EDITORIAL

Myoelectric functional hand prosthesis for total brachial plexus injury

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Global brachial plexus injuries (GBPIs) with multiple spinal root avulsions have permanent and devastating physical, psychological, and socioeconomic sequelae in patients and the community. The advances in treating these injuries, including microsurgical techniques, selective spinal nerve root reimplantations, primary nerve transfer to reconstruct the injured BP by using nerve repair or nerve grafts, and secondary free muscle transfer have led to improved outcomes compared to the natural history in this severe nerve injury.2,5 The results have been particularly promising in obtaining shoulder stabilization and elbow function.11,12 Nonetheless, the prognosis and the expectation of restoring hand movements have been generally gloomy for adult patients. Among the factors that hinder restoration of distal muscle function is the long distance between the sites of injury and the target end organ. A long time period (1.5–2 years) is required for the regenerating axons to traverse this distance,6 during which irreversible distal muscle atrophy and joint stiffness can occur, rendering the joints and muscles functionally useless even in the presence of successful axonal regeneration, which itself is hindered by the extended length of chronically denervated nerve distal to the injury. Misdirection of the regenerating axons may also preclude proper muscle reinnervation. Additionally, the discrepancy of the number of nerve fibers between the donor and recipient nerve has a negative impact.13 It is mandatory to have efficient hand function, shoulder stabilization, elbow flexion, and to a certain extent wrist flexion and extension (or stability) to attain purposeful hand movements. In spite of unsatisfactory results in the restoration of useful hand function, several surgical modalities have been attempted for these injuries.

Because of the limited options in GBPIs, Gu and colleagues proposed using contralateral C-7 nerve transfer to the injured BP. When the transfer recipient was the median nerve, patients reported reasonable wrist and finger flexion, with power ranging from Grade 2 to 3 on the British Medical Research Council (MRC) scale, in addition to protective sensation in the hand.8 Doi and coworkers used a double free muscle transfer technique in highly selected patients after GBPI. These individuals were able to achieve some hand grasping, along with voluntary control of the shoulder and elbow.6

Xu et al. used full-length phrenic nerve that was thoracoscopically harvested and transferred to the medial cord (motor fibers for hand and finger flexion) contribution to the median nerve. These researchers were able to restore MRC 3–4/5 hand prehension.13 The technique of using full-length phrenic nerve enables the surgeons to shorten the coaptation site to the forearm muscles, in addition to avoiding the need for an interpositional nerve graft.

A vital aspect that has seldom been addressed in the literature is reanimation of hand sensation. In this regard, intercostal nerves or rami were transferred to either median or ulnar nerves by Hattori et al. to restore limited protective sensory function in the hand.9 Nonetheless, in 2011 Bertelli and Ghizoni reported their considerable experience in GBPIs and concluded that useful reconstruction of hand function is not yet possible. They also found that most patients preferred to use thoracobrachial and forearm abdominal grasping to hold the objects.4

In a somewhat more complex and sophisticated maneuver in 2014, Zhang et al. performed a 2-staged reconstructive method to reanimate thumb and finger flexion and extension in 2 patients who sustained C7–T1 complete lesion and who already had normal shoulder and elbow joint muscles with some controllable wrist movements.14 In the first step (nerve transfer), a supinator motor branch was...
transferred to the posterior interosseous nerve to restore finger and thumb extension, and brachialis motor branch transfer to the median nerve (to restore finger flexion) was also performed. In the second stage (tendon transfer), the intact brachioradialis muscle was used for abductorplasty to restore thumb opposition. Overall the patients achieved satisfactory hand function. Nevertheless, these 2 patients had normal C-5 and C-6 spinal nerve roots—which permitted nerve transfers from preserved nerves to denervated ones—and not GBPIs.

In the absence of a reliable neurological reconstructive method for restoring finger extension, as well as the limited hand functionality attained by using tendon transfer, free muscle transfer, or extensor tenodesis techniques, the goal of finding nonbiological alternatives or substitutes for the functionless hand becomes mandatory. In this respect, in 2015 Aszmann et al. presented a new concept and reported for the first time on 3 cases of restoration of hand function in GBPI, and they coined the term “bionic reconstruction.” In their innovative work, they used 2 reliable myoelectrical signals from the forearm to create movements in a prosthetic hand, specifically between the thumb and the other fingers. Before the surgeon delicately amputated the flail biological forearm and hand to replace it with the new fitted prostheses, the patients were exposed to intensive and systematic training to use the prosthesis. The patients were able to conduct new tasks (including bimanual performance) with the new prosthesis. In the Journal of Neurosurgery, the same group now presents their detailed strategy for selecting the candidate patients who may benefit from this sophisticated approach.

As an extension of their original pioneering report, the authors present herein their treatment algorithm for bionic hand (myoelectric interfaced prosthetic hand after elective transradial hand amputation) reconstruction in patients with global (flail arm) brachial plexopathies, along with reporting the “long-term” functional outcome in 5 patients who were followed for more than 3 months after final surgery. In their 5-year prospective experience, 34 patients were evaluated, of whom 16 met the inclusion criteria, which was failure of all previous hand reconstruction procedures. Although 11 patients are still in the training process, final functional outcome measurements obtained using 3 validated instruments (the Action Arm Research Test [ARAT], the Southampton Hand Arm Procedure [SHAP], and the Disabilities of the Arm, Shoulder, and Hand [DASH] questionnaire) demonstrated significantly improved function compared to the pretreatment scores in the 5 prospectively followed patients.

The authors are to be congratulated on pioneering an innovative, although controversial, bioengineering solution for how to achieve hand functionality in patients with severe GBPIs. Several caveats need to be considered. The authors followed a necessary, careful, and multidisciplinary approach for assessment of the patients’ initial arm/hand function, psychological status, amputation impact on the patients, and use of electromyography and imaging studies in a highly specialized center. They used strict selection criteria. Notably, 18 of 34 patients (53%) were excluded because previous BP reconstructive procedures were able to restore sufficient hand function. This is a pivotal point because this approach is only indicated for treatment of the most severe cases in patients who despite conventional and even heroic reconstructive modalities (BP exploration and graft repair, nerve transfers, and tendon transfers) still have a functionless hand. We would also add that patients need to be highly motivated and psychologically prepared.

The authors emphasize the importance of stable and dynamic shoulder and elbow function because this may present a significant limitation for use of the prosthetic arm even if distal hand function has been restored. A somewhat surprising and important finding, which requires further elucidation, was the improvement in deafferentation pain by the functional prosthetic hand replacement. Some questions remain. Does the transradial amputation itself produce a phantom perception and/or phantom pain, for instance? Were patients with severe deafferentation pain excluded from the ongoing trial? The palliation of horrible deafferentation pain is an important value to add to functional hand capacity restoration, and we look forward to future experience and follow-up.

Overall, this procedure portends great promise but remains experimental. The future results of the other 11 patients in the study may provide further supporting evidence for the validity of this approach. Conversely, the longer period of follow-up may uncover the downsides of this approach that are still hidden in the shadow of early success. We look forward to future research and experience that will build on and evolve these exciting discoveries to further improve the prospects for patients with GBPI.

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**Disclosures**
The authors report no conflict of interest.

**Response**
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Global brachial plexopathies are among the most devastating nerve injuries.5 Besides the apparent functional sensorimotor deficits, the psychological distress resulting from chronic deafferentation pain is of great socioeconomic impact in affected patients.4 In spite of advanced microsurgical techniques and concepts, the hand function that can be expected after avulsion of the lower roots C7–T1 is poor, with the additional burden of chronic intracable pain.3

In cases of severe BPIs and/or failure of timely biological primary and later secondary reconstructive procedures, the recently introduced concept of bionic reconstruction provides a viable treatment alternative.2 This procedure allows restoration of hand functionality by means of biotechnological solutions: the functionless, flail hand is replaced by a mechatronic device, resulting in useful hand function. This restoration is not trivial, because deafferentation pain is not only the result of various pathological processes occurring at the level of injury (namely, the dorsal root entry zone of avulsed nerve roots3,4) but is also due to the CNS needing the neural connection to an extremely relevant piece of anatomy—which in fact entertains most of the primary motor and sensory cortex related to movement. The loss of hand/arm function burdens the affected individuals not only with the detectable loss of function, but also with a dramatic loss of afferent input, and it also burdens individuals psychologically because of the loss of the ability to interact with the world around them.

The fact that a large part of the CNS again finds a functional expression via prosthetic hand replacement is thus extremely rewarding and satisfying to the patient in many ways. In fact, we have observed that patients with severe deafferentation pain benefit most from prosthetic hand replacement, because the prosthetic hand is integrated into the patient’s body image and seems to replace the painful deafferented or phantom hand. We agree that further long-term follow-up as well as increased patient numbers will elucidate underlying mechanisms and strengthen the socioeconomic benefit of bionic reconstruction.

In our article we describe the treatment algorithm ranging from initial patient review to final prosthetic fitting. Our experience with 5 individuals who have undergone variations of bionic reconstruction reveals benefits both in general health terms (36-Item Short Form Health Survey outcomes) and in detailed multidimensional pain questionnaires related to deafferentation and phantom limb pain. This data set, however, was not included in the manuscript due to the scope and limited space of this article. According to patients’ statements, shortly after elective transradial amputation their subjective perception of the hand (whether previously painful or not) did not change. In none of our patients did the amputation produce a novel or altered phantom perception. Deafferentation pain was reduced only after final prosthetic fitting and prolonged wearing and usage time of the new prosthetic hand. Even re-entry into working life was achieved in some patients, which was not only due to the functional gain but also to pain reduction and subsequent enhanced resilience in daily life.

We agree that patient identification is of utmost importance in the context of bionic reconstruction, because it is only indicated after all other reconstructive efforts have failed. Psychological support and hybrid hand fitting before bionic reconstruction are of great importance within the treatment algorithm and allow the patient to explore the limits and possibilities of the expected outcome (see Fig. 1 in the original article). High motivation and long-term patient compliance obviously are key factors that allow for optimal outcome in prosthetic hand use.

**References**