Case Report

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Reconstruction of pediatric hand injuries caused by automatic cup-sealing machines in Taiwan

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Abstract

Objective: This study was performed to share our clinical experience and provide treatment strategies for pediatric hand injuries caused by automatic cup-sealing machines in Taiwan.

Methods: Thirteen pediatric patients with an average age of 3.6 years were included in this retrospective study. Treatment was based on the location and depth of the injury and included full-thickness skin grafts, free or local flaps, and digital replantation. Some patients underwent contracture release during follow-up.

Results: Thermal crush injuries affected the left hand in five patients and right hand in eight. Four patients with nine amputated fingers were treated by emergent digital replantation, four were treated by skin grafting, one was treated by nail bed repair, one underwent reconstruction with a local reversed dorsal digital and metacarpal island flap, one underwent reconstruction with a fascia graft for extensor tendon repair and pedicled groin flap coverage, and two underwent reconstruction with free anterolateral thigh fasciocutaneous flaps with a vascularized fascia lata graft for dorsal hand defects. All replanted fingers survived.

Conclusion: Pediatric hand injuries, especially those caused by cup-sealing machines, can be devastating. Aggressive treatments including early reconstruction and rehabilitation should be performed for all pediatric hand injuries to achieve satisfactory functional restoration.

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Article summary

Strengths and Limitation of this Study

- Strength: A new algorithm was devised for management of pediatric hand injuries caused by cup-sealing machines.
- Strength: The long follow-up period allowed for determination of whether the surgical planning was correct.
- Limitation: This was a retrospective study with a small number of cases.

Introduction

Hand trauma is frequent in childhood and may result in a variety of soft tissue and bone injuries.[1] Furthermore, injuries involving a combination of both soft tissue and bone are possible in some accidents. The severity may range widely, involving skin laceration, joint dislocation, tendon or joint disruption, neurovascular injury, bony fracture, amputation, and any other injuries in combination with these. Different mechanisms are responsible for different kinds of injuries.[2]

Some injury mechanisms are unique in children because of children's insufficient life experience and curiosity at their young age. For example, bicycle chain injuries and door slams usually cause crushing or avulsion injuries, while home exercise equipment such as treadmills and bicycle machines may cause abrasions, burns, lacerations, or traumatic amputations.[3]

In Taiwan, "bubble tea" has been popular since the late 20th century. It has also become a worldwide trend as a pastime tea-based drink. An automatic cup-sealing machine (Figure 1) has been designed to prepare these drinks. A thin plastic film is heated to seal the cup, and the seal is effective even when the cup is turned upside down. Although the machine has been improved over time, children, especially younger ones, can still sustain severe injury to their hands because of their curiosity and handling of the machine. Mutilating hand injuries that cause diminished hand function negatively impact the psychological and social aspects of patients' lives.[4] The generally accepted indications for attempting digit replantation after traumatic digit amputation are broader for children than adults. In the pediatric population, replantation outcomes may benefit from an increased healing potential and lack of comorbidity.[5] In addition, long-term follow-up studies have suggested good functional outcomes in children.[6]

This study was performed to share our clinical experience, including patient outcomes, and provide treatment strategies for pediatric hand injuries caused by automatic cup-sealing machines in Taiwan.

Materials and methods

This study was approved by the Institutional Review Board of Kaohsiung Chang Gung Memorial Hospital (Approval No. 201800224B0). Institutional guidelines for the use of completely de-identified patient data were followed.

Figure 1. Cup-sealing machine

Patient consent was obtained for all surgical and wound management procedures, including the possible use of photographs without identifying marks or facial features.

We retrospectively reviewed the medical charts of children who underwent treatment of hand injuries caused by automatic cup-sealing machines at Kaohsiung Chang Gung Memorial Hospital from June 2004 to February 2016. All patients were brought to our hospital for first aid without other associated trauma. Our treatment strategies were based on the location and depth of the injuries. A full-thickness skin graft was the first choice for superficial burns over the dorsal hand or fingers. Deep burns with tendon or joint exposure were treated with free or local flaps following tendon reconstruction to obtain the best functional outcome. Digital replantation was performed for all amputations. Some patients underwent contracture release, debulking procedures, and tenolysis during follow-up.

Results

Thirteen pediatric patients (six girls, seven boys) were included in this study (Table 1). Their ages ranged from 1 to 11 years (average, 3.6 years). The average length of hospitalization was 24.6 days, and the average follow-up period was 79.3 months (range, 2–134 months).

Four patients with nine amputated fingers underwent replantation, four patients were treated with skin grafts, two were treated with a free anterolateral thigh (ALT) flap and fascia graft, one was treated with a reverse dorsal metacarpal artery flap, one was treated with a groin flap and fascia graft, and one underwent nail bed repair only. All initial surgical procedures were successful except in the patient who underwent reverse dorsal metacarpal artery flap reconstruction; this patient developed superficial skin necrosis and healed by second intention. No donor site morbidity occurred.

All replanted fingers showed good functional outcomes; however, one patient returned to undergo contracture release during the follow-up period. Furthermore, patients who had undergone flap and fascia graft reconstruction required secondary procedures such as contracture release, debulking procedures, tenolysis, or Z-plasty (Table 2).

Case presentations

Patient 1

A 3-year-old girl sustained a thermal crush injury with complete amputations at the middle phalanx level of her left index, middle, and ring fingers (Figure 2(a)).

Table 1. Injuries in patients and operations performed during initial hospitalization

Patient No.	Sex	Age (y)	Side	Injury	Zone	OP 1	OP 2	OP 3
1	M	2	L	Index: amputation Middle: amputation Ring: amputation	2	Index: replantation Middle: replantation Ring: replantation		
2	F	2	R	Index: amputation Middle: amputation Ring: amputation	1	Index: salvage FTSG Middle: replantation + subdermal pocket Ring: replantation + subdermal pocket	Division	
3	F	3	L	Index: amputation Middle: amputation Ring: amputation	1	Index: replantation + subdermal pocket Middle: replantation + subdermal pocket Ring: replantation + subdermal pocket	Division	Index: FTSG Middle: FTSG Ring: artificial bone replacement material (Terudermis; Olympus Terumo Biomaterials Corp., Tokyo, Japan)
4	F	4	R	Index: nail bed injury Middle: nail bed injury	1	Index: repair Middle: repair		
5	M	11	L	Middle: amputation Ring: nail bed injury	1	Middle: replantation + subdermal pocket Ring: repair	Division	
6	M	3	R	Index: skin defect Middle: PIPJ exposure Ring: PIPJ exposure Little: skin defect	2	Index: FTSG Middle: RDMA flap Ring: RDMA flap Little: FTSG	Middle: FTSG Ring: FTSG	
7	F	2	R	Dorsal hand: contact thermal burn (third-degree)	3	Debridement	STSG	
8	M	11	R	Dorsal hand: contact thermal burn (fourth-degree)	3	Free ALT flap + tendon graft (fascia lata)	Debridement	

(continued)

Table 1. Continued.

Patient No.	Sex	Age (y)	Side	Injury	Zone	OP 1	OP 2	OP 3
9	F	2	L	Index: contact thermal burn (third-degree) Middle: contact thermal burn (third-degree) Ring: contact thermal burn (third-degree)	2	Groin flap + tendon graft (external abdominis fascia)		
10	M	2	R	Index: contact thermal burn (third- to fourth-degree) Middle: contact thermal burn (third- to fourth-degree) Ring: contact thermal burn (third- to fourth-degree)	2	Debridement	Free ALT flap	Debulking
11	F	2	R	Index: contact thermal burn, PIPJ exposure (third-degree) Middle: contact thermal burn, PIPJ exposure (third-degree) Ring: contact thermal burn (third-degree)	2	Debridement and repair	FTSG	
12	M	2	L	Dorsal hand: contact thermal burn (second- to third-degree)	3	Debridement	FTSG	Remove stitches
13	M	1	R	Dorsal hand: contact thermal burn (third-degree) 234^{th} EDC, EIP, ECRB injury	4	Tendon repair (234^{th} EDC, EIP, ECRB)	Terudermis	STSG

Abbreviations: ALT flap, anterolateral thigh flap; EDC, extensor digitorum communis; EIP, extensor indicis proprius; ECRB, extensor carpi radialis brevis; F, female; FTSG, full-thickness skin graft; L, left; M, male; PIPJ, proximal interphalangeal joint; R, right; RDMA flap, reverse dorsal metacarpal artery flap; STSG, split-thickness skin graft; OP, operation

Table 2. Follow-up periods and further procedures

Patient No.	Hospitalization (days)	F/U (mos)	F/U OP 1	F/U OP 2	F/U OP 3
1	17	118			
2	17	64	Release contracture; debulking		
3	39	4			
4	2	104			
5	22	66			
6	20	134			
7	24	132			
8	26	116	Release contracture (Z-plasty, first web); debulking	Debulking; Z-plasty	
9	13	98	Division and FTSG	Separation; debulking	Tenolysis
10	44	70	Release contracture + FTSG (23 webs); tendon spacer		
11	31	45			
12	34	78			
13	31	2			

Abbreviations: FTSG, full-thickness skin graft; F/U, follow-up; OP, operation

A third-degree contact thermal burn was present over the dorsal skin, which appeared to be crushed and burned. Revascularization of all amputated fingers was performed immediately with phalangeal bone shortening in the little finger (Figure 2(b)). The extensors and flexors were also repaired after precise fixation of the phalangeal bones. Because of the small caliber of the veins, a subdermal pocket was designed for venous drainage of all three revascularized digits (Figure 2(c)). After 2 weeks, a division procedure was arranged, and all three digits survived with satisfactory functional recovery (Figure 2d)).

Patient 2

An 11-year-old boy sustained a third-degree contact thermal burn and crush injury on the dorsal side of his left hand (Figure 3 (a)). After serial debridement, the second to fourth metacarpal bones were exposed with defects of the extensor tendons. The soft tissue was reconstructed with a free ALT fasciocutaneous flap harvested from the patient's left thigh (Figure 3(b)). A fascia lata graft was simultaneously harvested from the same donor site and separated for extensor tendon reconstruction (Figure 3(c)). The ALT flap appeared to be bulky after surgery, and a debulking procedure was performed 6 months later (Figure 3(d)). Complete flap survival with restoration of the extensor tendon function was noted during follow-up (Figure 3(e)).

Discussion

The hand is a very important element both functionally and aesthetically. In adults, severe damage due to heat-press injury to the hand is primarily caused by dry cleaning laundry equipment and industrial

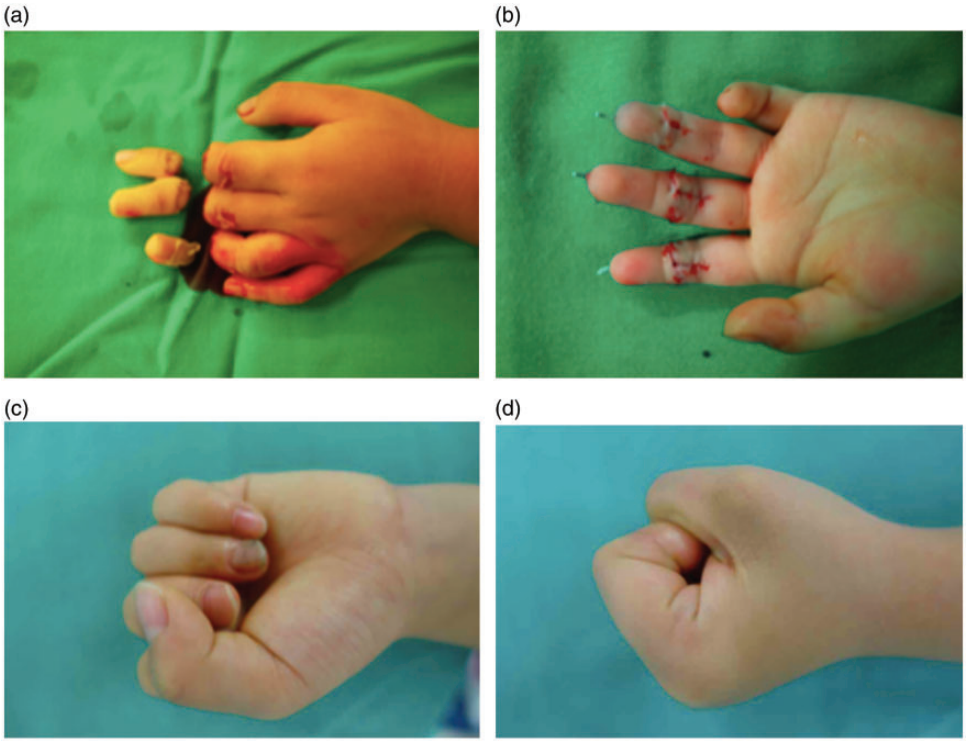

Figure 2. (a) Complete amputation of the left index, middle, and ring fingers at the middle phalanx level. (b) Successfully salvaged fingers. (c) Good flexion during follow-up. (d) Good grasp function during follow-up

machinery, which can cause second- to third-degree burns over the dorsal side of the hands and fingers in adults. Furthermore, amputations of fingers and hands by heat-press injury have also been reported.[7,8] Amputation may be unavoidable when there is difficulty in recovering function in the damaged fingers. Therefore, when the function cannot be recovered, plastic surgeons must consider the aesthetic aspect of treatment.[9]

Reports of injuries caused by cup-sealing machines in children are very rare, but such injuries are usually severe. Because of the unique nature of the thermal crush injury inflicted by cup-sealing machines, serious injuries of children's hands occur.[9] An automatic cup-sealing machine may cause both crush and burn injuries during the process of sealing the top of a cup by a thin plastic film. The compression force (pressure) may reach 2 to 5 kg/cm^2, which causes bone fractures, extensive soft tissue injuries, or even amputations of pediatric hands, as in the cases described in the present report. The working temperature is about 140°C to 160°C, which commonly induces deep contact thermal burn injury. With high temperature and pressure, extensive soft tissue or even bone destruction can occur within only a few seconds.[9]

The compressive pressure from the machine can also result in a broad injury zone with second- to third-degree burns. In 2006, Lin et al.[10] described three cases of hands that had been injured by

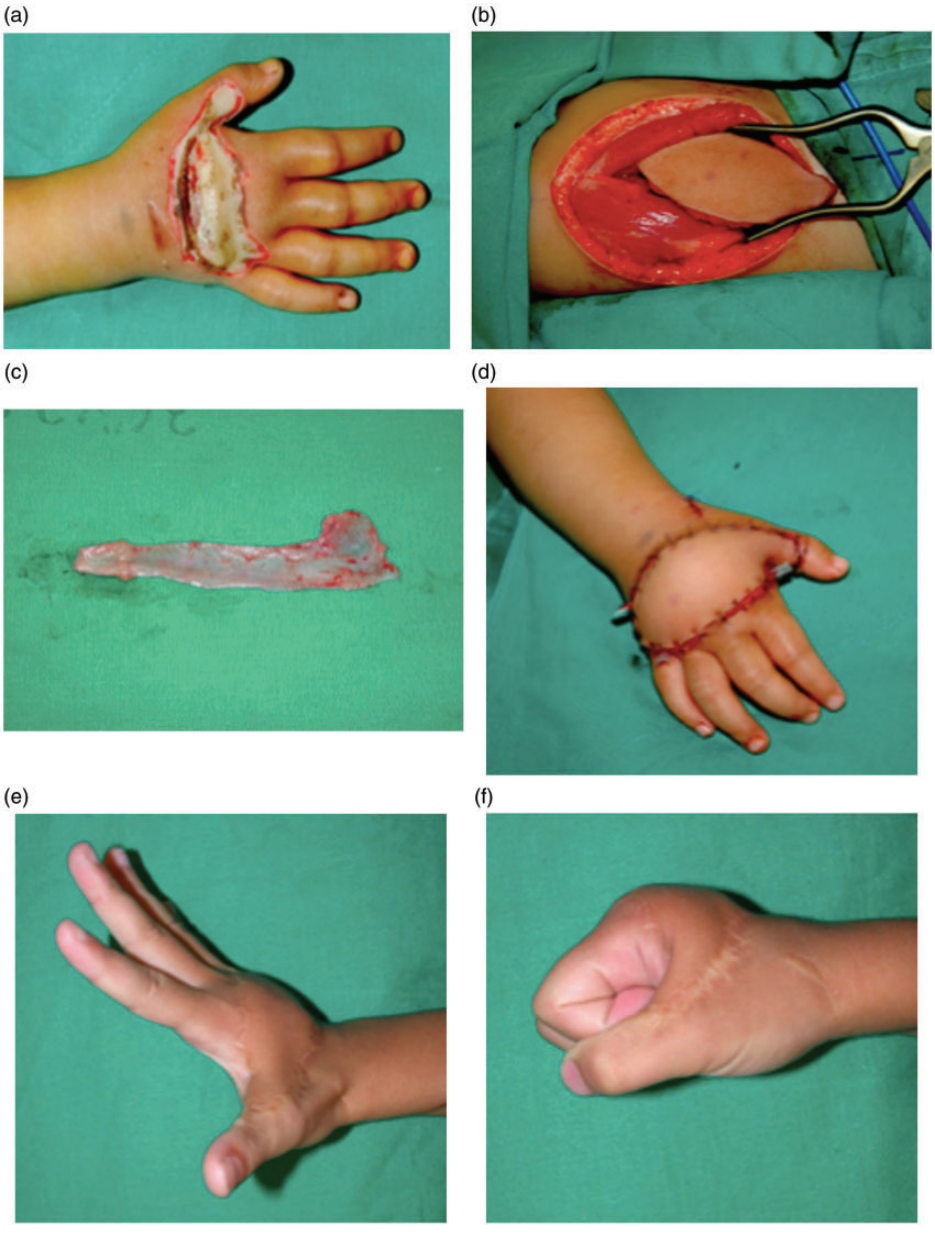

Figure 3. (a) Third-degree contact thermal burn over the right dorsal hand. (b) Anterolateral thigh flap. (c) Tensor fascia lata graft. (d) Complete reconstruction. (e) Follow-up appearance

cup-sealing machines and were reconstructed with skin grafts and local flaps. No other reports of injuries inflicted by cup-sealing machines were found in our literature review, demonstrating that this is a rare and unique mechanism of injury in Taiwan. Our data showed that boys were more prone to injuries than girls, as

also reported by Jeon et al.[11] Among children younger than 6 years, 75% of all injuries occurred at home, only 8% occurred in a daycare center, and adults were present when 84% of the injuries occurred. These findings may be associated with some Taiwanese families running their bubble tea business at home.

Initial assessment of the burn depth in such cases of tissue destruction is not always accurate, even by an experienced examiner.[10] These mechanisms of injury contribute to traumatic amputation and thermal burn injuries on the hands of children within a few seconds. Superficial hand burns in children may have an excellent functional outcome and appearance with ordinary wound care. Deep partial- and full-thickness hand burns generally require tangential excision and skin grafting.[10]

Because of the lack of sufficient soft tissue on the dorsum of the hand, heat-press injuries caused by automatic cup-sealing machines are often deep. Early debridement and an aggressive flap reconstruction procedure are indicated to salvage the hand in patients with in fourth-degree burns.[10]

The basic principles of reconstruction are similar in adults and children. The absence of associated comorbidities and the clear, unscarred anatomy are encouraging in children. However, the technical challenges are much greater in these young patients because of their smaller structures.[12] Fortunately, children have exceptional regenerative abilities that allow procedures to be performed in less-than-optimal conditions. However, the body image of young children can be permanently distorted despite aggressive reconstruction, and this can lead to social difficulties once they reach school age.[9]

Replantation is undoubtedly indicated for finger amputation caused by heat-press injury in children. The survival rate of the digits in such cases reportedly ranges from 58% to 97%.[13] Amputations are more common in boys with an average age of 10 years, and they are difficult to treat because of the technical challenges of performing vascular anastomoses on such a small scale.[12] Overall, the results of replantation for finger amputations in children are excellent, with survival rates of nearly 98% and functional recovery superior to that seen in adults.[4] However, several challenges remain. Functional outcomes vary in different reports because of different types of trauma and injury levels. In the present study, 4 of 13 patients underwent replantation, and all digits survived with satisfactory outcomes including the grasp, pinch, and extension functions. Sensory recovery in children occurs more rapidly than in adults, probably because of the shorter regeneration distance and higher regenerative capacity.[14]

The use of free flaps is a versatile technique when burned hands cannot be covered with skin grafts.[10] Although free flap reconstruction in pediatric hands is still technically demanding, microvascular surgery in children is a feasible, safe, and reliable modality with a high survival rate. Shenaq and Dinh[14] presented the largest series of pediatric free tissue transfers and reported a high survival rate of 99.8% (2 failures in 433 cases). Defects on the dorsal side of the hand could be reconstructed with thin, pliable tissue with good vascularization. The use of free flaps in children is a simple and reliable procedure that provides surgical safety and good outcomes. However, a secondary flap division procedure and postoperative limb fixation is sometimes unacceptable by young children and their parents.[15]

Fasciocutaneous perforator flaps can provide advantages such as a longer pedicle, thinner flap, and preservation of muscle function, and these properties are essential to the growth and development of children. Another advantage of using this type of flap

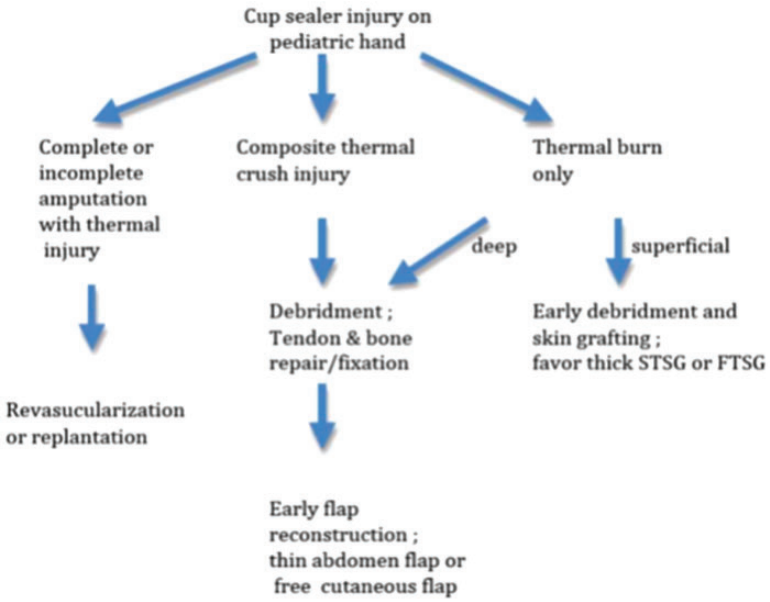

Figure 4. Flowchart for pediatric hand injuries caused by automatic cup-sealing machines. STSG, split-thickness skin graft; FTSG, full-thickness skin graft

is that it allows gliding of the extensor tendon in the dorsal hand.[10] Wei et al.[15] successfully performed free ALT flap transfer in 20 pediatric patients (mean age, 9.5 years). The authors found that a pediatric ALT flap has a smaller-caliber pedicle and shorter perforators than those in adults, and a primary thinning procedure was not advisable in pediatric patients.[15] In the present series, 2 of 13 patients underwent free ALT flap reconstruction with good functional and cosmetic results.

Our reconstructive protocols were based on our experience in managing hand injuries inflicted by cup-sealing machines and were performed according to the degree of thermal and crush injuries (Figure 4).[9] Although this algorithm has some limitations, such as concern regarding accuracy because of the lack of sufficient patient numbers, it may be used as a primary reference tool for surgical management of the unique injuries induced by cup-sealing machines in pediatric patients. Most importantly, this algorithm is expected to improve after higher patient numbers have been accumulated.

1. **Thermal crush injuries with complete or incomplete amputation.** Because successful replantation is very important to children's well-being and psychosocial development, replantation or revascularization should be attempted in all cases to obtain satisfactory functional and cosmetic outcomes. Because of the concomitant thermal injury and small caliber of vessels in children, repair of veins can sometimes be very difficult. The subdermal pocket procedure introduced by Lin et al.[16] can be an alternative choice when no suitable recipient vein is available.
2. **Composite thermal crush injury.** This type of injury will result in a skin defect with possible tendon, joint, and bone damage. Serial debridement, tendon repair, bone

reduction/fixation, and early flap reconstruction should be attempted whenever possible. The choice of a local flap, thin abdominal flap, or free flap should be based on the clinical situation such as the defect size and collateral damage of composite tissue, characteristics of the medical facility, surgeon's capability, and patient's compliance.

3. **Thermal burn-only injury.** Superficial burns are less frequently observed in patients with cup-sealing injuries because the mechanism of such thermal burns involves contact and pressure. Either wound care or early debridement with a skin graft is a suitable choice for management of second-degree burns; however, such conservative wound care management may result in long-term hospitalization and impairment of hand function due to increasing severity of scar contracture. Furthermore, we use full-thickness rather than split-thickness skin grafts because full-thickness grafts contain more dermis tissue, which may attenuate the occurrence of wound contracture and promote better recovery of hand function. When the thermal injury is deep and involves bone or tendon damage, early tendon reconstruction with flap coverage is necessary for a better functional outcome.

Preventive measures such as keeping the cup-sealing machine in manual mode are advised. In manual mode, the machine will not proceed to the next step after a cup has been placed in the tray until the start button has been pressed. However, this safety precaution is not commonly used because it slows down the cup-sealing process. In addition to adjusting the automatic cup-sealing machine to the semiautomatic mode, it is suggested to place a barricade outside the entrance where the cup bracket moves into the heating area of the machine and to closely supervise children who are in the vicinity of the machine.[10]

Other measures that may be necessary to reduce the chance of injury include adding a protective hood over the cup seal, installing motion sensors to detect objects other than cups, and decreasing the gap between the cup tray and sealer to reduce the chance of a child's hand entering the machine.[9]

Conclusions

The hand is one of the most frequently injured parts of a child's body. Thorough knowledge of the pediatric hand anatomy is necessary to guide the evaluation and management of hand injuries in children. Appropriate and timely management strategies have important functional and cosmetic outcomes and should thus be individualized to the patient's skeletal maturity, injury type, and injury severity. Aggressive treatments including early reconstruction and early rehabilitation should be undertaken in all pediatric hand injuries to achieve satisfactory functional restoration. However, prevention is the best policy to avoid future incidents.

Contributorship statement

This paper was written by Yueh-Ju Tsai, Carolina Carvajal Forero, and Nicolas Flores Molte. The patients' data were collected by Tsung-Shin Lin, Johnson Chia-Shen Yang, Yuan-Cheng Chiang, and Pao-Yuan Lin. Finally, the paper was revised by Pao-Yuan Lin.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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