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Advances in Upper Extremity Prosthetic Technology: Rehabilitation and the Interprofessional Team

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Abstract

Purpose of Review The aim of this paper is to explore current trends and advancements that lead to improved practitioner knowledge and patient care resulting in better outcomes. It is common for the physiatrist to lead the team of interprofessional practitioners in the care of individuals with upper limb absence. The focus of the care is to understand and access prosthetic options, but there are often other health factors and relevant issues to consider.

Recent Findings Some of the latest updates offer solutions to pain management, prosthetic control, access to relevant evidence, and outcomes-related data. An interesting finding was the influence of telehealth service delivery on multiple issues faced by this population. These issues include lack of information, pain management, monitoring skin breakdown and peripheral vascular disease, prosthetic training, and access to peers and specialized practitioners.

Summary The diverse technology advancements in surgical techniques, materials, outcome measures, and data management, as well as telehealth, work together to assist the collaborative interprofessional team to provide contemporary and comprehensive care to this unique population.

Keywords Upper limb absence · Prosthetic rehabilitation · Interprofessional

Introduction

Upper limb absence (ULA) may be a result of surgery, trauma, disease, or due to a congenital manifestation. Regardless of the cause, it is common for the physiatrist to lead the team of interprofessional practitioners in the care of individuals with ULA. While the focus of the care is to understand and access prosthetic options, there are often other health factors and relevant issues to consider. The rehabilitation process itself begins by educating the individual with ULA and their caregivers and encouraging them to engage actively and collaborate with the team members to establish goals, research prosthetic options, and make decisions [1].

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Incidence and Prevalence

"Amputation" refers to the surgical removal of all or part of a limb or extremity resulting in the absence of a limb [2]. Not all limb absence is due to an acquired loss as some individuals are born with congenital absence or difference. Because of this, the population may be collectively described as individuals with limb absence (LA). There are approximately 2 million Americans living with LA (1:200 people); there are an additional 28,000,000 individuals who are at risk for amputation. Approximately 185,000 amputations occur in the USA each year. The number of individuals living with limb loss is projected to more than double by 2050, largely due to the rise of vascular disorders [3,4, 5]. Individuals with lower limb absence (LLA) outnumber those with ULA by a ratio of 4:1 [5]. Upper extremity amputation affects approximately 41,000 persons or 3% of the LA population. Increased awareness of work safety and changes in workforce patterns may contribute to diminished rates for traumatic upper extremity amputations. Current data reveals that trauma-acquired upper limb loss occurs at a rate of 3.8 per 100,000 persons. Loss of digits, particularly a single finger, are the most common of trauma-related upper limb amputations (2.8 per 100,000) [6, 7]. Following this, acquired loss at the trans-radial (47%) and trans-humeral levels (25%) is the next most common levels of upper limb amputations, with elbow disarticulations occurring least common (2.1%) [7].

Congenital upper limb difference affects approximately 1500 (4 in 10,000) infants in the USA and may present with longitudinal and/or transverse deficiencies [8, 9]. Longitudinal deficiency involves the absence of or shortening of a bone, such as in the radial clubhand. Transverse deficiency presents as the total or partial absence of bony segments; a common example is a trans-radial congenital difference, in which the forearm, wrist, and hand are not present. Congenital absence is the primary etiology of approximately 90% among the pediatric population; acquired loss accounts for about 10% of the pediatric population. As the congenitally involved population ages, this ratio shifts so that by adulthood only 10% of upper extremity absences are congenital. Unfortunately, there is a lack of literature following these children into adulthood, particularly in relation to prosthesis use, satisfaction, and challenges toward optimal function [5, 6, 10]. This is a prime example of how physiatrists familiar with human development might implement a life course health development model to influence the plan of care.

Challenges to Care

National and global health initiatives state that specific attention from health care and public health professionals is necessary to address the needs of populations and to prevent further disparities [11, 12, 13]. Specific issues faced by members of this group include the experiences of loss, pain, and isolation as well as understanding prosthetic technology and its control, and accessing technology.

Specialized Care

It is vital for the population with ULA to receive specialized care for the presenting multi-faceted challenges. Unfortunately, it is difficult for many individuals with ULA to access specialized care. The care of individuals with ULA often requires specialized training that is not easily available to most generalist clinicians. The course of intervention and outcomes of people with ULA varies and is based upon the individual needs. Regardless of the unique patient/client factors, optimal outcomes require the expertise of a specialized collaborative interprofessional team: individual practitioners from diverse disciplines who collaborate, contribute knowledge, skills, and experiences to offer optimized care. The communication and collaboration must transcend beyond the different institutions for which the practitioners work. A collaborative interprofessional team for ULA often includes surgeons, physiatrists, nurses, prosthetists, occupational therapists, physical therapists, vocational rehabilitation counselors, social workers, case managers, and, in some cases, life care planners [14, 15, 16, 17•]. A physiatrist, specializing in physical medicine and rehabilitation, is knowledgeable about the developmental, physical, and psychosocial processes and the resources needed for optimal outcomes. Sheehan and Gondo [18] reported on the effect of limb loss in the USA, stating that each well-trained member of the specialized amputee rehabilitation team has a specific and important role in the care and recovery of people with limb loss.

Impact of Loss

Regardless of the level of loss, the presentation, or the etiology, absence of the upper limb may be devastating to the individual and/or the family because of the impact to social and physical function [18, 19, 20, 21, 22, 23]. During a recent conversation, David Crandell, MD, Medical Director for the Amputee Program at Spaulding Rehabilitation Hospital in Boston stated that it is vital for practitioners to remember that "limb loss does include loss. Even with all the good technology, we must build in the psychological support for someone that is experiencing loss. We need to move the momentum to help people and their families to see limb loss not as an end point but a new beginning. I tell people that an amputation shapes you but doesn't define you." [24]

Pain

Individuals with ULA are very likely to experience the pain of diverse etiologies. These may include overuse syndrome, phantom pain, neuromas, or heterotopic ossification. Individuals with ULA, whether congenital or acquired, are at risk to experience overuse of the sound side. The presence of pain and deteriorated musculoskeletal function of the sound arm in individuals with unilateral or bilateral ULA is well documented [25, 26, 27, 18]. Gambrell [26] documented the importance of preventing overuse syndrome and recommended a team approach, with practitioner responsibility to educate patients to the likelihood of overuse and methods that impede development. Secondary conditions affect physical and mental health; current standard medical treatments often exclude psychosocial interventions [28].

Advancements

Recent advancements in different forms of technology and techniques have helped to address the challenges experienced by this population and thus improve patient/client care and outcomes.

Pain Management

Individuals with ULA may experience a variety of pain issues including neuromas and phantom pain. Phantom pain affects 80% of persons with limb loss. It is common for an individual to experience pain in the phantom limb soon after a loss that also diminishes over time [3]. Intervention for phantom sensation and phantom pain is implemented in the acute postoperative phase [2, 7, 29]. Interventions include active participation in functional tasks, gentle massage, prosthetic wear, transcutaneous electric nerve stimulation (TENS), and mirror therapy [30, 31, 32•].

Surgical techniques that may reduce pain and improve prosthetic control and function include targeted muscle re-innervation and osseointegration. These procedures can influence the future course of intervention, outcomes, and prognosis, and are typically considered to attain better functional outcomes [2, 22, 31, 33, 34, 35].

A nerve that is severed or injured attempts to regenerate and can result in a painful neuroma. Targeted muscle re-innervation (TMR) is a procedure offered at the time of or following amputation that provides nerve endings with a new host muscle to innervate in a way that will not cause a neuroma or phantom limb pain. TMR can improve a person's ability to use and control some prosthetic technology by using a concept called pattern recognition [34, 36, 39].

Osseointegration is a major advance in amputation surgery in which an artificial implant is permanently, surgically anchored, and integrated into the bone, which then grows into the implant. The procedure offers a direct skeletal connection between the natural bony anatomy and the prosthesis extension. Research shows that osseointegration improves mobility and proprioception (osseoperception), reduces nerve pain, and eliminates common problems associated with fitting the residual limb into a socket [35].

Technology

Technology has advanced the care for the person with ULA in numerous ways.

1. Prosthetic materials and components

   New materials, such as silicone, and processes, such as additive manufacturing, have influenced options on every level for the prosthetic user. Passive functional esthetic devices are static prostheses that appear to look like a hand; functions include stabilizing, supporting, and improving cosmesis. Advancements have resulted in more lifelike appearances helping the user to more easily blend into society and often improving self-esteem and quality of life. More robust materials have enhanced the development of activity-specific devices to accommodate more rigorous activities or harsh environments. Likewise, the use of softer silicones, air bladders, and temperature management systems are yielding more comfortable sockets for different types of prostheses. The control of the body-powered prosthesis has been improved with newer materials for harnessing, and even the elimination of the harness through the application of adhesives [38, 36]. Externally powered prosthesis control has been improved by pattern recognition, a mechanism that requires a set of myoelectric signals, corresponding to possible prosthesis movement, recorded, and used to calibrate the control system [37, 39]. It has also been improved by radio-frequency identification (RFID), a wireless communication that typically involves a RFID reader and a tag. The tag has information stored in its memory, and the reader (using an antenna) can read this information [40]. Another option for prosthesis users is additive manufacturing, or 3-D printing, which is a three-dimensional device that resembles a prosthesis. It is fabricated from computer-aided manufacturing (CAM). Such devices are less costly and typically less robust requiring more frequent replacement, and not reimbursed by health insurance [41, 42, 43].

2. Data

   Outcome measures that accurately assess areas of concern to the key stakeholders are important to determine efficacy and to aid in access to specialized healthcare, technology, and the reimbursement for such services. Technology has also influenced patient care with the opportunity to create and collect data, using diverse outcome measures developed to interpret function, frequency of use, satisfaction, and quality of life [44, 45, 46, 47••, 48, 49, 50]. Collection of data to diverse repositories, such as search engines and even the "cloud" offers practitioners the evidence upon which to make informed decisions to guide care, and to justify it for insurance authorization and reimbursement. This technology development further gives individuals with ULA the opportunity to access more than one type of prosthesis because data regarding functional outcomes, prosthesis use, and satisfaction are more readily available. The lives of people are complex, with multiple roles and various responsibilities, and no one prosthesis can accommodate for the multiple functions of the natural hand. Different prosthetic technologies can offer opportunities to the user to live fully and to protect the remaining anatomy from overuse. Blair Lock, CEO of Coapt Engineering states that there now exist different types of data collection and computing analysis. This is important because of how the information can be crunched by the "cloud" and disseminated to practitioners for patient care. The information gives insight into "what we need to know, why we need to know it and how we can use it for better patient outcomes, incorporation to daily life, and product development. The data becomes more real, valuable, and valid." [51]

3. Telehealth

Individuals with ULA often report receiving little to no information from medical professionals about preventing secondary conditions [3]. Often, these individuals are invited to peer support groups, for the purpose of education, engagement, and empowerment; however, because the groups are often predominated by people with LLA, they do not return. This leads to further isolation, and lack of information. Telehealth offers a remote pathway for practitioners to collaborate and consult with each other and offers individuals with ULA access to specialized practitioners and to peers [52]. Recently, Hewitt et al. [53•] discussed the ways that COVID-19 has catalyzed virtual health care for persons with limb absence. The areas cited include surgical decision-making, monitoring of wounds and peripheral vascular disease, postoperative care, prosthetic training, residual limb care, pain management, and psychosocial needs. Many times, natural disasters, wars, conflicts, and even pandemics have resulted in technological advancement and utilization. It appears that the effects of COVID-19 have had similar results.

Conclusion

Managing the health of the person with ULA is strategic and complex. In addition to being knowledgeable about the absent limb(s), the provider must also be cognizant of the impact to other anatomy, in its current state and projected for the future over the life course. The rehabilitation team should be aware and understanding about the individual's response to the limb absence, and understanding of the psychosocial aspects that may include change in self-image and body image, acceptance of the residual limb, and feeling comfortable in society as a person with limb absence. Health providers should facilitate and reinforce good communication with the client-centered health care team, allowing the individual patient to be an active stakeholder to establish the plan of care and rehabilitation goals [54••, 55, 56, 57]. Health care practitioners cannot be expected to know everything, but collaborating with an interprofessional team will help providers to be more aware of resources, advancements, and make appropriate referrals to improve patient health, function, satisfaction, and quality of life.

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Declarations

Conflict of Interest The author declares no competing interests.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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