FROM THE IRON HAND TO HAND TRANSPLANTATION

Prof. Črt Marinček, MD, PhD
Institute for Rehabilitation, Ljubljana, Slovenia

Summary

The iron hand from Slovenia, its form and function are described to demonstrate prosthetics achievements in the Middle Ages. Another big step forward in the field of hand replacement is high resolution digital CAD-CAM system combined with silicon technology, developed in Ljubljana. In the third part, an up-to-date review of hand allotransplantations is presented.

THE IRON HAND

In 1907, an ancient iron hand prosthesis was found in a walled-in niche while pulling down the old castle at Vransko in central Slovenia. It was manufactured somewhere in Europe between the years 1500-1650. The owner, probably one of the local nobles, has remained unknown. The prosthesis, weighing 795 g, was made to replace a male right hand (Fig. 1). It roughly imitates the shape of the human hand. The manufacturer went so far as to indicate the nails. The thumb is shorter, rigid, and placed in opposition to the palm, which is most important for function. It enables a cylindrical grasp which would have made it possible for the amputee to hold a sword, a spear, reins and tools (Fig. 2). The fingers (the thumb is rigid) move in pairs in three steps but not coming into full contact with the tip of the thumb and the palm of the prosthesis. The noblemen of those times wanted the aid to serve them in such vital activities as eating, drinking, use of weapons, and riding. The question is who in fact manufactured these prostheses. It could have been manufacturers of cuirasses, well trained as to technical construction, armourers or, to cite Pare (1840) with respect to "Le Petit Lorraine", locksmiths. It would be interesting to know when individual prostheses were made. It is possible to fix the period of Gotz's hand (1505-1508); we also know one of the manufacturers by name, one ''Le Petit Lorraine''. These two hands and the one from Ruppin probably served as models to all other manufacturers, which is deduced from the fact that their technical solutions resemble one another, even though some are rather simple and others more sophisticated.

Figure 1

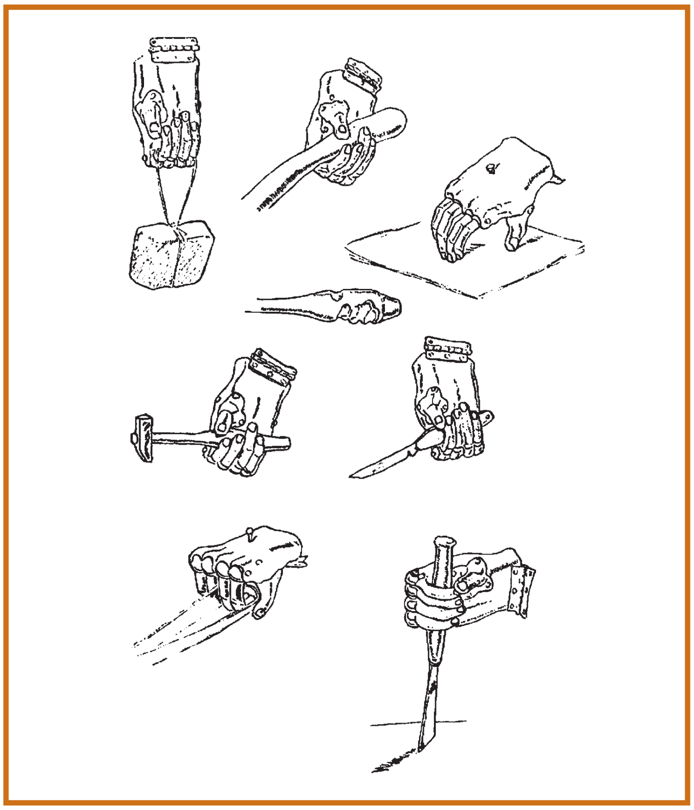

Figure 2

HIGH RESOLUTION DIGITAL COMPUTER AIDED DESIGN – COMPUTER AIDED MANUFACTURING (CAD-CAM)

The idea of using CAD/CAM systems in prosthetics appeared in the late 60s, while the first system dates back to 1983, when it was presented at the 4th ISPO congress.

The prosthesis or orthosis manufacturing is based on a model that is modelled upon the real, physical model. The picture of the real model is captured and digitized. Image acquisition is performed by video camera or laser beam. CAM of the designed prosthetic models employs numerically controlled machines and milling machines. The successful CAD/CAM technology application demands a computer-skilled prosthetist. In 2-year time, we have supplied patients with 45 transtibial and 168 transfemoral prostheses and more than 120 spinal orthoses. We can conclude that CAD/CAM systems might soon replace the classical production of the prosthetic products with plaster and offer a complete database of every single patient accessible over the network.

The development of CAD-CAM technology, Rapid Prototyping and Rapid Tooling technologies has advanced significantly in recent years and made those technological procedures more usable in the field of prosthetics and orthotics.

Our experiences show that patients wish to replace the lost part of their body with a prosthesis or epithesis that is a mirror image of the relevant healthy part of the body. Four years ago, the Institute for Rehabilitation linked up with other institutions, companies and the University of Ljubljana in order to search for new advanced technological possibilities to bring the form of epitheses closer to the form of a healthy hand or part of the face. Healthy and impaired parts of the body were scanned. A digital virtual model was constructed by using a computer program. 3D printing technology, DMLS (direct Metal Laser Sintering) and SLS (Select Laser Sintering) technology were used to build up the first model or mould for manufacturing a silicone epithesis. Through our development project, we found the way for the high-resolution digitizing of body parts and technology to produce a prototype model and mould, allowing for fine recognition of skin details.

CAD-CAM technology processes were also defined to enable the production of silicone prostheses after partial hand amputation, which in their form mirror the patient's healthy hand. Most centres for manufacturing silicone hand prostheses nowadays use the procedures of manual modelling, whereby the quality of such prostheses depends on the artistic skills of the prosthetist. By using CAD-CM high resolution technology, the highest-quality prosthetic design can be achieved even when the prosthetist lacks artistic skills.

HAND ALLOTRANSPLANTATIONS

The first successful solid organ transplantation was performed in 1954. It took 44 years for a success at transplanting the hand. The first attempt to transplant a human hand was undertaken in Ecuador in 1964. As immunosuppressants were not available at that time, the hand was rejected after 2 weeks.

As of 2007, there have been 43 reported hand transplantations worldwide, including 19 unilateral hand transplants, 22 bilateral (11 patients), and 2 partial hand (digital) transplantations. Unfortunately, published accounts of clinical outcome data in the peer-reviewed medical literature have been limited; detailed follow-up information at 3 years or more after transplantation is available for only 5 to 7 patients, and access to current patient data at the International Registry on Hand and Composite Tissue Transplantation website (http://www.handregistry.com) is limited.

Composite tissue allotransplantation (CTA) is a newly emerging field of transplantation that involves the simultaneous transfer of multiple tissues with differing antigenicity. Hand transplantation, the most widely recognized form of CTA, aims to improve function and the quality of life of upper limb amputees.

CTA is a term that encompasses transplantation of multiple tissues of ectodermal and mesodermal origin. The field involves simultaneous transplantation of tissue components including skin, muscle, nerve, bone, tendon, and other tissues. Limb transplantation was confined largely to animal models until clinical success was achieved in 1998. Transplantation of hand is one of the best examples of the CTA concept.

Hand transplantation is a prime example of a composite tissue allograft, comprising skin, subcutaneous, neurovascular and mesenchymal tissues, such as bone, cartilage, muscle, fascia and skin. The potential benefits of composite tissue allografts for defects caused by trauma, resection of tumours or congenital deficiencies are immense. Complex reconstructions, presently performed using local or free flaps, never perfectly replicate the lost parts, whereas this can be accomplished by transplantation of matched tissues from a brain-dead donor.

Transplanted body parts with epiphyseal plates would maintain their growth potentials. Examples of composite tissue allografts other than the hand performed successfully in the past decade include the larynx, abdominal wall and knee/femur, the latter transplantation being indicated in patients with major post-traumatic destructions of the joint and quadriceps apparatus.

Since May 2002, all groups performing hand transplantations have supplied information to the International Registry on Hand and Composite Tissue Transplantation (IRHCCT). The analysis of all cases with follow-up information up to September 2007 is presented in Transplantation. Hand transplantation is feasible with a high success rate and satisfactory functional outcome. From a functional point of view, a remarkably good recovery of sensibility has been documented in all transplanted hands. In particular, protective sensation was achieved in all patients within 6 to 12 months and, as time progressed, 90% showed tactile and 72% of them discriminative sensibility.

Recovery of motor function has enabled the patients to perform most daily activities, and 70% of the recipients returned to work, whereby improved manual skills allowed them not only to resume their previous jobs but also, in some cases, to find a more suitable employment. It is interesting to note that the average of sensibility and movement scores in unilateral and bilateral hand recipients were showing better recovery in bilateral hand transplantations. The importance of body image must specifically be taken into consideration, as the patient has been carrying and therefore showing his/her own disability for some time, causing a severe adjustment of his/her personality and ability to engage into affective relations. Seventy percent of recipients reported an improvement of their quality of life; bilateral hand transplanted patients were only slightly more satisfied than unilateral hand grafted patients. It is important to remark that motor and sensory functions improve for at least 5 years after transplantation in unilateral and bilateral hand transplantations. In conclusion, functional recovery has been well documented and not only is it based on nerve regeneration and cortical reorganization, but also on a good compliance of the recipient with the long and hard rehabilitation program, as well as with the immunosuppressive treatment.

The world's first double transplantation of complete arms was performed in a 16-hour operation by a group of 40 surgeons and nurses at the Munich Technical University Hospital in July, 2008. The recipient was a 54 year old farmer who had lost both arms in a farming accident six years ago. He was given the arms of a male donor who had died just before the surgery and whose family had given permission. The total preparation time for the operation was about 18 months. The patient, whose arms were cut off at the level of his T-shirt sleeves, was chosen because he was unable to use various arm prostheses and seemed psychologically stable and motivated. In the recovery period, the patient received electrophysiological muscle stimulation and physiotherapy to counteract muscle atrophy, together with psychological counselling.

REHABILITATION

Physiotherapy should be started early after transplantation, preferably on the first postoperative day, although this will depend on the quality of the tendon repairs. Physiotherapy is started with passive movements, but active mobilisation is encouraged as soon as possible. Between sessions of physiotherapy, the hand(s) should be kept in the intrinsic plus position by use of a thermoplastic splint. Sensory re-education and global motion pattern cortical reprogramming and, later, occupational therapy are indicated. Good results have been recorded using the specific cognitive exercise programme, which was originally developed for the treatment of replants. Physiotherapy should be intense and prolongued, since recent observations show that progress in hand function can still be achieved 5 years after transplantation.

In the above cases, the digits were fixed in metacarpophalangeal joint flexion during the first week; the wrist was placed in a dynamic brace and splinted in a neutral position from day 3 to 5 with gradual progression to a smaller splint over the next 6 weeks. A transcutaneous electrical nerve stimulation unit to decrease pain and an electrical muscle stimulator were used throughout the rehabilitation course. The patient and the support person were taught the exercises and the use of biomechanical devices. Active motion was initiated after vascular stability was confirmed, and the range of motion against resistance was increased gradually.

As already mentioned, hand therapy rehabilitation regimen is developed upon the principles for replantation cases. In a recent case, a forearm-based custom splint – a dynamic extension crane outrigger with adjustable thermoplastic metacarpophalangeal block splint and thumb abduction support (Orthoplast; Johnson&Johnson, New Brunswick, NJ) – was applied during the first week. The patients wore this splint for the first 6 weeks and the anticlaw splint for 1 year. The psychosocial evaluation consisted of a general diagnostic interview plus evaluation of social support system, history of medical compliance, emotional and cognitive preparedness for transplantation, and decision-making capacity. These included body-image adaptation after amputation, potential for psychological regression, anticipated comfort with a cadaver hand, level of realistic expectations regarding posttransplantation outcome, and recognition of the research nature of the procedure.

OUTCOME AND OUTLOOKS

Naturally, the outcome after hand transplantation is critically dependent on the patient's psychological status, his/her compliance and motivation, as well as the efforts of the rehabilitation team. Before 2001, the official position of the International Federation of Societies for Surgery of the Hand (IFSSH) was ''caution before proceeding with more transplants''. At its Istanbul 2001 congress, the Federation agreed ''to proceed with more transplantations in specialised departments''. At present, the best indication is probably a bilateral traumatic mid- or distal forearm amputation with stumps in good condition in a motivated patient devoid of psychological problems.

Relative contraindications include unilateral amputation of the non-dominant hand, a long delay between amputation and transplantation (although one hand transplantation has been performed 25 years after amputation with reasonable results – Lanzetta et al., 2004), anticipated psychological problems (the transplanted hand is permanently visible to the patient), insufficient motivation, and/or a poor stump condition (vessels, muscles).

To summarise, mankind has come a long way in replacing one of its most precious instruments and essential characteristics – the hand. The path travelled so far is successful and looks even more promising for the future.

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