Replantation of Amputated Parts of Extremities

*Kwang Suk Lee, M.D.

Department of Orthopedic Surgery, Hanyang University Hospital, Seoul, Korea

Bernard McC. O'Brien, M.D., F.R.C.S., F.A.C.S., F.R.A.C.S.

Director of Microsurgery Research Unit, St. Vincent's Hospital, Melbourne, Australia

-초 록-

사지절단부위의 재접합

한양대학병원 정형외과

이 광 석

미세외과의 발달은 1887년 Halsted와 Hopfer가 동물의 사지나 수지를 절단한 후 재접합수술을 실험적으로 시작한 이후 1960년 Jacobson과 Suarez가 현미경하에 미세혈관의 봉합수술을 시도하므로써 이들이 미세혈관 외과에 선구자로써 각광을 받았으며 또한 그후부터 여러분야로 임상에 응용되어 왔다. 특히 사지의 골, 관절을 주로 취급하는 정형외과 분야에 있어서는 1962년 Ronald Malt가 12세 소년의 절단된 우측 상지를 미세혈관 봉합술로 재접합을 시도하여 성공하므로써 급속히 발달하여 왔다. 저자는 지난 1년간 Melbourne대학 부속 St's Vincent's병원에 근무하면서 1971년 12월부터 1979년 2월까지 총 34예의 사지절단환자(수지제외)를 수술후 원격조사하여 다음과 같은 결론을 얻어 보고하는 바이다.

1. 총 34예중 생존율은 88.2%였고 절단부위가 광범위한 좌멸창이나 박리창인 경우는 국소 좌멸창 보다 생존율이 낮았다.

2. 전박부 이하 절단인 경우 비교적 근육조직이 적은 관계로 생존율은 100%이였고 수지기능도 양호하였다.

3. 하지에서 슬관절이하 절단은 재접합후 기능보다 의족착용후 기능이 비교적 좋은 것으로 판단되었다.

Key words: Replantation of limbs

Scientific background for limb and digit replantation has been evident since the experiments began by Halsted in 1887[14], Hopfer[16], and the studies of Carrel and Guthrie[6]. By 1944 the surgeon's attitude and skill were unquestionably adequate[13]; yet, even in two major wars replantation was not carried out. Jacobson and Suarez, pioneers in microvascular surgery, demonstrated the value of the operating microscope in 1960[21]. Salmon and Asimocopoulos, Buncke, Schulz and Cobbett were responsible for improvements in instrumentation and experimental work in digital amputations and replantations[3,4,5,9,32,33]. Clinical application was initiated by Dr. Ronald Malt in 1962 with the replantation of the right upper extremity of a 12 year old boy[25].

Within a short period, two separate successful replantations were performed by Ch'en, Ch'en and

* Formerly Fellow in Microsurgery, St. Vincent's Hospital Melbourne, Australia.

Pao in 1963 and by Horn in 1964[7, 17]. Since then there have been many successful replantations reported[20, 27, 34, 35].

O'Brien et al.[28] reported seven cases of complete amputation of the upper extremity and one of the lower limb with an overall survival rate of 67%.

Although there have been many reports of microvascular surgical technique for successful replantation involving digits, hand and upper extremities, little has been mentioned about the functional results in these patients[2, 8, 10, 18, 19, 22, 24, 29, 30, 35].

It is now time to evaluate the results of these efforts and arrive at guidelines which will help in selection, understanding of success, and functional results to be expected in these patients. As stated by the Chinese surgeon, Ch'en Chun-Wei, "Survival without restoration of function is not success"[1].

The purpose of this paper is to analyze the statistical and functional results obtained in replantation of severed limbs from metacarpophalangeal joints of hand and metatarsophlangeal joints of foot to shoulder and hip joints of patients seen and treated at the St. Vincent's Hospital, Melbourne.

Clinical Material and Results

Thirty-four patients with 21 complete amputations and 13 incomplete amputations were treated by replantation from December 1971 to February 1979. The average follow-up of all patients analyzed was 3 years 11 moths. Their ages ranged from 30 months to 69 years with an average of 24.9 years, and 67.8% of them were between 11-30 years (Table 1). The ratio of male to female was 5.8:1 and male was remarkably dominant in injury of limb amputation. The level of amputation at 34 replantations were as follows: 15 cases were hand, 9 forearm, 7 upper arm, 2 lower leg and 1 foot. Thirteen cases of these patients have had incomplete amputations, with a 100% survival rate and a total of 34 amputations have been replanted with a success rate of 88.2% (Table 2).

Table 1. Age Distribution of 34 Patients

Age in Years	Number of Patients (%)
0 - 10	3 (8.8%)
11 - 20	11 (32.4%)
21 - 30	12 (35.4%)
31 - 40	3 (8.8%)
41 - 50	3 (8.8%)
51 - 60	1 (2.9%)
60	1 (2.9%)
Average Age: 24.9	TOTAL 34 (100%)

Table 2. Replantation (Total 34 Cases) From December 1971 to February 1979

Number of Cases	Type	Viability (%)
21	Complete	17 (81%)
13	Incomplete	13 (100%)
Total 34		30 (88.2%)

The injuries were classified as guillotine, localized crush, diffuse crush and avulsion. A guillotine injury was one sustained with a knife and usually resulted in a sharp amputation. The guillotine and avulsion injuries accounted for 21 replantations in total 34 cases. Localized crush injuries were those resulting from a circular saw, chains or punch presses. The localized and diffuse crushing injuries accounted for 13 replantations (Table 3).

As expected, there was a definite relationship between the type of injury and the survival rate. Guillotine amputations had the greatest potential for survival, with 100% of the sharp amputations

Table 3. Survival Fate of Mode of Injuries.

Mechanism of Injury	No. of Cases	Survivals (%)
Guillotine	10	10 (100%)
Local crush	6	5 (83.3%)
Diffuse crush	7	6 (85.7%)
Avulsion	11	9 (81.8%)
Total	34	30 (88.2%)

remaining viable as compared to 85.7% of diffuse crush injuries and 81.8% of avulsion injuries (Table 3).

In this series, replantation of amputated limbs at the hand, forearm and upper arm levels gave results of 100%, 77.8% and 71.4% survival rate respectively (Table 4). Replantation of the amputated hand has surprisingly achieved the most successful survival rate.

The causes of amputation were mostly industrial accidents (61.8%) and traffic accidents (26.5%) (Table 5).

The causes of industrial accidents are detailed as followed: ball grinding machine (4); circular saw (4); plastic presser (2); weaving machine (2); auger (2); paper making machine (2); winch (20); cement mixer (1); brick pressing machine (1); and

Table 5. Causes of Injuries

Causes	No. of Cases
Industrial accident	21 (61.8%)
Traffic accident	9 (26.5%)
Train accident	2 (5.9%)
Meat mixer	1 (2.9%)
Window glass	1 (2.9%)

Table 4. Survival Rate of Level of Limbs

Site	No. of Cases	Type of Injury		Mehanism		Survival (%)
Hemihand	3	Complete	1	Avulsion	2	
		Incomplete	2	Guillotine	1	3 (100%)
Hand	12	Complete	10	Guillotine	7	
				Local crush	2	
		Incomeplete	2	Diffuse crush	1	12 (100%)
				Avusion	2	
Forearm	9	Complete	5	Guillotine	1	
				Local crush	1	
		Incomplete	4	Diffuse crush	2	7 (77.8%)
				Avusion	5	
Upper arm	7	Complete	3	Guillotine	1	
				Local crush	1	
		Incomplete	4	Diffuse crush	3	5 (71.4%)
				Avusion	2	
Lower leg	2	Complete	1	Local crush	1	
		Incomplete	1	Diffuse crush	1	2 (100%)
Foot	1	Complete	1	Local crush	1	1 (100%)
Total	34					38 (88.2%)

printing machine (1).

The occupations of the 34 total replantation patients were as follows: 5 unemployed; 4 students; 3 laborers; 2 machine operators; 2 butchers; and others were variable.

In considering the relationship of artery-to-vein anastomosis ratio to survival rate, an artery-to-vein anastomosis ratio of 1:2 or 2:4 appears to greatly enhance the chance of success[29, 30]. The survival rate of vein graft to artery of amputated limbs was 84.6%. Primary tendon repair was carried out in 12 (80%) of 15 cases of hand injuries only, but both tendon repairs of the flexor and extensor tendons were carried out in only 11 of these patients (10 complete amputations and 1 incomplete amputation)

Secondary tendon repairs were carried out in 2 (13.3%) of 15 cases of hand injuries. An avulsion case of 3 amputations from fingers to wrist level was excluded in this group.

Follow-up examinations of these 12 hand amputation cases from 4 months to 7 years and 6 months after injury demonstrated excellent or good function in 8 patients (66.7%) and poor results in 4 patients (33.3%) with the criteria reported by Kleinert et al.[23]

Primary nerve repair was carried out in 21 (70%) of the successful cases, with secondary neurorrhaphy performed in 4 patients (13.3%) and 4 of 5 patients had intact nerves, and one case has not yet been repaired because of nerve defect continuity at the time of accident.

Two-point discrimination ranged from 6 mm to 40 mm with an average of 12 mm at follow-up examination. Two-point discrimination of 10 mm or less was considered an excellent result, and protective sensation was considered a good result. Poor results were those with no demonstrative sensory innervation. In 30 successful replantations there were 6 excellent (20%), 19 good (63.3%), and 2 poor results (6.7%). Three cases were not followed-up.

Secondary procedures for 30 successful replantations are shown in Table 6. There was a total of 4 failures (11.8%) in the 34 replantation patients. The failures were all above the midforearm level, 2 cases of avulsion, 1 case of local crush and 1 case of diffuse crush injuries. All were complete amputations. Two of 4 failures were induced by infection from Clostridium welchii and Clostridium perfringens, and the other 2 from an overwhelming pseudomonas infection after replantation.

The mean ischaemia time for a successful replantation was 8 hours. Successful hand replantations have been performed after ischemia time ranging from 4.5 hours to 17.5 hours with cooling preservation (average 10.6 hours) (Table 7). All 4 failures were above average ischemia time. Most patients with successful replantations complained of cold intolerance in the replanted part. Symptoms were more common in winter. The appearance in all successful cases was satisfactory except for mild to moderate atrophy.

Discussion

Replantation of a severed limb is an elective procedure and, as such, must be assessed individually in each case. Naturally, the treatment of manifest life threatening injuries must always have priority. There are some situations wherein damage to vital organs is not obvious and this may be a cause of failure in restoring an extremity. Moreover, during prolonged operation, untended minor damage in the contralateral limb may come to assume major functional importance. A further important consideration is the amputated extremity and the amount lost. The arm is progressively more valuable from shoulder to finger then

Table 6. Secondary Procedures after Replantation

Site	No. of Case	Operation	No. of Operation
Hand	15	Tenolysis	5
		Skin graft	4
		Tendon graft	4
		Tendon transfer	3
		Nerve graft	3
		Free groin flap	1
		Capsulotomy	1
		Silastic joint implant	1
		Arthrodesis	1
		Opponensplasty	1
Forearm	8	Skin graft	5
		Tenolysis	3
		Tendon graft	2
		Tendon transfer	1
		Fasciotomy	1
		Bone graft	1
		Pedicle groin flap	1
		Silastic rod implant	1
		Capsulotomy of metacarpophalangeal joint	1
		Nerve pedicle graft	1
		Free gracilis muscle transfer	1
		Opponensplasty	1
		Free groin flap	1
Upper arm	4	Skin graft	3
Lower leg	2	Skin graft	2
		Bone graft	1
		Pedicle groin flap	1
Foot	1	Tendon transfer	1
		Arthrodesis	1

Table 7. Ischemia Times.

Site	No. of Survival Cases	Time (Average)
Hand	15	4.5 - 17.5 hrs (10.6 hrs)
Forearm	7	1.5 - 12 hrs (5.8 hrs)
Upper arm	5	1 - 6.5 hrs (4 hrs)
Lower leg	2	6 - 10 hrs (8 hrs)
Foot	1	11.5 hrs (11.5 hrs)
Total	30	Average : 8 hrs

the leg which is of less significance.

Successful replantation of an amputated extremity depends mainly upon the accurate repair of blood vessels, but the final goal must be complete restoration of function. Before a decision to replant is made, the extent of tissue damage, the patient's age and general condition, sex, occupation and the patient's wishes regarding replantation are evaluated. The success of micro-

vascular anastomosis depends mainly on the application of magnification, especially made instruments and fine suture materials appropriate to the vessel size, and finally, the surgeon's skill in the technique. The technique of microvascular anastomosis is varied in detail by several surgeons but the universal principle of the anastomosis is in the atraumatic handling of the blood vessel. Advances in microsurgical technique now permits the restoration of circulation to injured or amputated parts with a relatively high degree of success. In spite of this prognosis, many problems continue to plague the surgeon in his efforts to obtain initial tissue viability and subsequent function.

Many problesm concern the technical aspects of small vessel surgery, but there are numerous other pitfalls and potential problesm related to patient transportation, decision-making, anesthesia, soft tissue loss, bone shortening and fixation, bone healing, timing of nerve repair, postoperative vasospasm, edema and scar formation, rehabilitation and other facets of microsurgery performed for severe upper extremity injuries. These problems have stimulated us to reconsider operative indications, formulate new approaches to technical problems and correlate certain aspects of early care with long-term problems which may be anticipated.

For successful replantation in technical consideration, the patient and the severed part must be delivered in good condition to a hospital where sugery can be performed. The simplest preparation of the severed limb is to wrap it in a plastic bag surrounded by ice.

Experimental cooling, prior to periods of ischemia, has been shown to reduce postoperative edema, to increase postoperative blood flow, and to reduce postoperative shock and mortality[11, 15].

With immediate cooling of a major amputated part, preferable to 4°C, successful results have been reported by the Chinese of up to 36 hours for a foot, 33 hours for an arm and 12 hours for a digit[1].

O'Brien reports establishment of circulation with survival of up to 20 hours in digital replantation with cooling, and experimental work by Hayhurst and O'Brien suggests that this can be extended to at least 24 hours[30].

Once satisfied that contraindication to replantation does not exist, the indications for replantation also must be considered. In amputation of digits, all multiple digital amputations proximal to the distal inter phalangeal joint and individual thumb amputation should be replanted whenever possible in addition to forearm or upper arm amputations.

There is no conclusive evidence to support perfusion of the amputated extremity before replantation. Clinical reports of replantation frequently emphasize that no clots were obtained at the time of perfusion and that the perfusate immediately became clear[31].

O'Brien reported that preoperative perfusion involves manipulation and abnormal pressure of the vasculature which may result in vascular damage[28]. Prolonged perfusion may result in major decrease of potassium and magnesium, and manipulative attempts may damage vessel end[28].

Parenteral antibiotics are given as soon as possible before replantation. Penicillin and ampicillin have been used. Postoperative infection is frequently associated with replantation failure. High dosage for gram positive organisms including Staphylococci should also be provided and the appropriate tetanus prophylaxis also given.

Bone shortening is important before stabilization of bone. Various methods have been used including Kirschner wires, intramedullary pins and plates. All appear to have their place depending on the situation of bone and all can be successful.

Recently compression plates have been suggested as an advantage in certain cases[26]. In our 30 successful cases, there were 2 cases (6.7%) of non-union in forearm and lower legs. In the forearm,

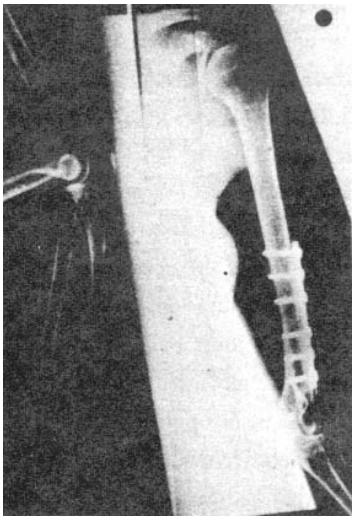
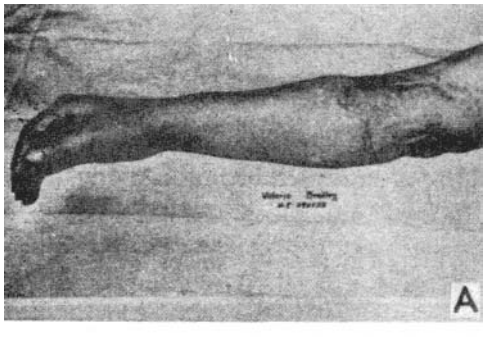


Fig. 1. X-ray appearance of the pre and post-operation after amputation.



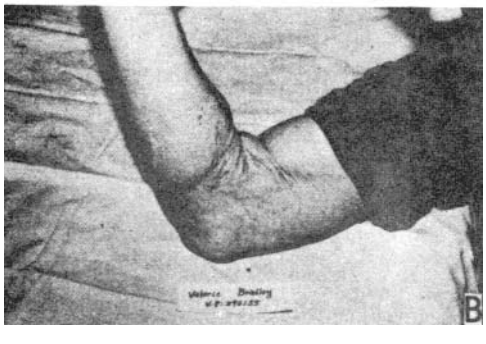


Fig. 2 A and B. Extension and flexion 10 months after replantation.

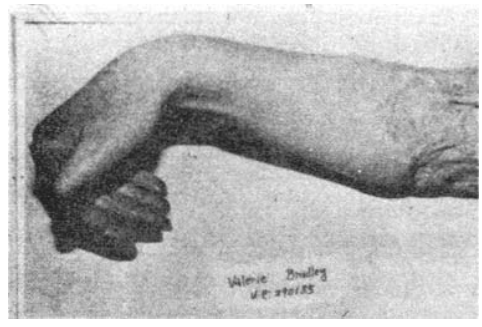
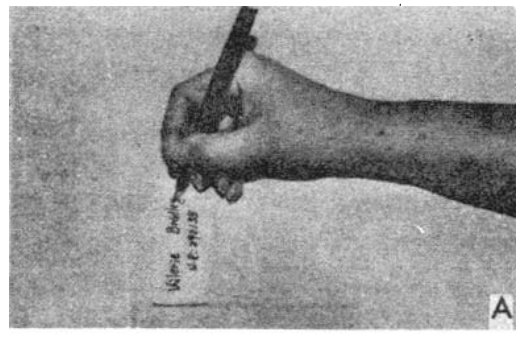


Fig. 3. Flexion of the wrist joint 10 months after replantation.



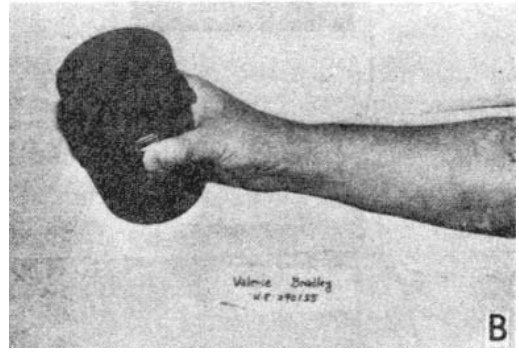


Fig. 4 A and B. Appearance and nearly full finger function 10 months after replantation.

there was non-union of the radius but union of the ulna.

Due to the possibility of manipulation causing injury to fragile vascular anastomoses the deep muscles and tendons are repaired early. At proximal levels, the deep structures, muscles, and tendons are repaired first, and at lower levels in the forearm, the wrist and digital extensors are jointed initially, followed by the veins. However,

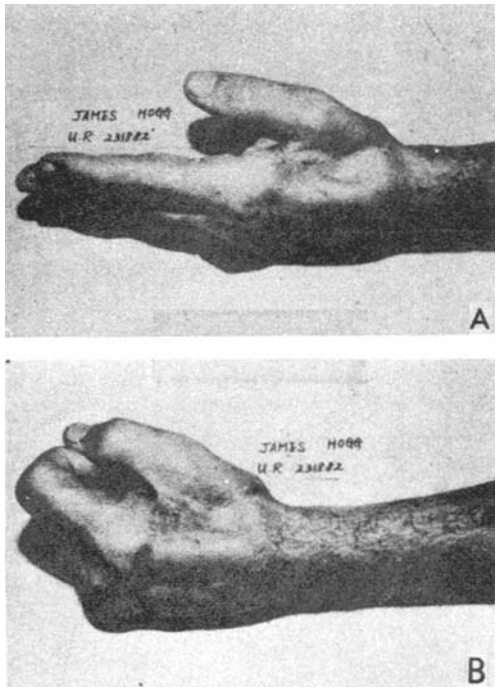


Fig. 5 A and B. Extension and flexion 14 months after replantation of complete amputation.

on the volar aspect, muscles and tendons are not repaired until the arterial anastomoses have been completed. If the period of ischemia has been relatively short, the veins on the dorsal surface are anastomosed first, followed by the arteries. Approximately twice the number of veins as arteries are joined and veins accompanying the arteries are anastomosed.

Primary repair of tendons and nerves should be carried out whenever possible. Excessive scar at the replantation site is a strong argument for primary reconstruction in an effort to avoid secondary procedures. Kleinert and Lendvay have been encouraged by the use of silicone rod primarily to avoid closure of the digital thecal tunnel[23]. O'Brien has performed two-stage flexor tendon grafting using silastic rods in the first stage[30].

Success of a surviving limb depends primarily on sensation obtained; therefore, accurate primary nerve repair is an essential part of the replantation effort. The results of secondary neurorraphy in this series have been disappointing while all patients with primary nerve repair obtained at least protective sensation or two-point discrimination of less than an average of 12 mm.

In our 30 successful replantations no anticoagulant therapy has been used except in three cases, and only aspirin 1 g daily, and Persantine, 250 mg q.i.d., postoperatively with 6% Macrodex,

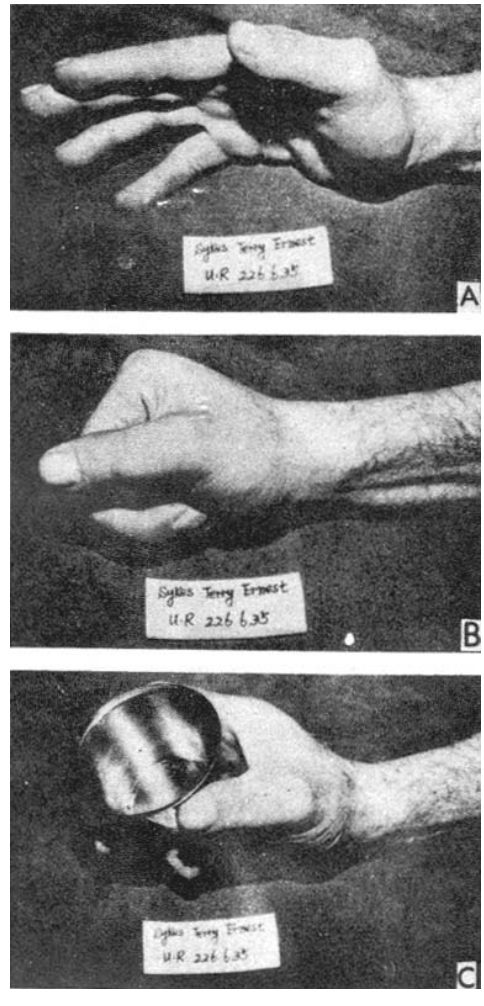


Fig. 6 A, B and C. Functional result 18 months after replantation of hemihand amputation.

½ 1 daily for 3 days.

Postoperative systemic heparinization has been supported by any surgeons, but recently some surgeons will not use heparin postoperatively[12]. The Shanghai group used heparin previously but because of the risk of hematoma formation and some systemic reaction, they no longer use it. Adhesions between muscles or tendons are the major problem in the restriction of motion postoperatively.

Selective repairs of muscles or tendons essential for function and early rehabilitation provide an answer to this problem. Joint stiffness can be overcome by early physiotheraphy on the replanted extremity. Continuous use of dynamic splints is important while the functional position of all joints is maintained throughout the rehabilitation period.

Summary

Replantation is the restoration of a completely amputated part as opposed to simply restoring circulation to an incompletely severed part.

The results of replantation of 34 amputated limbs performed from December 1971, to February 1979, were evaluated.

Results have shown an 88.2% overall survival rate of the amputated limbs, however, diffuse crush and avulsion injuries are decidedly poorer than local crush injuries at the replantation of severed limbs.

Amputation below the midforearm level involves minimal muscle content and there have been relatively good functional results and 100% survival.

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