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SEVERE UPPER LIMB INJURIES WITH OR WITHOUT NEUROVASCULAR COMPROMISE IN CHILDREN AND ADOLESCENTS—ANALYSIS OF 32 CASES

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AQ2 SARANTIS G. SPYRIDONOS,[1] NIKOLAOS E. GEROSTATHOPOULOS,[1] and PANAYOTIS N. SOUCACOS, [2]

The healing and regeneration capacity of the injured tissues in childhood, adolescence, and adult life differs significantly. As a result, the prognosis of compound injuries of the upper limb in different age groups varies; therefore, the decision making and management of these cases should be age-specific. This article presents a series of 32 patients aged 2–14 years, with compound injuries of the upper limb that have been treated in our hospital during the period of the last 4 years. Ten of the above cases involved major vascular lesions that required revascularization or replantation. The injuries were classified according to the SATTy (Severity, Anatomy, Topography, Type) classification system. This study shows that the outcome of compound upper limb injuries is age-related, while the SATTy classification system is a valuable tool in the decision making process. Further research should be undertaken to determine age group-specific indications for the management of compound upper limb injuries, based on the SATTy classification system. © 2008 Wiley-Liss, Inc. Microsurgery 00:000–000, 2008.

Compound injuries of the limbs are characterized by injuries of two or more tissue types, besides any bone injury. Several variations exist for example injury to the tendons and nerves, to the nerves and vascular vessels, and to the vessels and tendons. In children and adolescents, the prognosis and outcome of adequately treated compound injuries of the upper limb differs in certain aspects from similar injuries in adults. The major factor responsible for the better outcome of compound upper limb injuries in childhood and adolescence is the improved ability to neural regeneration in younger patients, as it is the case with bone healing and remodelling in bone injuries.

The younger the child, the faster and more efficient is nerve regeneration, limb sensory reeducation, and restoration of function. In clinical practice, the injured nerves capacity to recover is faster and better in children compared to adults as it is evident in obstetrical brachial plexus injuries[1] and other iatrogenic nerve injuries such as radial nerve lesions after stabilization of supracondylar humeral fractures using Kirschner wires.[2] Similar observations have been made regarding surgical treatment and reconstruction of tendon injuries in children. Permanent postoperative stiffness in children hand tendon surgery[3] is rather the exception than the rule.

It is generally accepted that young age is a strong positive predictive factor for encouragement of replantation procedures following upper limb amputation[4,5]; if the distal, avulsed limb part is not extensively crushed, revascularization and replantation should be performed. Besides the ability for improved nerve regeneration due to the young age, another advantage in childhood is the better vascularity and thus the faster and probably more efficient revascularization of tissues after surgery. The disadvantages of limb and especially finger injuries in children are the small diameter of the vascular vessels that is associated with significant intraoperative technical difficulties when vascular repair is carried out, the need for closer monitoring and immobilization after surgery, and the reduced ability especially of the younger children to cooperate with physical therapy after the reconstruction.

Severe compound upper limb injuries in younger children are usually accidentally caused by penetrating trauma such as by glass fragments, knifes, or cutting machines. In older children, injuries are usually caused by explosion and rarely after working or motor vehicle accidents. Inappropriate treatment may lead to permanent disability and loss of function. Early recognition and treatment of upper limb injuries in children may prevent unfavorable outcome. The purpose of this study is to propose a classification for severe upper limb injuries with and without neurovascular compromise, and to present our experience in the treatment of such injuries in children and adolescents.

MATERIALS AND METHODS

Between 2002 and 2004, 32 children and adolescents aged 2–14 years were admitted to the authors' institution

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Table 1. The SATTy (Severity, Anatomy, Topography, Type) Trauma Evaluation System

SATTy trauma evaluation system		
Severity	S1, viable	S2, nonviable severe vascular damage
Anatomy	A1, isolated-one anatomical structure	A2, extended-compound injury
Topography	T1, palmpar	T2, dorsal T3, amputation
Type	Ty1, clear cut injury	Ty2, crush injury, avulsion

with severe compound upper limb injuries. All injuries were classified according to the S.A.T.T. (Severity, Anatomy, Topography, Type) evaluation system that is
T1 closely related with the prognosis of the injury (Table 1). A detailed presentation of the patients involved in this study including demographic data, severity of injury, initial treatment, and final result is shown in Table 2. T2

Regarding the anatomical distribution, all patients had compound injuries of the upper limb involving more than one tissue type (type A2). Ten cases were admitted with nonviable (S2) limbs or fingers (partial or complete amputations). Six of them were S2Ty1 guillotine type and four were S2Ty2 crush and avulsion type amputations. One patient had a partial two levels (humerus and forearm) amputation. Among the non-amputating injuries, there were 4 crush-avulsion S1Ty2 type injuries secondary to motor vehicle accidents (2 cases) and blast injuries because of fireworks explosion (2 cases) who were treated with flaps. The remaining 18 patients had compound, clear cut injuries of the fingers, the wrist, or the forearm. In 15 of them, primary end-to-end tendon and nerve repair was performed; in the 3 patients, nerve grafting in sensory nerves was performed. Regarding topography of injuries, the palmar surface (T1 injuries) was more frequently involved compared to the dorsal surface (T2 injuries) and complete amputations (T3 injuries) of the upper limb.

Surgical repair was performed using microsurgical instruments, small size sutures (10-0 or 11-0), assisted with loupes magnification and the operating microscope. Postoperatively, in all revascularization and replantation procedures, the patients were confined in bed, using heat lamps, dextrane, antiplatelet agents, and peripheral vascular vasodilating agents.

RESULTS

Postoperative follow up ranged from 1 to 4 years; all were been included in the postoperative evaluation.

F1 Among the 10 cases with complete (Figs. 1a and 1b)
F2 and partial (Figs. 2a and 2b) amputations, revascularization was successful in 6 cases. In 4 cases revascularization failed because of severe crushing (in 2 patients with forearm and 1 patient with palm amputation) or small size of the vessels of the avulsed index finger. Among the three crush-avulsion type injuries (S1Ty2), four emergency flaps were performed (three fasciocutaneous ulnar artery based flaps and one groin flap). In 1 patient, the ulnar fasciocutaneous flap was combined with ray amputation. One of the abovementioned flaps underwent partial necrosis; the defect was treated with a complementary reverse flap based on the distal perforators of the radial artery.

The 15 patients with compound injuries of the forearm, wrist, palm, and fingers were treated with end-to-end suturing of the tendons and nerves; in these patients, significant improvement of the function according to Dellon-McKinnon score was observed. The average postoperative recovery of sensation and active range motion was approximately 80% of the normal contralateral limb. In the 3 cases in which a nerve graft has been used, sensation was significantly deficient compared to the normal side. Sensory recovery was tested using static and moving two-point discrimination test,[6] and the tactil gnosis[6] according to the modified Moberg's pick-up test.[6]

Grading of sensory recovery was assessed by classifying the values of the two point discrimination test according to the score system S1-S3, in normal (static less than 6 mm, moving 2–3 mm), fair (static 6–10 mm, moving 4–6 mm), poor (static 11–15 mm, moving 7–9 mm). Motor recovery was evaluated by the strength and function of the reinnervated muscles based on the use of gravity and motion against resistance. Grip and pinch strength were assessed with the aid of dynamometer[6] JAMAR and were measured in kilograms according to the AOS system (American Orthopaedic Society), numerically beginning at 0 for the weakest muscle and ranging through a grade of 5 (M1-M5 or trace-poor-fair-good-normal): 0 (nil), no contraction; 1 (trace), no joint motion; 3 (fair), complete range of motion against gravity; 4 (good), complete range of motion against some resistance; and 5 (normal), complete range of motion with full resistance. The average sensory and motor capacity in the above patients recovered upper limbs arrived to the 75% of the contralateral normal hand score (S2M3 to S2M4 in 12 from the 15 patients, while only 2 were graded with S2M2).

All patients except for the smaller children were compliant to the postoperative rehabilitation program. Postoperative stiffness and muscle atrophy or weakness was observed in the patients in whom a replantation procedure has been performed. In the remaining patients, restriction of the range of motion was less than 25° especially in patients with comminuted intraarticular fractures or zone II tendon lacerations. In 4 patients, secondary reconstruction

Table 2. Data of the Patients Involved in this Study

Pts	Age (yrs), sex	Severity	Anatomy	Topography	Type	Location	Operation and cause of injury	Initial treatment	Final result
1	12, male	S2	A2	Amputation	Ty1	Proximal	Replantation	Direct closure	Good
2	14, male	S2	A2	Palmar	Ty1	Ring finger	Replantation, MVA	STSG	Satisfactory
3	13, male	S2	A2	Dorsal	Ty1	Index and palm	Revascularization, explosive	Transpalmar replantation	Good
4	13, male	S3	A2	Dorsal	Ty2	Elbow	Revascularization, MVA	STSG	Good
5	13, male	S2	A2	Palmar	Ty1	Littler, ring finger	Revascularization, work accident	Ulnar nerve repair	Satisfactory
6	1.5, female	S2	A2	Amputation	Ty2	Transcarpal-digital	Stump closure	Diverse	Satisfactory
7	7.5, male	S2	A2	Amputation	Ty2	Forearm	Skin closure, MVA	Skin graft	Good
8	8, male	S2	A2	Amputation	Ty2	4 digits	Skin closure, MVA	Skin closure	Good
9	3, male	S2	A2	Amputation	Ty1	Thumb, distal phalanx	Skin closure, accident at home	V-Y flap	Satisfactory
10	14, female	S1	A2	Dorsal	Ty2	Extensor tendons, metacarpals, skin loss	Skin closure, MVA	Ulnar artery based perforator flap	Good
11	13, female	S2	A2	Dorsal	Ty2	Extensor tendon, skin	Skin closure, MVA	Ulnar artery based perforator flap	Good
12	12, male	S1	A2	Dorsal	Ty2	Hypothenar crush injury	Skin closure, work accident	Ulnar artery based perforator and 5th ray amputation	Satisfactory
13	14, male	S2	A2	Palmar and dorsal	Ty2	Thumb degloving injury	Flap, blast injury from explosives and fireworks	Groin flap	Satisfactory
14	14, male	S2	A2	Palmar	Ty1	Partial double level amputation	Revascularization, work accident	Revascularization and neurorraphy	Satisfactory
15–32	2.5–14	S1	A1	Palmar (12) and dorsal (5)	Ty1	Fingers, palm, and forearm	End-to-end repair or grafts, variable	Nerve suturing and nerve grafting (3 cases)	Satisfactory

STSG, split thickness skin graft; MVA, motor vehicle accident.

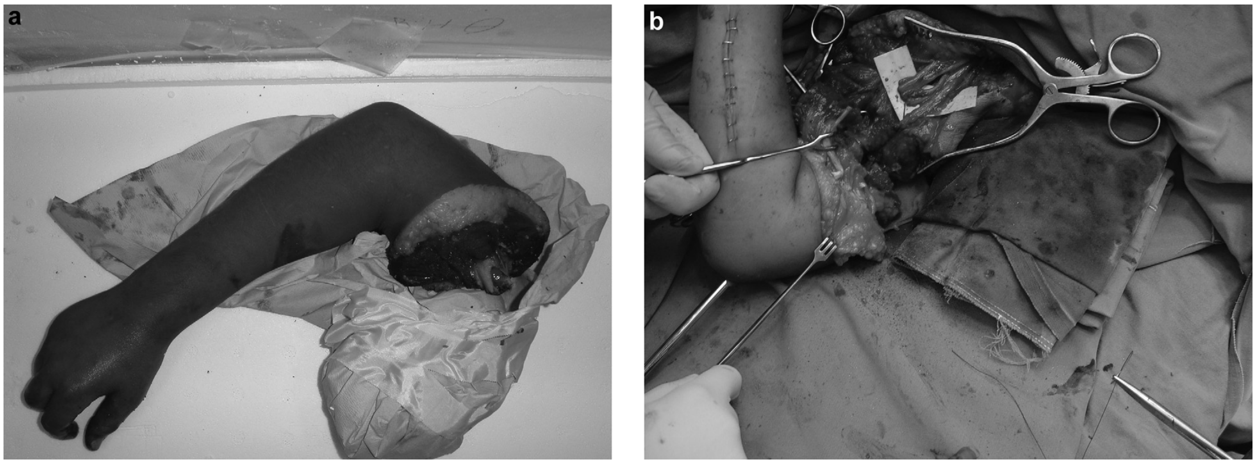

Figure 1. *(**a**) Complete midhumeral amputation of the right arm of a 12-year-old boy. (**b**) Intraoperative photograph during arm replantation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]*

Figure 2. *(**a**) Nonviable compound injury of the left elbow of a 14-year-old boy. (**b**) Intraoperative revascularization of the brachial artery using a saphenous vein graft. (**c**-i and ii) Postoperative result. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]*

Figure 3. (***a***) *Index finger nerve grafting and flexor tendon z-elongation technique in a 2-year-old boy with compound injuries of the index finger. (**b**-i and ii) Postoperative result. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]*

procedures in two or three stages such as arthrodeses, tendon transfers, or tendon plasties were performed. In one case with failed tendon and nerve repair, reoperation was done using tendon Z-plasty and sural nerve grafting (Figs. 3a and 3b). F3

DISCUSSION

This study showed that severe upper limb injuries in children if treated promptly and in an appropriate fashion provide favorable results in terms of function without significant complications.[7]

In combined upper limb injuries in children the preoperative evaluation and the surgical techniques as well as the order with which the surgery is performed is similar with adults.[8] The surgical reconstruction starts with restoration of the bony injuries and proceeds with tendon, vessel, and nerve repair. Use of a tourniquet, special microsurgical instruments, and magnifying loupes or microscope is essential. Nevertheless, for performing surgery in children several modifications are necessary. The dimensions of the tourniquet are smaller in children as well as the inflation pressure and 10-0 or 11-0 sutures are regularly used. Additionally, in children younger than 12 years, general anesthesia is preferred over brachial plexus block because of limited tolerance and cooperation and to avoid accumulation of local anesthetic as well.

In replantation and revascularization cases the outcome seems to be better than in adults because of improved ability for nerve regeneration and fracture healing. Additionally, the tendency to develop joint stiffness is limited in children. The rules for amputated limb transport and preservation are similar to those applicable to adults (cold ischemia, 6 h time limit for a limb and 12 h for a finger). In children finger amputations, the tolerance limb for replantation regarding the condition of the amputated finger increases as compared to adults. In finger amputations with mild crushing or avulsion replantation should be attempted because of the improved healing

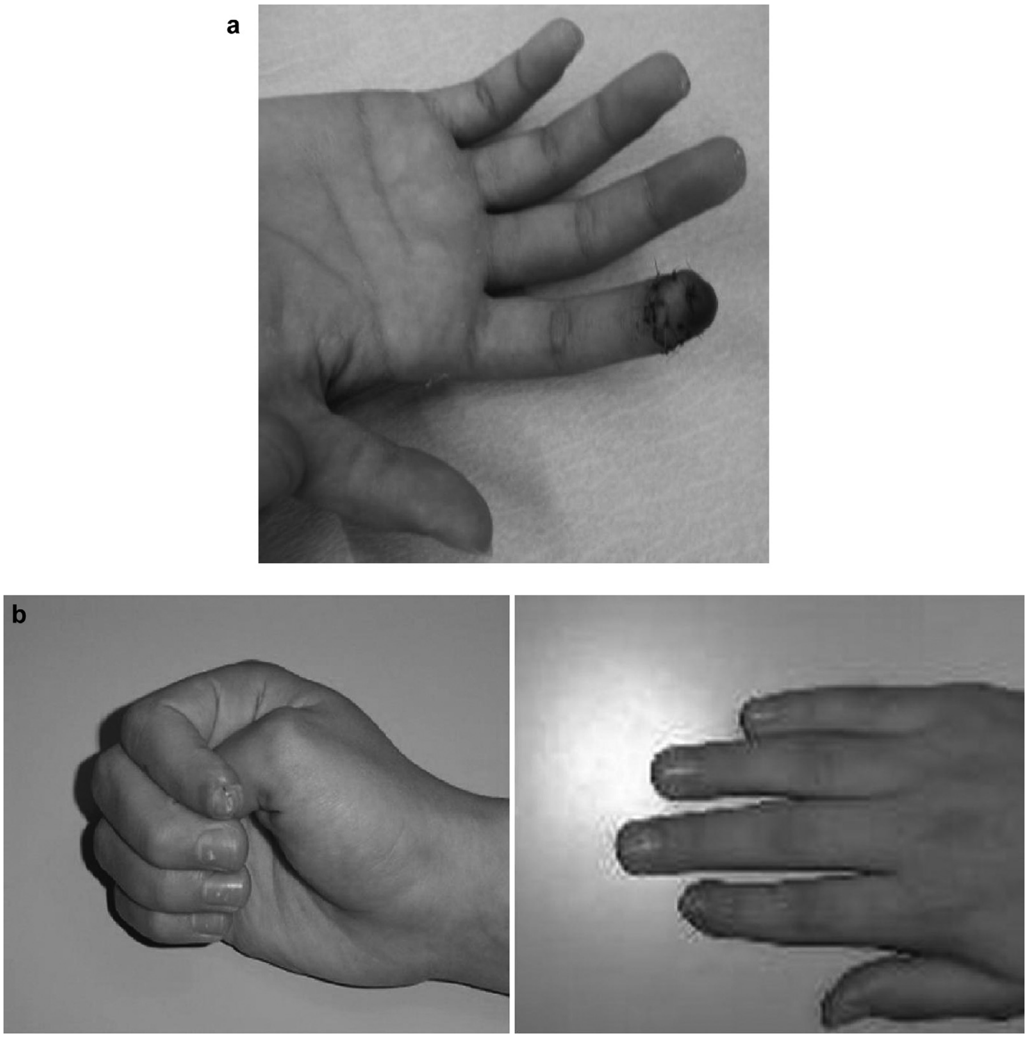

*Figure 4. (**a**) Amputation of the distal phalanx of the right index of a 14-year-old girl. Reattachement using a kirschner wire was done without revascularization. (**b**-i and ii) Results at 3 months postoperatively. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]*

ability in children tissues. In cases of severe crushing or avulsion replantation is not indicated. In fingertip amputations distal to the nail matrix replantation without microsurgical revascularization may be attempted (Figs. 4a and
F4 4b). Serious problems may pose postoperatively the limited tolerance of children to the extended postoperative rehabilitation necessary for the restoration of limb function. Older children or adolescents are usually more cooperative. Special rehabilitation instruments and physiotherapists are necessary for the rehabilitation of children.[8]

CONCLUSION

The outcome of childhood severe upper limb injuries seems to be good and surgical repair should be attempted according to the guidelines set for adults. Specific intraoperative and postoperative difficulties should be dealt accordingly with the appropriate instrumentation, techniques, and dedicated physiotherapists. Limb replantation in children is encouraged according to our experience.[4,5] A correlation seems to exist between the outcome of treatment and the classification of the injury according to the SATTy system. In cases with crush-avulsion injuries S2-Ty2 (S2-A2-T3-Ty2) reconstruction was not possible, while in cases classified as S2Ty1 ή AQ3
S1Ty2 the outcome was more or less improved. All operations are performed under tourniquet ischemia under magnification and occasionally the wound is injected with long acting anaesthetic to provide postoperative analgesia. Excessive administration of analgesics is avoided in children. Fasciocutaneous flaps based on perforator arteries[9] are a very important tool in the sur-

geon's armamentarium in type S1Ty2 cases (viable but with crush or avulsion injury) because sacrifice of a major artery is avoided.

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