ASRM Scientific Paper Presentations: Extremities
Tuesday, January 17, 2017, 10:15am – 11:00am

122. Ex Vivo Normothermic Limb Perfusion and Limb Specific Monitoring Evaluation of Perfusion Quality

Cleveland Clinic Foundation, Cleveland, 224, USA

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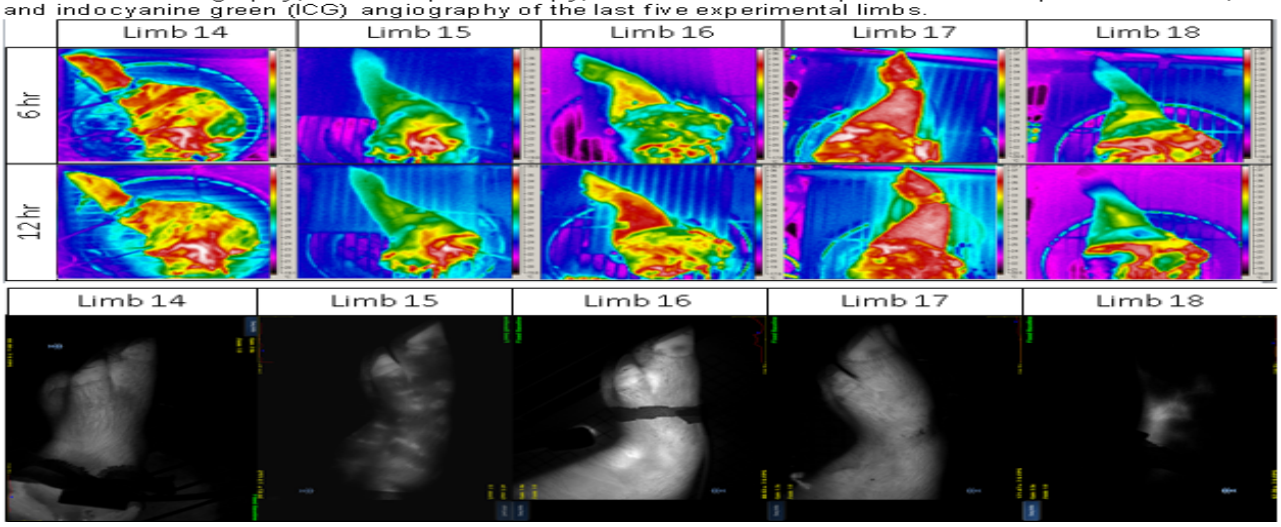
Purpose: Ischemia time represents a significant limitation for successful extremity replantation and transplantation because of the rapid deterioration of ischemic muscle. Static cold storage (SCS) of the limb is the standard clinical practice. Normothermic ex vivo perfusion system has the potential to prolong viability providing oxygen and metabolites after limb amputation. The aim of our study was to establish a perfusion protocol with limb specific diagnostic tools to evaluate the quality and uniformity of perfusion in an ex vivo model.

Methods: A total of 18 swine limbs were perfused, five of them followed the final, optimized protocol. Limbs were perfused at 39^{O}C for twelve hours using an oxygenated colloid solution with packed red blood cells. Glucose and electrolytes were kept within physiologic range by the addition of hypertonic solution or by partial hypotonic perfusate exchanges. Limb specific perfusion quality was assessed by muscle contractility upon electrical nerve stimulation, compartment pressure, creatine kinase(CK) and myoglobin concentrations, tissue oxygen saturation (near infrared spectroscopy), indocyanine green (ICG) angiography, and infrared radiation emission by thermographic imaging.

Results: All five limbs reached the 12 hour perfusion target maintaining normal compartment pressure (16.23±7.94 mmHg), minimal weight increase (0.54%±0.07), mean muscle temperature of 33.54±1.5^{o}C, and tissue oximetry readings of 59.67%±10.21. Average values of final myoglobin and CK were 875±291.4 ng/mL, and 53344±14850.34 U/L, respectively. Muscle movement was present in all limbs until cessation of perfusion. Differences in uniformity and quality of distal perfusion were demonstrated using thermography and angiography imaging after 12 hours of perfusion. Colder areas on Thermographic imaging correlated to mal perfused areas on ICG angiography.

Conclusions: Ex-vivo normothermic limb perfusion preserves limb physiology and function for at least 12 hours. Thermography and ICG angiography are valuable tools in the assessment of limb perfusion quality with the advantage of providing an immediate evaluation which allows for the visual identification of perfusion gradients and regions of mal-perfusion. Muscle contraction upon nerve stimulation, a uniform physiologic temperature and tissue oxygenation, and the distal dye distribution on angiography identify a successful perfusion. These methods may have important future implications on the decision to transplant or replant a perfused limb. Myoglobin and CK concentration increased in all limbs during ex vivo perfusion, but the functional significance of this is still to be determined.

FIGURE: Thermography, infrared spectroscopy, of the five last limbs perfused at time points 6 and 12, and indocyanine green (ICG) angiography of the last five experimental limbs.



123. Osseointegrated Neural Interface (ONI): Exploiting the Medullary Cavity of Long Bones for Integrating Peripheral Nerves with Robotic Prosthesis.

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Introduction: There have been substantial advances in prosthetic limb technology; however patients still can't control these devices with ease and precision. Typically these devices are actuated by myoelectric signals from soft tissue interfaces subject to motion artifact and muscle signal cross talk, ultimately preventing widespread clinical application.

This study was undertaken as a proof of principle for creating an Osseointegrated Neuronal Interface (ONI) to be eventually used for controlling prosthetic devices. A common surgical method for preventing terminal neuromas following amputation, whereby the terminal nerve ending is redirected into bone was first described ~70 years ago. Re-directing these nerve endings into the medullary cavity of long bones protects the nerve from mechanical and electrical stimuli, and surrounds the damaged nerve end with the regenerative bone marrow stem cell niche. This unique environment presents the perfect *in vivo* bioreactor for the potential interface between severed nerves and electronic prosthetic devices. This study describes the development of the ONI model, including a pilot study using a mock electrode to test proof of principal.

Materials and Methods: Transfemoral amputation was performed in New Zealand white rabbits. Briefly, the sciatic nerve was isolated and severed above the point of bifurcation. The femur was amputated at the midpoint and the nerve passed through a corticotomy. The terminal end of the nerve was sutured into a PDMS nerve sleeve, representing a mock electrode, which was pressed back into the opening of the medullary cavity, forming a tight seal. The muscle and skin were closed over the femur. Animals were explored at 5 weeks via histology and electrophysiology.

Results and Discussion: Gross examination of the ONI limb demonstrates healthy myelinated nerves, with visible Schwann cell nuclei and no signs of neuroma formation. However, substantial axonal loss is also evident. Cross sections of proximal portions of the nerve demonstrate the ONI nerve contains smaller myelinated axons than the control. Electrophysiology demonstrates that the nerve is alive within the bone, as demonstrated by compound action potentials equivalent to half that of the control side, which correlates with the smaller diameter of the myelinated axons in the ONI nerve. **Conclusions:** Terminal ends of amputated nerves are functional following being re-directed into the medullary cavity of the femur at 5 weeks. This result acts as proof of principal for the ONI model and its ability to house

functional prosthetic interfaces. Work is currently underway to test various electrodes in this model.

124. Vascularized Fibula-Based Physis Transfer for Pediatric Proximal Humerus Reconstruction: A Study of Longitudinal Bone Growth and Complications

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Introduction:

Vascularized free fibula epiphyseal transfer has been shown to be a viable option for proximal humeral reconstruction after sarcoma resection in the pediatric population. However, few studies have detailed the longitudinal growth patterns and complications. The purpose of this study is to provide an assessment of surgical outcomes including growth pattern and rate, flap survival, and complication profiles for free fibula epiphyseal transfers.

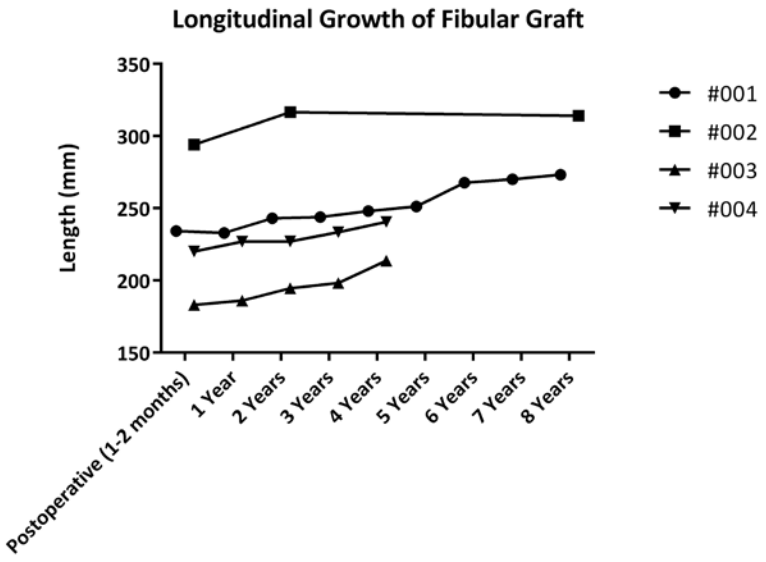
Methods:

We performed a retrospective review of 4 patients at our institution that underwent free fibula epiphyseal transfer following oncologic resection of osteosarcoma affecting the proximal humerus. Oncologic details reviewed included primary tumor pathology, location of malignancy, presence of local or metastatic recurrence, and the need for adjuvant therapy and duration. Reconstructive details included longitudinal growth of the flap from the time of implantation to the most recently available radiograph, and postoperative complications. The length of the flap over time was measured from the humeral head to the olecranon process using both anteroposterior and lateral views. When more than one radiograph was available for analysis, the average length was used. Radiographs obtained for annual post-operative oncologic surveillance (± 30 days) were used to assess longitudinal growth over time.

Results:

The average longitudinal growth rate of the free fibular transfer was 0.62 cm/year. As shown in Figure 1, each patient demonstrated satisfactory and consistent longitudinal bone growth over time. In our study, all 4 cases suffered from a complication of postoperative fracture. All fractures occurred in the humerus. Three out of 4 patients experienced unremitting peroneal nerve damage. In addition, all patients' demonstrated minimal active shoulder abduction and forward flexion, however they all demonstrated normal wrist and hand motion with a normal arc of elbow flexion and extension.

Conclusion: Longitudinal limb growth is preserved in the pediatric patient requiring oncologic resection and reconstruction of the proximal humerus.


Longitudinal Growth of Fibular Graft
Length (mm)
350
300
250
200
150
Postoperative (1-2 months)
1 Year
2 Years
3 Years
4 Years
5 Years
6 Years
7 Years
8 Years
#001
#002
#003
#004

125. Comparison of Proximal and Distal Neurotization for Acute Brachial Plexus Injuries Based on Functional Restoration of Elbow

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Introduction

Proximal and distal nerve neurotization for elbow reconstruction were both commonly used in acute brachial plexus injury but still with much controversy. This study aims to compare the functional outcome and speed of recovery of elbow flexion by these two strategies.

Methods

147 patients with either proximal or distal neurotization for elbow flexion reconstruction after acute brachial plexus injury were a retrospective review. All the data were collected and analyzed for the recovery of elbow flexion and the speed of which this improvement achieved. The improvement of shoulder abduction and the reduction of grip power in patients with distal nerve transfer also recorded.

Results:

Of the 147 patients, 76 patients received proximal nerve neurotization, 71 patients received distal nerve transfer for restoration elbow flexion (Oberlin-I method: 28; Mackinnon/Oberlin-II method: 43). All the patients are followed up at least four years. The recovery rate of functional elbow flexion (>M3) were comparable between proximal nerve (84.2%) and distal nerve transfer (Oberlin I method: 67.8%; Mackinnon/Oberlin-II method: 100%). Of the 76 patients received proximal nerve neurotization, 67 patients (88.2%) receive additional shoulder abduction restoration and 59 patients (59/67; 88.1%) gain shoulder abduction to 60 degrees. Significant decrease grip strength between normal and operated hand was noted in patient received distal nerve transfer (Oberlin method: 57.1%; Mackinnon method: 62.9%) ($p<0.001$)

Discussion:

Proximal nerve neurotization is a traditional strategy method for both the diagnosis and treatment. Distal nerve neurotization is a new approach with quick surgery time and immediate result, but the decrease grip power is the main drawback. We suggest combined proximal exploration first then combine proximal and distal nerve transfer to achieve the best results.

126. Cadaveric Nerve Allografts

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Purpose: Although autologous nerve grafting is the gold standard treatment for nerve injuries with ≥ 1 cm gap, it can be limited due to the supply of donor nerve, to insufficient caliber of graft and to donor site morbidity. These limitations is possible to overcome by the use of cadaveric nerve allografts (CAN). The purpose of the current study is to report a single Center's experience with CNA for functional restoration following traumatic nerve injuries.

Methods: Sixteen patients were included in the current study. The main indication for the use of CNA was nerve gaps ≥ 1 cm in which both the proximal and distal stumps of the injured nerve were available. The patients were given the option of selecting between autologous nerve grafts and CNA following a detailed consult regarding prons and cons of each treatment option. Only allografts from cadavers were used, and none of the patients underwent immunosuppressive treatment.

Preoperative workup included a detailed neurologic examination. Postoperative electromyography studies (EMG) were performed in patients with mixed nerve injuries at 3 months interval following reconstruction and then at 6 months after the first EMG study. Good and excellent results were considered those graded ≥ 4 for both sensory and motor function, using the MRC scale.

Results: There were 6 male and 10 female patients. Fourteen patients were adult and 2 were pediatric. The majority of the lesions was located in the upper extremity (n=13). The majority of the nerves involved were sensory (n=11), followed by mixed nerves in 5 patients. Sensory recovery was graded as good and excellent in 12 out of 15 patients (80%), while motor recovery was graded good and excellent in 3 out of 5 patients (60%). Factors related with functional outcome was the level of the injury ($p < 0.05$) and the patient's age ($p < 0.05$).

Conclusions: Although our study has limitations (small sample size, lack of a control group, heterogeneous group of subjects, variation in the length of nerve grafts), the results of the current study suggest that peripheral nerve injuries can successfully be treated by the use of CNA. Avoiding donor site morbidity, minimizing operative time and availability are the most important advantages of using CAN instead of autologous nerve grafts. On the other hand, cost and the risk of graft-versus-host disease, although no cases has been reported till today, are the main disadvantages of the use of CNA.

98. Reconstruction of Forearm Defects with Modified Radial Foreram Free Flaps Harvested from the Ipsilateral Extremity Proximal to the Level of Injury.

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Introduction: Reconstruction of distal forearm defects occasionally requires free tissue transfers. In cases where the radial vessels have been destructed, a modification of the radial forearm free flap, harvested proximal to the injury has been utilized.

Materials and Methods: 25 cases were performed between June 2005 and March 2016 in a Level 1 trauma center. There were 19 males and 6 females. Ages ranged from 19 to 67 years with a mean age of 38 years. The “racing stripe” modification of the radial forearm free flap, designed with a narrow 1- to 2.5 -cm skin island centered on the axis of the vessels and includes a much wider segment of the deep fascia extending from radial of the cephalic vein to ulnar of the palmaris longus tendon, was used. The average size of the flaps was 126 cm2 with the largest flap measuring 180 cm2. In 20 of the cases the flap was moved in linear fashion from the proximal to distal direction and the radial vessels on the distal end of the flap were anastomosed to the transected radial vessels at the wrist in an end-to-end fashion. In 4 cases where the vessels at the distal end of the flap were found patent but damaged, the flap was rotated 180 degrees and the radial vessels on the unaffected proximal end of the flap were anastomosed to the radial vessels at the wrist, in the same fashion. In 1 case retrograde flow through the transected recipient radial vessels was judged inadequate and the radial artery of the flap was anastomosed end-to-side to the ulnar artery. An attempt was made to create one antegrade venous connection which considerably decreases the early venous congestion associated with distally based flaps. Harvesting a longer segment of the cephalic vein frequently permits connection to a patent dorsal vein. The exposed fascial segment of the flap is covered with a STSG. Harvesting of the flap with a narrow strip of skin permits linear primary closure of the donor site without tension.

Results: There were no flap failures. There was one unscheduled return to the OR for evacuation of a hematoma.

Conclusion: When feasible, a modification of the radial forearm free flap harvested with an extended fascial component proximal to the level of injury can be safely used for precise reconstruction of forearm defects, avoiding distant donor sites without affecting the functional capacity of the injured extremity.

128. Examining the Use of Post-Debridement Cultures to Optimize Debridement and Improve Outcomes in Lower Extremity Reconstruction

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Purpose: Adequate debridement is vital to the success of chronic wound reconstruction. However, guidelines for debridement endpoint are poorly defined and based largely on subjective wound appearance. This study explores the relationship of positive post-debridement cultures on reconstructive outcomes after lower extremity wound reconstruction and raises the question of utilizing objective culture data to guide the timing of wound closure.

Methods and Materials: Patients who underwent reconstruction of chronic lower extremity wounds utilizing either local muscle flaps or free tissue transfer (FTT) [2006-2015], with minimum 90-day follow-up, were retrospectively reviewed. For each cohort an overall wound complication rate was tabulated that included rates of infection, dehiscence, delayed healing, flap loss, and reoperation. Univariate and multivariate analyses were performed to assess the effect of positive post-debridement cultures on overall wound complication rate in each cohort.

Results: Sixty local muscle flaps and 72 free flaps were performed for reconstruction of chronic lower extremity wounds. Among these, positive post-debridement cultures were identified in 22 patients (36%) and 25 patients (35%) reconstructed with local muscle flaps and FTT, respectively. Overall wound complication rate was higher among patients who underwent FTT (43% vs. 28.3%, $p=0.86$). Positive post-debridement cultures (OR:17.3, CI95%:4.7-80.1, $p<0.001$) were significant predictors of wound complication among patients who underwent local muscle flap reconstruction only. These associations remained consistent in multivariate modeling.

Conclusion: Objective culture data may be used as a guide to standardize debridement practices and improve outcomes in lower extremity wound reconstruction. Serial debridement to negative cultures is paramount if performing local muscle flap coverage, but may be of less significance in the setting of FTT. Free flaps may be indicated for patients with persistently positive cultures.