The Reconstructive Ladder for Revision Surgery of Combat Amputees

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Abstract

Findings and Outcomes: Combat injury related amputations are associated with a higher number of complications. Little attention has been given to the role of surgical treatment concepts to treat residual limb pain after combat-related amputations and complications at the residual limb. This case series shows the impact of surgery and of the reconstructive ladder in the management of complications after combat injury related amputations for 10 amputees. After conservative treatment methods have been exhausted, a treatment algorithm considering the reconstructive ladder seems to direct the appropriate surgical techniques to targets at the residual limb thereby reducing pain and managing complications at the residual limb. The result is better prosthetic fitting and successful rehabilitation for the amputee.

Conclusion: Revision surgery including microsurgical techniques targeting identified pathology at the residual limb should be considered to reduce residual limb pain and to manage complications after combat-related amputations.

Keywords: Revision surgery; Amputation; Residual limb pain; Phantom limb pain; Neuroma; Scars

Background

Combat injury related amputations

Combat Amputees

Phantom Limb Pain (PLP) describes a pain in a limb that is no longer present. PLP occurs with prevalence up to 85% [4,5]. The exact mechanism for the development of PLP is still unknown. A suggested mechanism is an initiation by changes arising in the peripheries that alter the afferent input that the brain and spinal cord receive, leading to central reorganization [5-9]. A wide range of treatments for PLP have been investigated in the literature. In practice, a multidisciplinary, multimodal approach is often necessary to improve pain and quality of life in patients with PLP. Pharmacological, physical and psychological treatments address those PLP-related pain-qualities and may help relieve the pain [6,10]. Most surgical procedures used for phantom pain have been abandoned because of poor results in pain reduction [5,6]. Recently published was the

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first randomized controlled trial showing how PLP is impacted by Targeted Muscle Reinnervation (TMR) [11].

**Residual limb pain**

In contrast to PLP, RLP is an acute nociceptive pain that can resolve after the wound heals. Infection or wound dehiscences are known to prolong postoperative pain. RLP can persist for much longer and seriously affect long-term rehabilitation and the patient’s quality of life. The incidence of chronic RLP ranges from 13% to 71% [5,12-14]. Chronic residual limb pain is defined as pain that outlasts normal wound healing time and can result from a localized pathology or painful neuroma. Localized pathologies can be: chronic infection, osteomyelitis, painful neuroma, displaced bone fragments, Heterotopic Ossification (HO), scar tissue, foreign bodies, insufficient or excessive soft tissue coverage at the weight-bearing zone, displacements of muscle slings and neuroma [15].

Patients with RLP are often unable to be vertile and rehabilitate because the pain limits the load of the prosthesis and the acceptance of the prosthesis. Before surgical revision is considered non-invasive treatments such as desensitization, adaption of the prosthetic socket, etc. should be exhausted to relieve the pain at the residual limb [5,16].

Among RLP, neuromas are the major reason (10% to 25%) for revision surgeries. Neuromas may often be overlooked, although their reported rate as cause of chronic pain neuromas are benign tumors and occur in every amputation. Abnormal growths of nerve tissue that occur at the end of injured nerve fibers can be very painful [12,16].

So called painful neuroma discharge ectopically and spontaneously from afferent nerves at the amputation site linked to an upregulation of voltage-gated sodium channels in the affected nerves [5,17]. Furthermore, neuroma may have an increased sensitivity to mechanical and chemical stimuli [5].

Persistent RLP can be very difficult to treat as approximately 55% of those with RLP also suffer from PLP. Identification and differentiation of the dominant factor can be difficult. Both pain qualities can maintain the other. Furthermore, RLP is identified as a risk factor for the development of PLP and insufficient prosthetic fitting, and comorbidities compromising wound healing are significant predictors for RLP [5].

Due to poor results of surgical approaches in the treatment of PLP, modern microsurgical surgical concepts have not been considered widely for the treatment of residual limb pain so far [5,16]. Common opinion is to avoid surgical revision of the residual and treat similarly to PLP if no obvious localized pathology is identified. The shown effects of TMR on PLP and RLP seem to change the paradigms in the treatment of postamputation pain [11].

**Current treatment options of painful neuroma**

Little attention has been given to the role of peripheral nerve surgery as a treatment option, although microsurgical techniques have been found to relieve pain [16,18]. After peripheral nerve surgery, there were significant changes on pain, spasms, quality-of-life, and amputation status following removal of the motor and sensory neuroma with implantation of the proximal nerve ending into adjacent muscle fixed by an epineural suture [16].

Targeted Muscle Reinnervation (TMR) is a new technique redirecting the nerve stumps at the residual limb to biomechanical no longer relevant muscles at the amputation site to permit intuitive control of the myoelectric controlled prostheses [19,20]. The donor nerves are coapted to the motor nerves of the target muscles through small recipient motor nerve branches. Clinical experience also suggests that TMR may serve as an effective therapy for neuroma pain [11]. Within the first randomized controlled trial TMR improved PLP and trended toward improved residual limb pain compared with conventional neurectomy and burying the nerve into a muscle. The trend and the lack to reach statistical significance might be due to the fact that residual limb pain is not solely caused by neuromas, rather often then to bone spurs, impaired vascular supply, insufficient soft tissue coverage and other conditions that were not addressed by the analyzed surgical procedure.

Within this cohort study we analyzed the efficacy of revision surgery to treat residual limb pain and complications in combat amputees following a set-up diagnostic and treatment algorithm using the reconstructive ladder. Herein, if neuroma was present it was treated by a selective nerve transfer and combined to standard reconstructive techniques to further improve the conditions at the residual limb.

**Methods**

**Inclusion**

Within a clinical set-up we established an interprofessional “Interdisciplinary Amputee Outpatient Clinic”. Up to 100 amputees with amputation-related pain qualities, socket suspension or harness-problems and difficult skin conditions, were seen on average yearly. Within this interprofessional set-up the patients were examined following a defined algorithm.

**Data assessment**

Preoperatively, the following variables were documented: Self-reported pain (Numeric Rating Scale, (NRS)), quality of pain (burning, numbness, electric), localization of HT sign was marked and photographed. Postoperatively, precisely after prosthetic fitting was finalized, the self-reported pain scale pain scale (NRS) and photo documentation was repeated and the type of fitted prosthetic components were documented. NRS Scores pre- and post-intervention were compared for statistical significance using paired t-test, p<0.05 as statistically significant.

**Surgical techniques**

Standard plastic-surgical techniques and specific amputation revision surgery techniques were used to improve soft tissue coverage of the residual limb according to the reconstructive ladder [21-25].

Painful neuroma at the residual limb were excised and submitted for pathologic examination, under loupe magnification, the proximal nerve stump was cut back to healthy fascicles, mobilized out of the weight bearing zone and either (1) buried tension-free into a neighboring muscle after opening the fascia and sutured to it via an epineural-epimyisal stitch with prolene 6 or 8-0 or (2) directly sutured to small sensory or motor nerve branches by an end-to-end epineurial suture with prolene 8-0 [18,26].

**Results**

**Demographics**

Ten traumatic amputees from North Africa and the Middle East were included. Nine were men and one was a woman. The average age was 26.9 years (range: 17 to 36 years). The cohort suffered the following amputation-levels: Three above-knee, one forefoot, one
partial hand, three transradial, and two transhumeral amputee.

Nine patients were unilateral, one quadruple amputee. One transradial amputee suffered an additional contracture proximally to the residual limb - at the elbow joint - which was revised within revision surgery.

Nine patients lost their extremity related to war injuries (blasting injuries), one due to a high-voltage injury. During the observation time two cases healed by controlled secondary wound healing (Figure 3), one needed re-revision surgery.

Seven patients were revised because of amputation-related pain or complications at the residual limb prohibiting prosthetic fitting after non-invasive treatment options were exhausted and the algorithm identified a pathology (Table 1 and Figures 4-9).

Pain at the RL

After revision surgery, there were changes of pain level. The mean numeric rating scale score of the preoperative pain level was 8.1 (range: 7 to 10) and was significantly reduced to 1.7 × (range: 0 to 3; p < 0.05) after revision surgery. Three amputees were revised because of poor soft tissue conditions at the residual limb avoiding sufficient
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Pathologies and complications at the RL

Seven patients suffered a painful neuroma, three inefficient soft tissue coverage of the RL (two insufficient, one excessive). In six patients the surgery removed foreign bodies related to the battlefield or calcifications of soft tissue resulting from the high energy of the trauma (Table 1 and Figures 4-9).

The surgical techniques

Following surgical techniques were used to reshape the residual limb with the revision surgeries: Scar excision, local and free flaps, Baumgartner’s myoplasty. Free Fibula transfer, k-wire arthrodesis were used for bone reconstruction. HO fragments and foreign bodies were removed and the remaining bone smoothed (Table 1 and Figures 4-9).

Prosthetic rehabilitation

Nine out of ten patients immediately started prosthetic fitting when the wound was fully healed, and the k-wire arthrodesis healed. Within the observation time of 12 months there was no recurrence of pain, tender points, impaired socket suspension limiting prosthetic fitting.

For eight out of ten patients revision surgery enabled prosthetic fitting which was not previously possible. One patient returned to his home-country before fitting was finished. A second patient is waiting for reinnervation of the muscle and returned during the ongoing rehabilitation process. To our knowledge the patient was revised due to infection (Table 1).

Discussion

Surgery for pain and complications at the residual limb?

Chronic pain after amputation is often dealt with treating dominantly the symptoms. Pain medications tend to be the first line of treatment when patients complain about pain at the residual limb. Pharmacologic treatments do not serve as a curative treatment for residual limb pain, but merely mask the pain.

Overall amputee care demands medical and technical knowledge. The clinical examination should be performed by a multi-professional team providing surgical, drug-, (physio-) therapeutic and technical knowledge. It is important to explore and evaluate the range of conservative treatments thereby avoiding to subjecting a patient to unnecessary surgical procedures and related risks. However, once these modalities have been exhausted, it is crucial to consider revision...
surgery for the treatment of pain at the residual limb, if there was found a clear and consistent pathology. So far, little attention has been given to the role of revision surgery as a treatment option [5,6,11-14].

If the right target is addressed, surgical treatments can substantially relieve pain sustainably. Excision and SNT of a painful neuroma can improve the prosthetic fitting, decrease pain and increase mobility [11]. Still, treating chronic pain effectively remains challenging because the presence of chronic pain can result in further psychological disorders and compensatory movements limiting function [5,6,12,13].

**The value of the reconstructive ladder for revision surgery**

In the decision-making process for surgical techniques validated principles such as the reconstructive ladder should be followed [21,22]. Following those principles, the most appropriate and the least complex level of reconstruction is selected. This is especially important in revision surgery as wound healing and rehabilitation time means immobilization of the patient and should be as short as possible to avoid muscle atrophy and contractures.

For the surgery-decision making processes and since treatment failure is possible, the algorithm (Figure 1) helps to select patient groups that will benefit from surgical treatment. The core goal is to identify and localize a pathology which can be addressed by the surgery. The algorithm helps the clinicians in patient selection, to choose the right treatment concept and reduce the number of misdiagnoses. Diffuse pain and inconsistent pain qualities and location should be reevaluated after additional non-invasive therapies. Furthermore, the patient-specific prognostic factors need to be considered.

In Figure 3 the history of infection with multi-resistant bacteria should have demanded swabs before free fibula transfer to avoid the resulting infection of the transplant. The elevator in this cohort study is the selective nerve transfer of neuroma at the RL.

A variety of surgical methods have been described for the treatment of painful neuromas including centrocentral anastomosis, excision with coagulation of nerve tip, and silicone capping other

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**Table 1**: Showing demographics of the cohort, the pre- and postoperative pain level (NRS), the identified pathology targeted by revision surgery and the following prosthetic fitting.

<table>
<thead>
<tr>
<th>Patient</th>
<th>NRS</th>
<th>Level of amputation</th>
<th>Localized pathology</th>
<th>Surgical Strategy &amp; Rehabilitation</th>
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M: Masculine; f: Feminine; NRS: Numeric Rating Scale; Th: Transhumeral; TR: Transradial; TF: Transfemoral; FF: Forefoot; PH: Partial Hand; SNT: Selective Nerve Transfer; MPK: Microprocessor-Controlled Knee
methods that have been described to prevent regrowth of a neuroma include burying techniques of the proximal end of the nerve into tissue to stop neuroma growth. Examples include burying the nerve into bone, vein, or muscle [18,27,28]. In 1959, Munro and Mallory reported success by crushing the end of an amputation stump neuroma and burying the proximal end of the nerve into muscle.

Some of the earliest reports of nerve implantation into muscle include [29]. He described resection of the neuroma and suturing it into an opening of muscle [18]. Have used the technique of resection and muscle implantation with great success. Few methods have been used to specifically treat amputation neuromas to relieve chronic pain. Regarding the application of this technique in amputees, we are aware of only one similar reported instance in one upper extremity patient and Ducics case series before [11]. Compared in 2018 in a randomized control trial burying the nerve into a muscle to a selective nerve transfer in upper and lower limb revision surgery. The transfer led to a reduction of phantom limb pain and tended to a reduction of residual limb pain.

In revision surgery it is important to recognize that previous surgical treatments can alter the anatomical location of the neuroma at the residual limb. Familiarity with these situations and the variable anatomy after combat-related amputations is necessary for a successful outcome.

Furthermore, often a combination of pathologies- as in our cohort study- is needed to be targeted to relieve the pain level and to solve the complications in prosthetic fitting and rehabilitation.

In the above named randomized controlled trial the failure to reach statistical significance when the nerve was selectively transferred was
since residual limb pain was not only caused by neuromas, but also
due to bone spurs, ischemia, or other conditions [11,15].

**Limitations**

In addition to the low number of analyzed amputees, the
participants were very heterogenous regarding amputation level.
Furthermore, a weakness of this study is the missing differentiation
between RLP from PLP which was rather difficult for this cohort due
to the language barriers, loss of sense in translation and the cultural
background and acceptance of PLP.

**Conclusion**

Revision surgeries including microsurgical techniques have a
value in the treatment of postamputation pain and amputation-
related complications. After conservative treatment methods have
been exhausted, an algorithm considering the reconstructive ladder
seems to direct surgical methods to appropriate targets at the residual
limb enabling prosthetic fitting and successful rehabilitation of the
amputee.

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