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Dermal substitute: a safe and effective way in surgical management of adults post-burn dorsal foot contractures

K. SERROR[1], D. BOCCARA[1], M. CHAOUAT[1], G. COTTONE[2], F. AMENDOLA[2], M. ALESSANDRI BONETTI[2], F. DE FRANCESCO[3], M. MIMOUN[1]

[1]Department of Plastic Reconstructive Surgery, Burn Center, Hôpital Saint Louis, Paris, France
[2]Department of Plastic Reconstructive Surgery, University of Milan, Milan, Italy
[3]Department of Plastic Reconstructive Surgery and Hand Surgery, Azienda Ospedaliero Universitaria Ospedali Riuniti, Ancona, Italy

Abstract. – OBJECTIVE: Neglected dorsal foot burns may result in typical forefoot deformities characterised by contractures leading to hyperextension of the toes and gait disturbance. These deformities usually cause a significant impairment in daily activities and difficulty in wearing shoes. This article presents a reconstruction series of severe forefoot deformities by means of dermal regeneration templates (also known as dermal substitutes) and split thickness skin grafts.

PATIENTS AND METHODS: We retrospectively reviewed our institutional burn database from 2010 to 2020 focusing on all those dorsal foot contractures treated with the use of a dermal regeneration template. The patients' demographics, burn injury mechanisms, depth, localization, surface, treatments and follow-up were described.

RESULTS: Twelve patients underwent this procedure and the mean affected area was 75 cm2. The mean time between the dermal regeneration template application and the split thickness skin graft was 19.6 days. Just for one patient, an additional skin grafting procedure was required. The mean follow-up was 4.6 years. We did not register specific complications at both the recipient (forefoot) and donor sites (scalp). All patients were able to wear shoes and walk after the procedure. No recurrence of contractures were observed. All patients were satisfied with cosmetic results, and they did not request any additional procedure of cosmetic improvement.

CONCLUSIONS: The use of the dermal regeneration template can be considered as an extremely safe and efficient treatment of severe post-burn forefoot deformities.

Key Words:
Dermal regeneration template, Dermal substitute, Foot burn, Foot contracture, Skin graft, Toe contracture.

Introduction

In extensive limb acute burns, the greatest attention is paid to the preservation of hands' functions but feet are sometimes less noticed and could be neglected in terms of wound management, surgical interventions and rehabilitation[1]. It is well stated that feet play a major role in ambulation, but not everybody knows that the initial foot burns management is crucial to maintain this role. Neglected dorsal foot burns may result in severe forefoot deformities characterized by deleterious dorsal contractures leading to hyperextension of the toes[2] and gait disturbance. These musculoskeletal alterations and limited range of motion often impair several daily activities[3]. As a result, these severe forefoot deformities commonly provoque contact ulcers and also chronic inflammation. For these reasons, a special attention should consequently be paid on post-burn foot reconstruction in order to restore a normal foot anatomy and a durable soft tissue coverage as well as to limit this contractive scar formation and/or relapse.

In this study, we aim to show the effective combination of contractures release and double layer dermal regeneration template (DRT; also known as dermal substitute) application in the management of dorsal foot post-burn sequelae.

Patients and Methods

This article reports a two-stage surgical management we performed to treat dorsal foot contractures in adults by means of the application of a DRT (Integra®, Integra Life Sciences,

Corresponding Author: Kevin Serror, MD; e-mail: kserror@gmail.com

Princeton, NJ, USA) to reach a viable neodermis regeneration, followed by a second surgical procedure with split-thickness skin graft (STSG) always harvested from the occipital region of the scalp.

We evaluated a retrospective cohort of adult patients (≥18 years old) affected by post-burn dorsal foot contractures who were treated by a surgical scar excision and subsequent coverage with Integra® DRT in our institution over the last 10 years.

After institutional review board approval, we searched in our institutional database with the following key-words: foot contracture, foot burn, dermal regeneration template, dermal substitute and Integra. Inclusion criteria were: (1) adult (i.e., ≥18 years old) patients; (2) dorsal foot contracture secondary to burn injuries; (3) functional deficit and/or chronic pain; (4) referral to our Burn Center from January 2010 to December 2020. All the patients gave their informed consent before answering the questions of the study. The patients' demographics (age, gender), burn injury mechanisms, depth, localization, surface, treatments and follow-up were showed in Table I. The study was conducted according to the Helsinki Declaration.

Surgical Procedure

The dorsal forefoot contracture was always incised transversally over the metatarsal bones in order not to expose the joints capsule. Adequate contracture release required not only the scar incision but also excision of some portions of it when incisions were insufficient. After skin contracture release, tenolysis or tenotomies were often necessary to put the toes back in the correct position. External mobilisation of the metatarsophalangeal joints was also required to release the capsular contracture due to prolonged hypomobilization. The width of the resultant soft tissues defect was measured from its proximal to distal edges. K-wire fixation was performed to hold the toes in proper alignment before the application of the DRT.

Patients were always discharged with these suggestions: (1) do not stand up and do not weight-bearing for one week; (2) do not let toes touch the floor until the next skin graft procedure; (3) return to full ambulation one week after the skin graft.

We always performed an outpatient evaluation once a week until the second surgical step. Around three weeks (mean time: 19.6 days) after the DRT application, we completed the procedure: the superficial silicon sheet was removed and the neodermis bed was accurately evaluated. After a gently curettage to revive the neovascularization, a thin STSG (always harvested from the occipital region by means of an air-powered dermatome set to 0.2 mm) was performed.

Table I. Patient demographics and interventions.

Age/ Sex	Etiology	Interval since burns (years)	Defect location	Dimensions of the loss of tissues (cm)	Exposed critical structures	Delay between 2 procedures (days)	Complications
27/F	Thermal burn	25	Right distal dorsal foot	10 × 6.5	Tendons	19	None
34/F	Thermal burn	33	Right dorsal foot and ankle	20 × 7	Tendons, joints	17	None
18/M	Thermal burn	17	Left distal dorsal foot	10 × 8	Tendons	20	Partial lysis of the graft
28/M	Thermal burn	10	Left dorsal foot and ankle	6 × 8	Tendons	22	None
21/F	Explosion	19	Right dorsal foot	6 × 8	Tendons	18	None
23/M	Thermal burn	4	Right distal dorsal foot and ankle	9 × 10	Tendons	21	None
25/M	Thermal burn	22	Right distal dorsal foot	8 × 9	Tendons	20	None
27/F	Electric burns	25	Left dorsal foot	10 × 7	Tendons, joints	19	None
18/F	Thermal burn	16	Right distal dorsal foot	11 × 8	Tendons	21	None
19/M	Thermal burn	10	Left dorsal foot	7 × 9	Tendons	21	None
20/F	Thermal burn	18	Right dorsal foot e and ankljoints	6 × 8	Tendons,	18	Partial lysis of the graft
22/F	Thermal burn	17	Right distal dorsal foot	8 × 10	Tendons	20	None

Results

The procedure was performed on 12 consecutive patients affected by unilateral dorsal forefoot post-burn contracture. Five men and seven women (mean age: 23 years old), were treated for the aforementioned burns sequeale occurred during childhood (before 3 years old for two third of the patients) or adolescence. All patients came from developing countries (Table I) and all of them were initially treated non-operatively with standard sterile dressings. The average delay from the initial burn trauma to our treatment was 18 years. All patients suffered from progressive gait disturbance due to toes hyperextension and difficulties to wear shoes.

Retractions involved toes, dorsal foot and ankle (Figure 1A-B and Figure 2A-B). After our surgical release of contracted tissues, the mean tissue loss area was 75 cm^2 (ranging from 48 to 140 cm^2) but a mean of 8 cm tissue advancement was always obtained by means of accurate undermining or

Figure 1. A, Pre-operative aspect of the right foot of a female patient (*frontal view*). **B,** Pre-operative aspect of the right foot of a female patient (*medio-dorsal threequarter view*). **C,** Per-operative aspect after contracture release and before application of the dermal regeneration template. **D,** Per-operative aspect after application of the dermal regeneration template. **E,** 6 months post-operative aspect of the right foot of the same patient (*frontal view*). **F,** 6 months post-operative aspect of the right foot of the same patient (*medio-dorsal threequarter view*).

Figure 2. A, Pre-operative aspect of the right foot of a male patient (*frontal view*). **B,** Pre-operative aspect of the right foot of a male patient (*lateral view*). **C,** Per-operative aspect after contracture release and before application of the dermal regeneration template. **D,** Pre-operative aspect after the application of the dermal regeneration template. **E,** 12 months post-operative aspect of the right foot of the same patient (*frontal view*). **F,** 12 months post-operative aspect of the right foot of the same patient (*lateral view*).

z-plasties (Figure 1C and Figure 2C). All patients received the already described two-step procedure, with a mean time of 19.6 days between the DRT application (Figure 1D and 2D) and the STSG. For just one patient, an additional skin graft procedure was necessary to optimize the wound healing because of a partial peripheral necrosis of the graft. Skin grafts were always harvested from the occipital scalp and no complications were observed on the donor site. No further procedures of touch-

up were needed. No recurrences were registered during the follow-up period (median follow-up time: 4.6 years) (Table II). The pain associated to toe contractures disappeared post operatively in all the patients except for two patients who continued to suffer from a plantar chronic pain reported before surgery. All patients were satisfied about the aesthetic appearance of the reconstructed foot (Figure 1E-F and Figure 2E-F) even if two patients developed an hypertrophic scar on the skin graft. The daily walking was improved in all patients and all of them also reported to feel more comfortable when wearing shoes.

Discussion

Dorsal foot contracture represents a common complication of lower limbs burns. Despite adequate treatments during the acute phase, contractures rate is reported[4] as high as 36%. Little attention has been given to the surgical management of post-burn contractures of the ankle and foot to date in the literature: a case series[1] reported the management of dorsal foot contracture using split or full thickness skin grafts, z-plasty, local or free flaps but no article was found describing the use of DRT in this scenario.

The growing interest of the medical community for this topic is testified by the recent publication of very interesting works.

Chang et al[2] in 2014 proposed an useful classification for toes burn scar contractures (TBSC): mild TBSC involve scarring of the superficial tissues only with no functional impairment and these were treated with scar release or local tissue rearrangement; moderate TBSC involve soft tissue shortages requiring skin grafts and occasional closed joint capsulotomy; severe TBSC cause the greatest impairment in function and involve burn injury to deeper structures. According to this classification, forefoot deformities in our patients can be classified as severe because of their functional impact. Leung and Cheng[5] suggested to treat mild and moderate contractures with z-plasty and skin grafts, whereas severe and mutilating sequelae with flaps or grafts. We believe our procedure can be used in most of the cases because DRT provide a correct and reliable coverage of exposed joints and articular capsules.

We also think that scar releasing incisions and additional partial excisions must be considered as one of the most effective treatment for severe and wide post-burn deformities, particularly when over the joints. Again, different procedures have been described in the literature to manage the resulting skin defect. Both the works of Constantino et al[6] and Dhanraj et al[7] stated that skin grafting is a quick and simple technique, but a STSG is more prompt to produce contracture recurrences after reconstruction[4]. Moreover, after contraction release, a tendinous exposition or capsular breach can occur and an isolated skin graft is not an effective way to cover it. To obtain and maintain good aesthetic and functional results, it is also important to avoid further damage to the remaining tissues while performing the surgical coverage in order to let ligaments and joints move freely. The in-

Table II. Functionnal evaluation (subjectively reported by the patient).

Age/ Sex	Follow-up (years)	Toe contracture pain	Confort when wearing shoes	Ability of walking	Remaining complain
27/F	6	Decreased	Improved	Improved	Syndactylie
34/F	5	Decreased	Improved	Improved	Hypertrophic scar
18/M	6	Decreased	Improved	Improved	None
28/M	4	Stable	Improved	Improved	Persistant pain of the footplant
21/F	1	Decreased	Improved	Improved	None
23/M	5	Decreased	Improved	Improved	Syndactylie
25/M	4	Decreased	Improved	Improved	None
27/F	7	Decreased	Improved	Improved	None
18/F	4	Decreased	Improved	Improved	Hypertrophic scar
19/M	2	Decreased	Improved	Improved	None
20/F	3	Stable	Improved	Improved	Persistant pain of the footplant
22/F	3	Decreased	Improved	Improved	None

terposition of a DRT plays this role. Local skin flaps including V-Y plasty or z-plasty can also be used, but these techniques are not effective in the treatment of extended contractures. They provide a limited coverage, making the reconstruction challenging in many cases. Moreover, in most of the cases even the surrounding tissues are cicatricial. Sen et al[8] described a technique of releasing incisions associated with a "quadra z-plasty" that can be useful for mild or moderate contractures in order to minimize complications of a classic releasing incision technique. Daya[9] reported a seven-flap local plasty associating Y-V flaps and z-plasty in two post-burn dorsal foot retractions but these procedures are highly dependent on the quality of the surrounding scars. Local flap techniques based on geometrical flaps (Y-V plasty, z-plasty and their variations) are not our choice for several reasons: the subcutaneous dorsal fat layer is extremely thin and blood circulation in distal lower limb is reduced expecially around scar tissue area; therefore, flaps have a high risk of necrosis in these cases[10]. Some pedicled local flaps (the distally based island dorsal foot flap[11] and the distally based dorsalis pedis island flap[12]) have also been described but they provide a limited skin coverage, too. Loco-regional flaps and expanders are not very suitable because they strongly depend on the characteristics of contracture and the availability of healthy surrounding skin. Eubanks et al[13] decribed the V-Y advancement of a dorsalis pedis-based cutaneous flap for limited dorsal foot contracture (advancement flap of 3.5 to 4 cm). Acarturk et al[14] described a case of left distal dorsal foot contracture reconstructed by means of a peroneal artery anterior perforator based rotation flap: even reporting a 20% distal flap loss, they reported a good outcome. Safety and feasibility of this kind of flap highly relies on the quality of the surrounding skin, but still, they often require skin grafting of the donor site with unaesthetic sequelae. Distant pedicled flaps such as cross leg flaps represent alternatives described by Ay[15] but these lead to a longer immobilization period, debulking procedures (in dorsal foot reconstruction, a thin flap is essential for post-operative ambulation and wearing shoes) and sequelae in the donor site. Eventually Lee et al[16] reported a series of seven patients successfully treated with the anterolateral thigh flap: they report no complications and just one debulking procedure. These procedures expose the patients to an higher risk of failure and complications and that is the reason why we consider free flaps as a second-line procedure to consider in cases of failure or unavailability of DRT. Bloemen et al[17] and Cottone et al[18] performed an objective and long term follow-up of dermal substitutes emphasizing an improvement in both scar and healing parameters in both acute and chronic wounds, proving a long-lasting effect on scar quality compared to skin grafts alone. We decided to use a two layer DRT because it is proven to be the best choice at long-term follow-up[19]: the double layer structure led to an optimal result in terms ofretraction rate, skin quality and mobility recovery. In our experience, local flaps could be used in association of a DRT when a linear post-burn scar contracture affecting the ankle dorsiflexion is also present[10] (Figure 1C and D).

Even if we did not perform bilateral correction, a study[7] showed the feasibility of simultaneous bilateral correction of post-burn foot contractures in children. It is important to outline that the splinting method also plays a crucial role in maintaining released tissues in the correct position until a complete wound healing. Calhoun et al[20] described the use of the Ilizarov fixator in the treatment of feet chronic burn deformities. Erdogan et al[21] reported the use of external fixators. Anyway, we consider these procedures heavy and invasive and this is the reason why we proposed a lighter stabilization by means of Kirschner wires associated with a plantar splint.

Alternative methods without the use of K-wires or external fixation have been described[22-25]. Wang et al[22] reported a postoperative temporary non-invasive fixation by using gauze and sutures to hold toes in a correct position. Guild[24] described a tailored thermoplastic splint fixed with velcro strap. But in conclusion we consider that to maintain the extension of metatarso-phalangeal joint is the main point, difficult to carry out without the use of K-wires.

Conclusions

Patients suffering from severe post-burn dorsal foot contractures deserve a meticulous combined management with scars transversal incisions, extensive tenolysis and external capsular release in addition to the use of a dermal regeneration template to cover the resulting loss of soft tissue. This technique provides a large and thin, soft tissue reliable coverage.

All our patients recovered a normal gait function a few weeks after surgery and were able to wear shoes once again. To date, we have not encountered any contractures reccurence.

A longer follow-up could be useful to draw stronger conclusions regarding the duration of both the technique and results. In case of contracture reccurence, other procedures including DRT re-application are still possible or otherwise other options including free flaps is worth considering.

Double-layer DRT appears to be a safe, efficient and reliable solution in the treatment of dorsal foot post burn contractures in adults.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Informed Consent

Detailed informed consent was obtained for every patient.

Ethics Approval

This study was approved by the Plastic Surgery Concertation Commitee, Saint Louis Hospital, APHP.

Authors' Contributions

Authors FA, GC, MAB, FDF and KS collected data and developed the database. Initial draft was written by KS, MC and DB. Final revision and finalization of the manuscript were performed by KS and MM.

Availability of Data and Materials

Data are not available for public, they can be requested directly at the clinical direction of the Hopital Saint Louis.

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