Extremity Replantation

A Comprehensive Clinical Guide

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I dedicate this book to my father, Amorn Salyapongse, whose lifelong passion for hand surgery and boundless enthusiasm in the face of countless replant cases fascinated me in my youth and continue to inspire me today.

A. Neil Salyapongse

To my family, Hannah, Anabelle, and Silas. Your wonderful and wild ways keep me smiling. To my parents, Henry and Nina. Your dedication, energy, and compassion inspire me. And to Ted Goslow—colleague, teacher, and friend.

Samuel O. Poore

To my two favorite mentors, friends, and role models: my mother, Karima, who showed me that you can be both a good parent and a good physician, and my father, Medhat, who completed his first replantation when I was 3 years old.

Ahmed M. Afifi

For Kim, Gretchen, Alex, and Eric.

Michael L. Bentz

Preface

Winter is coming. This certainty drives each of us to prepare for the inevitable occurrence that will threaten life and limb. It trains us to be seers, recognizing the patterns of disaster so that we might steer toward a better future. And, in contrast to the *lone wolf* surgeon stereotype, it leads us to value and encourage the abilities of a broadly experienced team. When the tragedy of extremity amputation comes, the best prepared and cooperative team offers the best chance of *survival and optimal function*.

When Kristopher Spring approached us about a book addressing replantation, we were struck by the fact that there had not been a comprehensive text covering the field for at least the past decade. Surely, an event that raises the health-care team's adrenaline levels almost as much as the patient's would spur some sort of survival guide; after all, countless individuals are now well prepared for the zombie apocalypse despite its relative infrequent occurrence compared to extremity amputation. We also recognized that the complexity of the subject matter ranging from the basics of nerve, bone, and tendon healing to the intricacies of maintaining vascular patency and providing appropriate postoperative rehabilitation therapy only provides bookends to a world of possible replantation scenarios.

In generating this guide, we have sought the wisdom and experience of a global team of authors, all of whom are well known in the fields of plastic and orthopedic surgery. Our goal has been to tease out specifics particularly relevant to different types and levels of amputation. As a result, while some elements of patient care and surgical technique may be present in each individual chapter, references to other chapters for commonalities are included, making the work function as a more coherent whole and, perhaps, leading an otherwise targeted reader to new knowledge they might not have anticipated needing to know.

Looking back on the process of assembling this book, I realize the importance of community not only in the care of the replant patient but also in the creation of the text. I am grateful for the excellent quality of the manuscripts received, for the insights that taught me new tricks, and for the encouragement and generous extension provided by our publisher. I would also like to thank the efforts of my coeditors and the guidance and direction of our developmental editor, Elizabeth Corra. Without the collective push forward, none of this would have come to fruition.

Ultimately, the proof of this guide's utility will be found in the battleground of the emergency departments, operating theaters, and rehabilitation units, where all our teams labor to provide the best outcomes for our patients. Winter is coming; it is best to be prepared.

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1 The History of Extremity Replantation

Wayne A. Morrison

Introduction

The first successful digital replantation in 1965 by Tamai [1] (Fig. 1.1) heralded the clinical era of microsurgery. Soon microvascular surgical techniques would be applied to free tissue flap transfers, introducing a new sophistication in reconstructive surgery. But was it destiny or an even higher intervention that guided the healing hand of this Japanese surgeon to reattach an amputated part? For in certain Japanese cultural traditions, the dead should be buried with all body parts intact. This taboo continues to limit transplantation in Japan as evidenced by low donorship levels. In western culture, the procedure evoked the opposite reaction in some; to them the concept of bringing the dead back to life was in defiance of nature's ordinance. Even today, observing the death pallor suffusing progressively to pink upon revascularization of a major body part such as a limb or even more so a face evokes a certain horror and unease.

Despite this, the history of reattachment of parts has a strong religious association, and the first recorded case is fittingly in the Gospel of St. Luke (22, 50–51). As the Roman soldiers were arresting Christ accompanied by his apostles, a commotion ensued and "one of them smote the servant of the high priest and cut off his right ear….and he (Christ) touched his ear and healed him." In his fascinating and erudite article on early free grafting, Thomas Gibson [2] refers to the Biblical debate regarding this incident. While all the evangelists record the injury, only Luke mentions total severance and the miraculous healing. Gibson highlights that Paula Zacchias (1584–1659), poet, painter, and personal

Fig. 1.1 World's first digital replant. Tamai 1965 (Used with permission from Kamatsu and Tamai [1])

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Fig. 1.2 Double capital depicting Saints Cosmas and Damian (guild of barber-surgeons) (Source: http://art.thewalters.org/detail/10296/double-capital-depicting-saints-cosmas-and-damian-guild-of-barber-surgeons/; In public domain)

physician to Pope Innocent X and founder of forensic medicine, in his treatise on miracles, concluded that if the ear was completely amputated before replantation it was a miracle of the First Order (one that could only occur supernaturally). However, if the ear was still attached by a tissue bridge, then it was a miracle of the Second Order (one that could possibly occur by a natural process). Harold Kleinert and team in Louisville had, 2 years prior to Tamai's replantation, revascularized digits, some with only minor skin bridges, using microsurgical technique [3]. Interestingly this same rigid canon distinction between complete and incomplete amputation was applied by modern-day inquisitors and denied Kleinert the award of First-Order Miracle status and the world's first acknowledgement. In the light of current knowledge, most would concede that proximal devascularizations attached solely by a small skin bridge or by tendons could only survive by a first-degree miracle. Many other legendary and miraculous reports of grafting, replantation, and transplantation have been recorded, the most famous of which involved the martyred physicians Cosmos and Damien (died 287 AD). They were indeed canonized for their good works including the transplantation of the leg of a Moor to replace that of a church worker after amputation for cancerous ulceration. They have since been adopted as the Patron Saints of barbers, physicians, and surgeons (Fig. 1.2 [4]). The miraculous replantation by St. Julius of the thumb of a church worker is the first recorded digital replantation and is celebrated in a painting in the church dedicated to the saint on the Isola San Giulio [5]. Saint Eligius of Noyon (590 AD), identified iconographically with a horse's leg at his side, is said to have successfully replanted all four limbs of a horse [6].

Renaissance Through Nineteenth Century

More credible evidence for surviving tissue reattachments by apparently natural means emerged in Renaissance times is detailed by Gibson and well summarized and elaborated on by Kocher [7] (*W J Surg* 1995) in his excellent review "History of Replantation." The famous case of the Italian physician Leonardo Fioravanti who successfully reattached the amputated nose of a Spanish gentleman lost after a quarrel with a soldier [8] offers an interesting protocol for preparing the amputated part "…I took it up and pissed thereon to wash away the sand and dressed it with balsama artificiato (dried blood powder) and bound it up and so left it to remain 8–10 days thinking that it would have come to matter, nevertheless when I did unbind it I found it fast conglutinated and then I dressed it only once more and it was perfectly whole." Balfour's report in 1814 of the reattachment of a carpenter's finger amputated at the PIP joint level is the most scientifically documented to that date [9]. Balfour was acutely aware of charlatan reports of the period and, sensitive to attracting similar skepticism, took the precaution of having affidavits sworn to verify the successful outcome. Some years preceding this incident Balfour had reattached three of his own son's fingertips which were caught in a door. He recorded that the finger was severed obliquely, spanning the proximal and middle phalanges, the longer side measuring 1.5 in., the shorter 1 in. from the tip. The part was cleansed and applied accurately to the opposing stump. No sutures were apparently used. The patient attended the following day but because of his doubts about its potential to survive sought advice from another physician with a view to having it removed. It was found to have adhered perfectly. Balfour next saw his patient 1 month later and noted that the nail had fallen off and the skin had desquamated but the finger was "the handsometh the man has and had recovered both heat and sensation."

Gibson [2] accredits Gottlieb Hoffacker [10, 11], doctor to the duelists of Heidelberg with the most critical and credible observations and hence the most valuable, in predicting success of free-grafting amputated parts. In analyzing the results of reported cases, including 16 amputated nose tips and lips sustained from dueling incidents that were his own, Hoffacker observed that contrary to common understanding, completely severed parts were not yet dead and the most predictable parameters for rescue were washing away blood, oblique amputation, and delay. The latter allowed bleeding to stop, the severed part to relax from its contracted state to its original dimension and for its blood vessels to reopen allowing lymph fluid exuding from the cut wound to reenter the now open ends. Replantation of the part facilitated accurate and maximum primary adhesion over the largest recipient area and favored first, rather than second, intention healing. These parameters appear obvious today as those which would most favor graft take, but it is of note that at this period, nearly 40 years before Revedin reported his skin grafting in 1870 [12], it was generally accepted that wounds could only heal by secondary intention.

Twentieth Century and into the Twenty-First Century

By the end of the nineteenth and beginning of the twentieth century, surgeons were experimenting with replantation and transplantation. In 1903 [13] Hopfner performed successful revascularization of canine limbs by vascular anastomosis, and Carrel and Guthrie [14] reported successful replantations though not without complications. Even before then, Briau, in 1896 [15], had anastomosed a canine carotid, and Halstead, in 1897 [16], had transfemorally amputated a dog's hind limb save for the femoral artery and transferred it to the opposite leg. He observed that subsequent division of the artery after 5 days did not result in death of the transplanted leg. Alexis Carrel who perfected the procedure in dogs and developed the foundations of vascular surgery and transplantation was awarded the Nobel Prize in Physiology and Medicine in 1912.

Although vascular repair had now been essentially mastered, its application for clinical replantation was a long way in the future. The safety of the procedure and the length of time that a part could be detached remained a mystery. Antibiotics and reliable bone fixation were unknown. In his excellent monograph, on "Major limb replantation and post ischaemia syndrome," Hans Steinau [17] outlines the relevant milestones in this field. World War I highlighted the phenomenon of crush syndromes and Volkmann's ischemia and their detrimental systemic effects including those following reversal of the ischemic insult. In 1930, Blalock [18], using canine hind limb tourniquet studies, disproved the theory that the toxins of ischemia produced "shock." Rather, he demonstrated the triggering factor to be extravasation of plasma from the circulation into the tissue and that this could be ameliorated by blood transfusion. In 1938, using the same model as Blalock, Allen [19] demonstrated that cooling to 2 °C dramatically decreased mortality. Further advancements were made During WW II by Bywaters [20] who demonstrated that postischemia syndrome was characterized by hyperkalemia, ECG changes, and renal damage from intravascular hemolysis.

Hall [21], in 1944, experiencing the mayhem of the war and the devastatingly high incidence of limb loss, published a detailed proposal and protocol for homologous transplantation of above-elbow amputations, 20 years before the first clinical replantation was performed.

Meanwhile canine limb replant studies were further developed in the 1960s with the work of Lapchinsky [22] in Moscow, and Snyder [23] and Eilsen [24] in the United States.

In 1962, Ronald Malt and McKhann [25] of Boston finally mustered the courage to try what had been technically feasible for many years and successfully reattached the above-elbow amputated arm of a 12-year-old boy. Chen Zong-Wei [26] independently pioneered replantation surgery in China and, in 1963, reattached completely amputated limbs. The following year, the first arm transplantation was performed in Ecuador in 1964 but quickly failed through lack of adequate immunosuppression.

In the meantime by 1960, microvascular surgery was being explored by Julius Jacobson and his student Ernest Suarez in Vermont [27], by Donaghy and Yasargil likewise for neurosurgery [28] and notably soon after by Harry Buncke for plastic surgery [29] in San Francisco. Jacobson had been appointed Professor and Director of the surgical research laboratory at the University of Vermont, and surgical research was, in many ways, the driver to perfect microvascular techniques. Small animal models were required to evaluate emerging clinical procedures such as portocaval shunting [30], transplantation, reperfusion injury, and drug development and opened up a new field of microvascular-based surgical research. Young, keen-eyed, hand-steady, and dexterous lab technicians were often the early masters of microsurgical technique. Many prior attempts at clinical replantation in the West and in China had failed because of the inadequacy of the tools necessary to achieve consistent results [31, 32]. In China polyethylene tubing was used as substitutes for suture anastomosis. The microscope already introduced for ENT and ophthalmology was greatly improved with Zeiss' introduction of the OPMI 1 in 1953. Jacobson noticed an OPMI 1 microscope abandoned in a corner of the surgical research lab that had been ordered by the ear surgeons for experimentation whose interests had since lapsed. Jacobson instantly realized the microscope's potential with its magnification of 25 times for the repair of small blood vessels. “The first experience in using the microscope for the performance of a vascular anastomosis can be likened to the first time the moon is looked at through a powerful telescope: a whole welter of unrecognized detail is seen” [33]. He reported 100 % patency of vessels 1.6–3.2 mm diameter

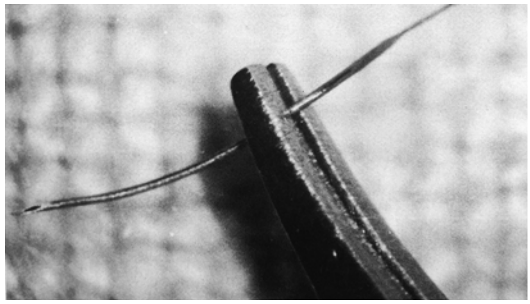

Fig. 1.3 The micro needle holder grasping the needle of a 19 μm metallized nylon microsuture (Used with permission from O'Brien [55])

[27], and soon the procedure was being adopted by others, and even smaller vessels were being repaired with high success rates [34]. The microscope was further enhanced by the insertion of a beam splitter so that two surgeons seated opposite each other could have the same view.

Sutures became finer and needles were perfected. Initially with Du Pont, Buncke designed metalized needles which were fashioned by dipping the tips of fine nylon thread into molten metal and polishing them to a point [35] (Fig. 1.3). Eventually the needles could be swaged onto threads in the same manner as larger sutures [36]. Micro-instrument development was also critical to the success of the microsurgical revolution. Needle holders [37] and scissors were modified from ophthalmology, jewelry forceps copied, and new vascular clamps invented [38]. Bob Ackland, working with Springler and Tritt, was instrumental in perfecting microsurgical instrumentation [36]. Many early attempts at automation were tried without gaining popularity. The stage was set for many to participate in this revolution, and soon thereafter, consistently high patency rates of vessels of the order of 1 mm diameter were published by Hayhurst and O'Brien [37]. Preeminent in this research arena was Harry Buncke who, after working with Tom Gibson in Glasgow in 1957, acknowledged that it was he who suggested the potential of small vessel anastomosis not only as a means of replantation but also for tissue transplantation [38]. Inspired by the work of Julius Jacobson, Buncke

Fig. 1.4 (**a**–**c**) Total face and scalp avulsion. (**a**, **b**) Before replantation. (**c**) Three months after replantation

realized its application for the wider field of free tissue transfer and developed techniques of toe-to-hand transfers initially in monkeys [39] and then humans [40]. Tamai had spent time with Buncke and accredits his microvascular initiation to this period. In a historic clinical case, Buncke transferred omentum to repair a scalp defect by anastomosing the omental vessels to those in the scalp. To quote Buncke, "… It succeeded and the rest is history" [41].

For most surgeons, the opportunity to learn and apply microsurgery was in the emergency center. By now large experiences of clinical digital and limb replantations were being reported [42–51]. With increasing training, experience, and exuberance, replantation has now been applied to almost all tissues of the body, including lower limbs, scalp, tongue, and facial parts. In September 1997, we experienced an extraordinary case where a young woman's whole face and scalp were avulsed when her hair was caught in a milking machine. Only one other case of face replant has since been reported [52]. The part was avulsed in a very superficial plane leaving all major vessels *in situ* on the patient. Replantation was accomplished by anastomosing an upper labial branch of the facial artery and one supraorbital artery, and its success presaged the feasibility of facial transplantation which was to follow (Fig. 1.4a–c).

Fig. 1.5 (**a**, **b**) Transposition of left to right leg in a case of bilateral leg amputation (prosthesis to left leg). Case of Chen Zhong-Wei, MD (Courtesy of Family of Chen Zhong-Wei)

The technical advancements and refinements in replantation have been accompanied by significant opportunities for creativity. Where multiple digits and limbs have been amputated, the most suitable amputated part can be transposed to the most appropriate site (Fig. 1.5a, b). When the patient is unfit for formal replantation, the part can be temporarily banked by microvascular anastomosis in an ectopic site as reported by Godina [53]. Stroke victims have had their paralyzed hand transposed to the opposite side in situations where their surviving useful hand had suffered severe injury or amputation [54]. Reports of parts being salvaged from dog and crocodile stomachs (Fig. 1.6), the extraordinary survival times of digits preserved in the snow, and the frantic forensic identification for the ownership of multiple fingers avulsed following the breakage of a tug of war rope when 20 digits were placed collectively into a plastic bag (Guillermo Loda – personal conversation) all add color and excitement to the history of replantation.

To quote from Kocher's abstract in his article on History of Replantation: "Severed body parts from the fingers to extremities are now being routinely reattached at medical centres around the world. The dream of replantation traces its rich history from miracles and legends to early laboratory experiments and clinical attempts, culminating in today's common place procedure" [7].

Fig. 1.6 Arm being retrieved from crocodile belly (Photograph by Jerome Bien)

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