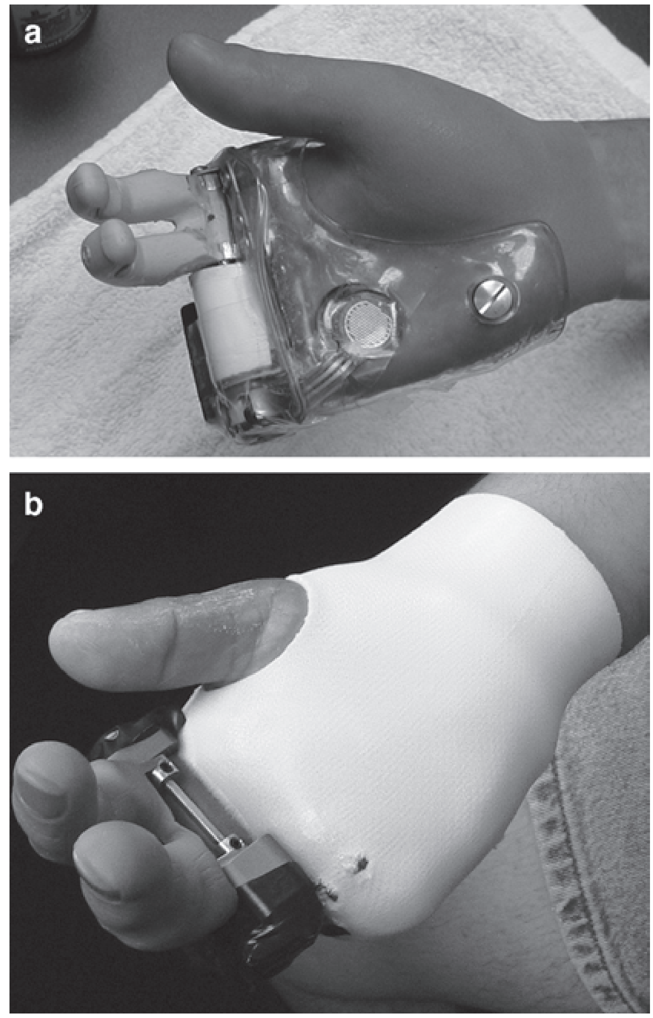

Figure 2. Early partial hand fitting techniques (a) rolled silicone liner from Otto Bock Silicone House (Canada) with suspension studs; (b) injected silicone liner covering a rigid frame.

against an intact thumb proved functional. Although their work did not ignite a prosthetic trend in the mid 1990s, it did bring new attention to this level of amputation.

Like Biden and Bush, my initial focus was more of a quest for a particular type of component to address this unique need (Figure 1). Over the last 8 years, however, I have changed how I approach and fit partial hand clients. Throughout the entire evolution of fitting this particular design within my clinic, I have tried out many different socket design concepts and suspension techniques (Figure 2).

In 2005, I shared my experience with fitting electric prostheses for partial hand level clients who had an intact thumb. I had worked with many of these individuals and, up to that point, my clinical recommendation varied between a static opposition post, an opposition post that could be positioned, or a passive silicone restoration. By 2005, after 5 years of evaluation and experimentation, I identified seven specific areas regarding componentry and fitting. I realized that these mechanisms needed back drive stability to withstand the pressure that an intact thumb exerts. As with all upper limb prosthetics, careful consideration of size and weight ensured the most aesthetic symmetry possible. In addition, programmability was important to promote intuitive usage through an adjustable control pattern. And as with past designs, the wrist had to be unrestricted so that more proximal joints would not be sacrificed by prosthetic treatment of the most distal one. Finally, it was necessary to address both suspension and cosmetics without sacrificing one for the other, as has often been the case historically.[6]

The most helpful insight in 2005 came not from the mechanical aspects of partial hand treatment, but rather from careful patient observation. While analyzing video of an individual performing identical tasks with and without an electric partial hand prosthesis, it was realized that the patient was more likely to attempt bimanual manipulation tasks with the prosthesis. Essentially, the prosthesis became a

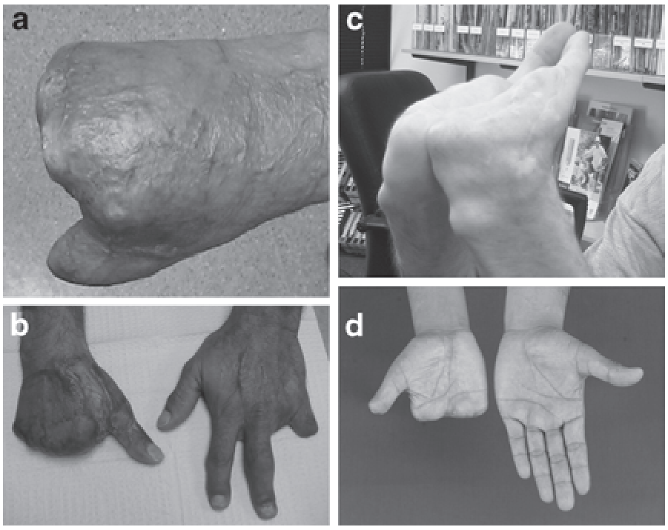

Figure 3. Various traumatic partial hand presentations.

complement, taking on an assistive role to the sound side versus a complicating one. This suggests that prosthetic management at this level may help to reduce the demand placed on the sound side.

PRIMARY GOALS OF PROSTHETIC MANAGEMENT

Early in my research for the *Atlas of Limb Prosthetics*, I realized that our emerging clinical experience pointed to several specific prosthetic management goals. Additional experience gained after that academic endeavor has strengthened and expanded those original goals.

Protection of the residual limb is the first goal. Given the common traumatic presentation of the partial hand level, the residual limb can be significantly compromised in any type of grasping pattern if consideration is not placed on protecting the residual limb (Figure 3). For this reason, socket biomechanics should focus on optimal stabilization of the prosthetic socket about the residual limb. One can accomplish this through several methods, including custom silicone restoration using a suction fit, nonwrist encapsulating or articulated wrist designs suspended over the residual anatomy, and suction type interfaces extending proximal to and encapsulating the wrist.[7]

The second goal of bimanual stability enables the patient to manipulate an object or perform a task using both the sound and affected hands. To use the prosthesis effectively, the socket must remain positioned about the residual limb. This underscores the importance of suspension under load. My clinical experience suggests that suspension is sacrificed in the aforementioned designs and a renewed focus on the socket interface is required. Further discussion of this can be found later in the article.

The third goal, restoration of prehension patterns, relies on maintenance of the residual limb protection and bimanual stability.[7] Studies performed both within the prosthetic field and in other medical disciplines, summarized in a recent literature review, highlight the risk and frequency of contra lateral overuse syndrome.[8] This ailment leads to decreased hand and arm function as well as pain and discomfort. In some cases, contra lateral overuse syndrome can necessitate surgical treatment if the conditions that exasperate this condition are not effectively addressed. Proper medical and therapeutic management combined with the restoration of prehension patterns and bimanual stability can reduce overreliance on the sound side and lessen the risk of this painful complication.

The last prosthetic goal is to provide acceptable cosmesis and durability. This goal has proven very difficult given the multiple and varied joint motions that a natural hand performs—motions that require the cosmesis to accept both tensile and compression forces. Pursuit of this goal is ongoing with the emergence of dexterous hands to upper limb prosthetics.

SHIFTING THE PARADIGM

Our ever-increasing technological arsenal has led many prosthetists, including myself, to join the quest to find just the right component that will solve the problems associated with fitting partial hand amputees. Without question, technological advances are opening the door to new opportunities for addressing challenging levels. Continued work with these individuals points to socket design as actually the most critical element in determining whether or not a patient can be truly functional with a type of prosthesis. The importance of good socket design is not a revolutionary concept, but it is one that has been eclipsed in recent years by the continuing rollout of promising mechanical innovations. In actuality, socket design is the foundation on which all else is built. Without a proper foundation, even the most cutting edge prosthesis is of limited value.

Partial hand amputations present both unilaterally and bilaterally. Specific amputation levels range from proximal carpal to metacarpophalangeal. Regardless of the amputation level, prosthetists would be wise to heed the advice of Hepp,[9] who half a century ago articulated upper limb prosthetic's most basic principle: "An anatomically correct fitting gives the amputee a feeling that his artificial arm is really a part of his body."

Currently, the prosthetic field is witnessing a true paradigm shift in how we look at this level of amputation. This shift started with how we design the socket interface and quickly transitioned into the type of materials that we use to accomplish our design goals. As our socket design becomes more definitive, how we recommend a surgical treatment of these individuals and our comfort level with talking to the surgeons becomes increasingly important. Finally, the technology paradigm shift takes into account the aforementioned three parameters and is charged with the production of unique, level-specific technology in contrast to adapting technology from other levels to simply make do.

SOCKET INTERFACE

From a socket interface perspective, there are three points the prosthetist needs to respect. The first point is of inherent stability. Sometimes in prosthetics, the addition of another harness strap, suspension sleeve, or even more progressive techniques, such as elevated vacuum, is initiated to stabilize the socket interface about the limb. At the partial hand level, it is important to take advantage of all the stable anatomy and thus ensure appropriate transmission of forces. The second aspect is to be anatomically considerate. The human hand has a unique kinesiology, with areas of stability and flexibility that should be preserved if at all possible. The third important aspect is that of promoting sensory feedback.

"Just as our eyes and skin do, the hand serves as an important sensory organ for the perception of our surroundings. The hand is also the primary effector organ for our most complex motor behaviors. The hand helps to express emotions through gesture, touch, craft and art."[10] When you view the human hand in this manner, it is easy to understand Cailliet's reference to loss of hand function as a major calamity. In respecting the hand as the most important sensory organ, socket designs should strive to cover as little of the hand as possible.

Like many of my colleagues,[11,12] I previously advocated for the use of silicone components that covered the entire residual hand and transitioned proximal to the wrist to some extent. My clinical experience now suggests avoiding this extensive encapsulation of the residual hand whenever possible. Interestingly, Putzi[13] concluded the same in 1992. His first objective of upper limb partial hand socket design was "to cover a minimal amount of surface area." The material concepts of Putzi did not use silicone but instead the lamination techniques available in the early 1990s.

In addition, socket design must keep in mind the mobility and stability of the hand. The hand is made up of three primary arches known as the longitudinal, proximal, and distal transverse. When combining the arches with their stability, note that the first, fourth and fifth carpometacarpal joints are flexible, whereas the third and second provide the rigidity of the hand (Figure 4).

When respecting that particular type of anatomy, the socket design should course in such a way to optimize stability while leaving the more flexible areas of the residual hand free. Approaches such as containing the musculature just below the cubital fold in a contoured pocket, as seen in more progressive transradial designs, is just as important at the partial hand level, but here the difference of the infracubital region is replaced by that of the hypothenar region. This helps provide the type of locking type mechanism that is enjoyed in more proximal levels (Figure 5).

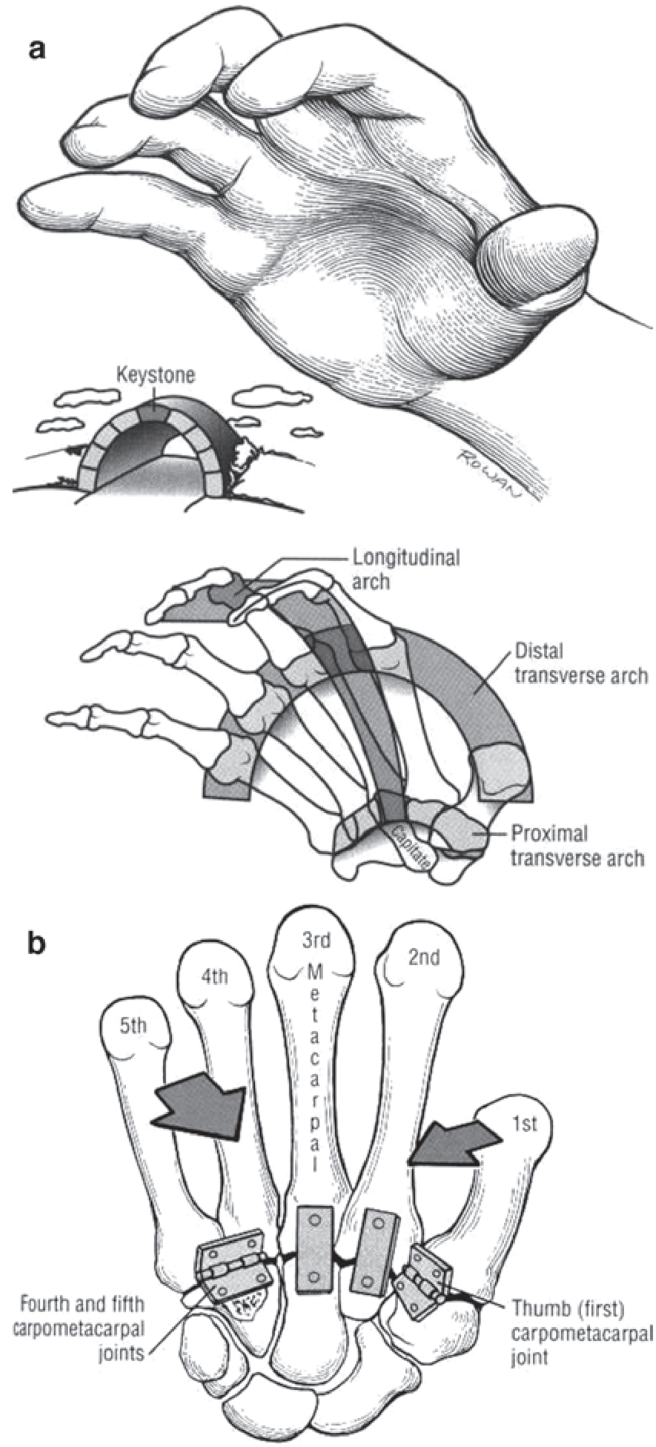

Figure 4. Hand architectural provides both anatomical stability and flexibility. This figure was published in Neumann DA. *In: Kinesiology of the Musculoskeletal System*. Amsterdam, The Netherlands: Elsevier Science; 2002:200–207. © Elsevier.

MATERIAL SCIENCE

From the material science standpoint, the use of silicone has seen a significant transition. Earlier designs were constructed almost entirely from silicone. Later designs used silicone primarily as a protective interface and secondarily as a suspension component. Once it was realized that the frame structure of the most distal section was inherently stable on its own, silicone became a place to locate components rather than a way to suspend the prosthesis (Figure 6). For desired interface strength, incorporation of advanced composites,

Figure 5. Use of the hypothenar compartment of the anatomical partial hand interface to promote sensation and stability.

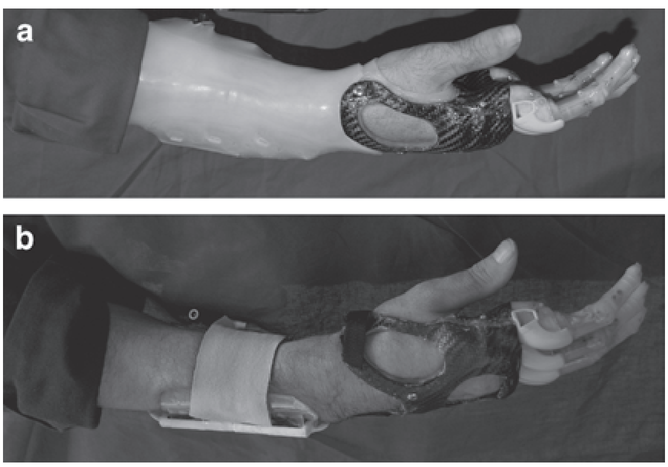

Figure 6. Transition from silicone as a suspension component to a protective and component placement role.

such as prepreg carbon and fiberglass, is necessary. These materials provide significant stability at an overall thickness of less than 1/16th of an inch.

SURGICAL TECHNIQUE

Historically, hand restoration has focused on saving as much of the anatomical structure as possible. This effort, albeit a worthwhile endeavor, often leaves individuals with residual limbs that are painful and more limited in function than is necessary. While more common at the phalangeal level, pain may be experienced in more proximal partial hand levels as a "result of an injudicious attempt to save length at all costs. Although maintenance of length is of concern, such residua seriously jeopardize function of the entire hand."[14] If the diverse limb presentations my clients have demonstrated over the last 8 years are any indication, surgeons handle partial hand trauma in many different ways, some of which further complicate later prosthetic options. Clearly, as prosthetic choices and strategies improve for partial hand clients, it is becoming increasingly important that prosthetists and surgeons collaborate to ensure optimal levels of amputation and techniques to maximize the upper limb prosthetic opportunity. Prosthetists will not only play a vital role in educating physicians on surgical parameters to maximize the rehabilitation of individuals with upper limb deficiency, but no doubt will also to continue to develop progressive socket designs.

PROSTHETIC TECHNOLOGY

Most of the technology readily available today targets more proximal levels of upper limb amputation. Partial hand amputations, however, require some very unique solutions. The mainstream input devices of upper limb prosthetics include myo electrodes, force sensing resistors, switches, and linear transducers.[15] These input devices combined with prosthetic microprocessors provide effective and proven solutions for more proximal levels of limb difference. At these more distal levels, a marriage of upper limb prosthetic technology and socket design, nanotechnology, and advanced processor technology promises to provide the finger mobility and control that the more rudimentary inputs cannot. Although these concepts are new to the prosthetics world, they are proven and tried technologies from other fields that can be integrated into our endeavors on an expedited basis. Furthermore, nanotechnology holds the likelihood of fitting within the tight clearances of these distal levels as well as performing well in adverse prosthetic environments. The usage of integrated multisensor arrays for input and sensing functions will likely be the first area of upper limb integration.[16]

CONCLUSION

Partial hand prosthetic management represents an exciting new frontier in the specialty of upper limb prosthetics. The application and benefit of treating this level are apparent (Figure 7). Currently, this level is very difficult because of the vast surgical presentations, traumatic nature of the resultant limb difference, as well as the complicated biomechanics present as a result of the aforementioned two issues. Electric prosthetic management requires specialized care that does not have its foundation rooted in any of the current, yet progressive upper limb care protocols used by today's specialist. Future stages of my research will include fitting protocols and techniques, fabrication, surgical considerations, and electronic handling.

As fitting techniques and componentry evolve, so will the clinical protocols. A unique opportunity exists at the partial hand level as our specialty enters a new prosthetic paradigm where evidence-based rehabilitation and sound research practices are expected by both the medical community and reimbursement agencies. The opportunity is significant—we have the chance to formulate research methods and clinical protocols from the ground up instead of retrospectively rationalizing clinical facts that lack the research base today's rehabilitation community requires.

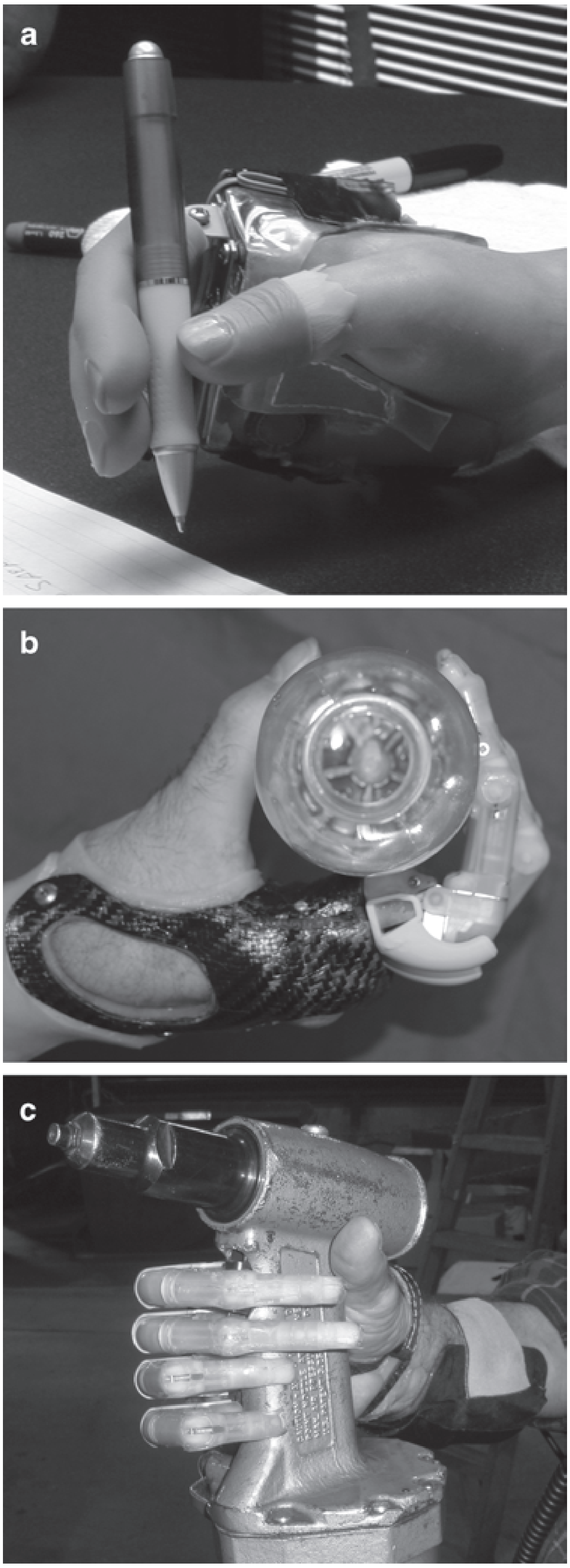

Figure 7. Various grasping scenarios.

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