Free Tissue Transfer and Replantation in Pediatric Patients: Technical Feasibility and Outcome in a Series of 28 Patients

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Received: 1 April 2013 / Accepted: 5 August 2013 / Published online: 17 August 2013
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Abstract Microsurgery in the pediatric population is still challenging because of technical difficulties in the small vessel diameter anastomosis and flaps dissection. The present study reports our experience of microsurgical reconstruction with free tissue transfer and replantation. Twenty-eight pediatric patients under the age of 15 years underwent different microsurgical procedures over a 10-year period. Twenty-one patients (75 %) underwent elective free tissue transfer, while emergency replantation was done in seven patients (25 %). The overall successful microsurgical procedures were 25/28 (89 %). All the 21 free tissue transfers survived (100 %), while three of the seven emergency replantations were lost (57 % survival rate) in this group. Microvascular surgery in children is a feasible, safe, and reliable modality with high survival rate. The indications, success, failure, and complication rates are very near to adults. Over the age of 10 years, procedure is nearly similar to adults. Between the age of 5 and 10 years, successful outcome can be achieved also but with greater challenges in surgical technique. Below the age of 5 years, more challenges could be problematic for successful outcome. Experienced surgical team remains one of the most important factors to obtain good results. Knowledge of multiple reconstructive options and mastering one of them seems essential for satisfactory results.

Keywords Microsurgery · Pediatric · Free flap · Replantation · Trauma

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Introduction

Microsurgery is a well-established practice in adults with success rates exceeding 70–88 % [1]. Despite an early report by Malt and McKhann in 1964 [2] about successful arm replantation in a 12-year-old boy, the surgeons remain concerned about the feasibility of microsurgery in young children. The first publications [3, 4] were sporadic, emphasizing mainly that microsurgical transfer was possible in children. It was not until the mid-1980s that the literature was enriched by larger series [5–12] that was demonstrating the feasibility of performing a variety of microsurgical transplantations in children.

The basic principles of microvascular transfers are nearly similar in adults and children. The absence of associated comorbid factors and unscarred clear anatomy is encouraging. However, the technical challenges in these patients are much greater and more complex [13].

The current study reports our experience of microsurgical reconstruction (free tissue transfer and replantation or revascularization) in a series of 28 pediatric patients under the age of 15 years. The technical difficulties, indications, outcome, and complication rates are presented.

Patients and Methods

Twenty-eight patients under the age of 15 years were included. These patients underwent different microsurgical procedures over a 10-year period at Ain Shams University Hospitals (Table 1).

Preoperatively, vascular duplex was done in elective patients (21 patients) and angiography was required in four patients to delineate vascular anatomy when duplex was not conclusive.

Table 1 shows the epidemiological data, indications, donor sites, outcome, and complications of all patients

Hospital stay (days)	Complications	Secondary procedure	Cause of failure	Outcome	Venous anastomosis	Procedure	Etiology	Age (years)	Pt. no.
6	Seroma (donor site)			Success	Single	Free rectus abdominis ms. for heel defect	Trauma	8	1
7	Flap congestion	Vein revision		Success	Single	Free rectus abd. for heel defect	Trauma	7	2
5	Hematoma			Success	Single	Free rectus abd. myocut. for amputated toe defect	Trauma	10	3
11				Success	Single	Free rectus abd. for exposed tibia	Trauma	8	4
11	- Flap congestion - Seroma	Vein revision		Success	Single	Free rectus abd. for exposed tibia	Trauma	9	5
10	Flap congestion	Vein revision		Success	Single	Free rectus abd. for exposed tibia	Trauma	9	6
18	Graft loss	STSG		Success	Single	Free rectus abd. for exposed ext. tendon	Trauma	12	7
7				Success	Single	Free rectus abd. myocut. for hemifacial microsomia	Congenital	9	8
6				Success	Single	Free rectus latiss. myocut. for hemifacial atrophy	Congenital	10	9
7				Success	Single	Free rectus abd. myocut. for hemifacial atrophy	Congenital	8	10
5				Success	2 veins	Toe to hand transfer	Trauma	5	11
6				Success	2 veins	Toe to hand transfer	Trauma	15	12
10				Success	Single	Free rect. abd for Volkmann's contracture	Trauma	10	13
10	Hematoma			Success	Single	Free rect. abd for Volkmann's contracture	Trauma	12	14
9				Success	Single	Free rect. abd for Volkmann's contracture	Trauma	15	15
9				Success	Single	Free rect. abd for Volkmann's contracture	Trauma	13	16
9				Success	Single	Free rect. abd for Volkmann's contracture	Trauma	12	17
10				Success	Single	Free rect. abd for Volkmann's contracture	Trauma	10	18
9	Hematoma			Success	Single	Free rect. abd for expose radial art	Trauma	12	19
10	Hematoma			Success	2 veins	Free radial forearm for penile reconst.	Trauma	15	20
10				Success	Single	Free fibula for mandible reconstruction	Tumor	14	21
7				Success	2 veins	Hand replantation	Trauma	12	22
6		Amputation and direct closure	Undiagnosed	Fail (3rd day)	Single	Digit replantation	Trauma	3	23
8		Amputation and direct closure	Undiagnosed	Fail (3rd day)	Single	Digit replantation	Trauma	5	24
7				Success	Single	Digit replantation	Trauma	8	25
7				Success	2 veins	Digit replantation	Trauma	15	26
8				Success	Single	Digit replantation	Trauma	6	27
5		Amputation and direct closure	Avulsion injury	Fail (2nd day)	Single	Big toe replantation	Trauma	2	28

Surgical Technique

All the microsurgical procedures were performed under general anesthesia and by the same surgical team. The microvascular anastomosis was done with the use of operating surgical microscope (Carl Zeiss, Germany) and the operative time was recorded. End to end anastomosis was used in all patients. One artery and single or two veins were anastomosed using 9-0 or 10-0 nylon suture with a tapered edge atraumatic needle. Interrupted sutures were used in arterial anastomosis for all the patients. For the venous anastomosis, interrupted sutures were used in 13 patients under the age of 10 years, while in 15 patients above the age of 10 years, running sutures were used.

Intraoperative heparinized saline was used for vessel irrigation and a bolus of heparin 100 IU was given immediately after vessels anastomosis. No routine postoperative anticoagulation was used in children who underwent elective free tissue transfer. Systemic low molecular weight heparin (Clexane, Sanofi Aventis, 150 IU/kg/day) was used for 1 week, only in patients who underwent replantation or revascularization, and in secondary revision cases. Pain control and antibiotics were maintained via intravenous route for the first 5 days then shifted to oral route. We have used direct clinical observation and handheld Doppler examination for postoperative monitoring of free flaps and digits or replanted hand.

Results

Over the last 10 years, we have performed 28 (20 males, 8 females) consecutive microsurgical procedures in pediatric patients under the age of 15 years. Twenty-one patients (75 %) underwent elective free tissue transfer while seven patients (25 %) underwent emergency replantation or revascularization. The age of the patients ranged from 2 to 15 years with mean age of 8.78 years. The indications for free tissue transfer were trauma in 17 patients, congenital defects reconstruction in 3 patients, and 1 patient underwent reconstruction after tumor resection. In lower limb trauma, reconstruction was carried on either as immediate procedure or late procedure (all cases were operated upon during first week post-injury). The hospital stay ranged from 5 to 18 days (average 7.54 days). The postoperative follow-up period ranged from 3 months to 5 years with average of 27 months.

The most commonly used donor site was the rectus abdominis muscle (16 flaps), one free fibula, one latissimus dorsi muscle, and one free radial forearm flap for penile reconstruction. The rectus abdominis was harvested as a muscle flap in 13 patients and as myocutaneous flap in 3 patients. In hemifacial atrophy cases, the rectus abdominis myocutaneous flap was used as a deepithelialized flap.

The overall successful microsurgical procedures could be achieved in 25/28 (89 %). All the 21 free tissue transfers

survived completely (100 %), including both the 19 flaps and the 2 toe to finger transfer. Three of the seven emergency replantations failed yielding 57 % survival rate for this group. The digit loss was evident on the second day postoperative in one patient and on the third day in two patients. Three patients (two free rectus abdominis muscle flap for coverage of exposed tibia and one for coverage of heel defect) required re-exploration on the second day postoperative for impending failure due to flap congestion (Fig. 1). On exploration, the three flaps had venous thrombosis that required revision of the veins and the three flaps were salvaged.

Nine complications (other than flap failure, flap congestion, or digit loss) occurred in eight patients (32 %). These complications included donor site hematomas and seromas in six patients, donor site infection in two patients, and skin graft loss over recipient site in one patient. These complications resolved by conservative management except in only one patient that required re-entry in the operating theater for skin grafting of the recipient site.

The recorded operative time ranged from 130 to 220 min with an average of 195 min for free tissue transfer (FTT) procedures and 153 min for replantation. *In patients with Volkmann's ischemic contracture, the operative time was recorded only for flap harvest, vascular anastomosis, and flap inset.* The time needed for recipient bed repair and tendon reconstruction was not calculated as a part of the microvascular procedure time.

Postoperatively, nine patients needed to be in the intensive care unit for 1–2 days. Blood transfusion (average 250 cc) was required in three patients in the elective free tissue transfer group and in one patient in the replantation group (hand replantation). Arm restrains and immobilization splints were needed in seven patients to protect the recipient site and decrease pain.

Discussion

Although microsurgery has had a relatively slower development in the children than in the adults, it has found its way to the pediatric population. At one time, it was considered impossible because of technical difficulties inherent in the small size of the vessels, prolonged anesthesia, and difficult postoperative care. However, with advances in operative microscopes, instruments, surgical, and anesthetic techniques, these problems could be largely overcome [4, 14–16]. Two particular problems were encountered in pediatric patients compared with adults: smaller vessel diameter and greater vasospasticity [14].

Small vessels (0.5–1.0 mm in diameter) have been successfully used for anastomosis although they are still challenging. Gilbert [17] set an arbitrary limit for vessel diameter of 0.7 mm as a lower limit vessel size for safe anastomosis and reported a 98 % success rate in a series of 49 toe transfers in children.

Fig. 1 Case 4: **a** an 8-year-old boy with tissue loss and exposed tibia on distal third of the lower leg; **b** 4 months after reconstruction with rectus muscle free flap and skin graft

Shapiro et al. [18] suggested that the minimal feasible vessel diameter for anastomosis is 0.5 mm. Canales et al. [12], in analysis of 106 pediatric patients, reported that small vessel size led to flap failure in only two children (1.9 %). Devaraj et al. [1] reported successful replantation in a child aged 2 years and had veins with an external diameter of 0.4 mm. They concluded that vessel size per se was not a limiting factor and the majority of vessels in their series exceeded 0.8 mm external diameter. In our series, the vast majority of patients were over the age of 7 years so vessels size was generally over

0.7 mm in replantation and over 1.5 mm in free tissue transfers (most in adolescence) and all patients had successful outcome.

In our study, only five patients were under the age of 5 years: three patients had failed replantation, one patient had successful replantation, and one patient had successful toe to hand transfer. In this age group, the vessel size was less than 0.7 mm. The failed replanted digits may be directly related to the avulsion and crushing type of injury. From our work, it seems that patients over the age of 10 years can undergo microsurgical procedures with relatively similar intraoperative and

Fig. 2 Case 7: **a** an 11-year-old boy after crush injury of the right hand with exposed extensor tendons, coverage with rectus muscle free flap and skin graft was decided; **b**, **c** preoperative markings for harvesting the

rectus abdominis muscle and the muscle after harvest; **d** the rectus muscle in place after the anastomosis; and **e** the hand after complete healing with STSG over the muscle after 10 months postoperative

postoperative course like adults. In the patients of 5 to 10 years of age, successful outcome can be achieved also but with greater challenges in surgical technique. On the other hand, for patients under the age of 5 years, greater surgical challenges can face the surgical team with less satisfactory outcome that could be achieved. Furthermore, in patients under the age of 5 years with digit replantation, especially more distal digital amputations, small vessel size seems of significant importance. These difficulties are more pronounced in the subcategory of patients under the age of 2 years. In addition, venous anastomosis was more challenging in this group of patients than arterial anastomosis.

The second difficulty that stemmed from the perceived pediatric propensity to excessive vasospasm is still controversial [12, 19]. Upton and Guo [13] do not believe that pediatric vasculature is more prone to spasm and thrombosis. Parry et al. [20] speculated that the underdeveloped muscularis layer in the vessels of children might be responsible for a less likely vasospasm. To reduce the risk of spasm in our patients, vessel dissection was performed with considerable care to avoid trauma. The vessels were covered by topical lidocaine 2 % and papaverine before and after anastomosis to prevent spasm. No problems of vessel spasm were experienced in our series, although transient vasospasms were noticed during surgery which agrees with many authors [1, 12, 18, 20–22].

The use of postoperative anticoagulants in pediatric free flap surgery remains controversial. Many authors did not recommend the routine use of anticoagulants [1, 20, 22]. Shapiro et al. [18] considered that systemic anticoagulation was not necessary, although they routinely used aspirin for 2 weeks postoperatively. Canales et al. [12] used dextran and aspirin without obvious adverse effects reported. Banic and Wulff [23] used anticoagulants only after revision of vessels in their trauma cases. In our series, we used the anticoagulants routinely in replantation or revascularization, and in patients who needed vein revision of the free tissue transfer in the form of low molecular weight heparin 150 IU/kg/day and we find it useful in these cases with no serious drawbacks.

While the main indications in adults are to reconstruct defects caused by trauma, tumor ablation, or vascular insufficiency, the main indication in our series was traumatic defects and replantation in 24 of the 28 patients (85.7 %), congenital deformities accounted for 3 patients (10.7 %), and tumor resection in only 1 patient (3.6 %). In other reports of pediatric populations, the indications were similar but with different percentages [12, 22, 24, 25].

Despite initial outcomes of high failure rates in children, recently reported success rates in excess of 95 % has been achieved in some series [2, 13, 15, 26]. Our results revealed a high overall success rate of 89 % which is consistent with the previous reports. There were no failures in the group of children undergoing elective microsurgery with success rate of 100 %, while the success rate of the replantation group was

Fig. 3 Case 19: 12-year-old boy after crush injury of left hand with exposed radial artery and flexor tendons; **b** the rectus muscle in place after the anastomosis; **c** the hand after complete healing with STSG over the muscle after 3 months, postoperative view

Fig. 4 The abdominal scar after harvesting rectus abdominis muscle in 13-year-old female patient

only 57 %. Furthermore, these rates of success are comparable to the success rate in adult series by Whitney et al. [27].

We encountered three failed digit replantation in the very young group in our series (2, 3, and 5 years old children). Although the vessels size was small in the first patient with big toe replantation, it was over 0.4 mm in the other two and we did not encounter significant difficulty in achieving the vascular anastomosis. In the three patients, the failure scenarios were similar; beginning with congested amputated stump that progressed to ischemic pallor followed by necrosis and the failure that was referred to the injury type (avulsion injury).

In pediatric patients, suitable donor sites are few because of the need for a long and reliable vascular pedicle of sufficient size [15, 28, 29]. Free rectus abdominis muscle was the main flap used by our surgical team. Its harvest via transverse incision leaves good hidden scar in pediatric patients (Figs. 2, 3, and 4). We preferred to use muscle only flap first, then grafting after 5–7 days in most cases for two reasons: first, flap monitoring is easier without grafting and, second, the grafting is a minor procedure that does not need a long operative time. Khouri et al. [30] found that the use of the rectus/TRAM flap compared with all other flaps had a lower failure rate (1.7 versus 4.8 %, respectively). Rinker et al. [31] used the latissimus dorsi muscle as the flap of choice for lower limb reconstruction as it has a consistent vascular anatomy of sufficient caliber. They suggested the preference of the latissimus dorsi muscle over the rectus abdominis muscle because its vascular pedicle is often quite small in younger patients. However, such finding did not match with our findings in lower limb reconstruction by free rectus muscle. Although the knowledge of multiple options for reconstruction is needed for choosing the appropriate reconstructive modality, however, we believe that mastering one of them is essential to achieve high successful outcome. Therefore, rectus abdominis was chosen as our workhorse as this choice saved surgical time, effort, and achieved satisfactory outcome.

Donor site morbidities were minimal and mostly resolved spontaneously with local wound care. The rate of donor site complications is comparable to the adult population [8] or may be fewer [6].

In spite that the microsurgical procedures in children are lengthy, children reportedly tolerate anesthesia better than adults [32, 33]. In this series, the mean anesthetic time was acceptable (195 min for FTT procedures and 153 min for replantation) and not significantly increased over adult procedures in our unit. Anesthetic time can be shortened with two operative teams' cooperation and good preoperative preparation.

Postoperative care is essential for successful outcome of pediatric microvascular procedures. The uncooperative behavior and anxiety of some children may sometimes lead to difficulties in postoperative care, which may result in wound complications such as donor site hematoma or skin graft loss but no anastomotic failure. We did not suffer from this too

much because most of our patients were above 6 years old. The single graft loss in our series was attributed to the shearing movement and the uncooperative child. Postoperative immobilization was achieved using splints and/or limb restrains in seven patients with younger age.

In the immediate postoperative period, four patients required blood transfusion (14 %): three patients in the elective group and one in the replantation group. However, Canales et al. [12] reported that 40 % of their patients have required blood transfusions.

The average hospital stay in this series which was 8.3 days (range 5–18 days) is comparable to the other published series (9–31 days) [1, 12, 14, 18, 20, 33–35].

The rate of complications in pediatric series of free tissue transfer in the literature varies from 2 to 62 % [1, 12, 13, 20, 31]. In our series, nine complications occurred in eight patients (32 %), other than flap failure or re-exploration. All of these patients received conservative treatment except one patient that needed reoperation for lost skin graft.

Khouri [36] reviewed the clinical experience of nine microsurgeons, which clearly indicates that operative experience is the single most critical factor related to improved success rates. All patients of our series were operated upon by the same surgical team.

Conclusion

Microvascular surgery in children is a feasible, safe, and reliable modality with high survival rate. The indications, success, failure, and complication rates are very near to adults. Over the age of 10 years, procedure is nearly similar to adults. Between the age of 5 and 10 years, successful outcome can be achieved also but with greater challenges in surgical technique. Below the age of 5 years, more challenges could be problematic for successful outcome. Experienced surgical team remains one of the most important factors to obtain good results. Knowledge of multiple reconstructive options and mastering one of them seems essential for satisfactory results.

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