Acellular dermal matrix and skin grafts: A long-lasting alternative for weight-bearing zone reconstruction after degloving trauma of the foot

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Received: October 02, 2015
Published online: November 04, 2015

Reconstruction of the weight-bearing surface of the foot presents challenging difficulties due to the unique anatomical properties of the heel and its fundamental cushioning effect. Despite the literature reported several available strategies, an ideal technique for reconstruction of the weight-bearing heel has not yet been elucidated.

In the last decade a combined use of acellular dermal matrices, negative pressure wound therapy and skin grafts has been proposed as a reliable and less invasive alternative for complex wounds management. We described 4 cases of severe degloving trauma of the plantar region with massive soft tissue defects of the foot successfully treated trough staged reconstruction with artificial dermis, negative pressure therapy and skin grafts during the period from March 2010 to July 2012. All of them were white Caucasian men with a mean age of 45,2 years (range, 29-55 years). A stable complete healing was obtained in all the patients after a mean time of 63 days (ranging from 58 to 71 days). Follow-up period ranged from 31 to 61 months (mean follow-up, 51,3 months). All patients were able to walk using orthopaedic shoes and they didn’t have immediate postoperative complication such as template infection or unsuccessful skin graft/dermal matrix engraftment. Despite the initial concerns about the use of acellular dermal matrices and skin grafts for this kind of injuries, they seems to be a simple and safe alternative for weight-bearing reconstruction of the degloved foot. The authors believe that the current study yields useful informations and reassurances about their long-term reliability.

Keywords: acellular dermal matrix; skin graft; foot reconstruction; weight-bearing; degloving trauma

Introduction

The fat pad of the human heel acts as a shock-absorbing system, protects against excessive local stress and reduce plantar pressures [1]. The heel, overlying the weight-bearing calcaneus, transmits 80 % of the weight, and the distal sole with the metatarsal heads transmit 20 % [2]. This fundamental cushioning efficiency is the result of its unique anatomical properties. The fat pad lies between the calcaneus and subcalcaneal skin and it consists of a matrix of elastic fibrous
connective tissue arranged in dense septae adhering skin to the underlying fascia and containing closely packed fat cells. The structure of the septa has developed in order to resist compressive loads during landing and its mechanical behaviour is related to the development of overuse injuries. Therefore reconstruction of the weight-bearing surface of the foot presents challenging difficulties. It is now accepted that restoration of heel function requires reconstruction of its anatomical structures including skin, subcutaneous tissue and bone. The “ideal” reconstruction should provide skin thick enough to resist bearing and bruising, bone hard enough to resist compression and a soft tissue layer between the skin and bone to absorb vibration. A great number of reconstructive options have been described throughout the history, including cross-leg flaps, skin grafts, locoregional flaps and free flaps, each of them with their pros and cons. Despite the large number of available techniques, no consensus exists and an ideal flap for weight-bearing reconstruction has not been made clear. Furthermore patients with significant hemodynamic changes from burn or severe trauma such as devastating crush avulsion injuries of the plantar surface may be not suitable candidates for flap coverage. In those cases harvesting tissue flaps through injured skin may jeopardize its survival, increasing the reconstructive problem. Moreover elderly patients with multiple chronic medical problems and high preoperative risks are poor candidates for flap reconstruction as well. To overcome these problems several alternative approaches such as the combination of negative pressure wound therapy (NPWT), acellular dermal matrix (ADM) and subsequent split thickness skin graft (STSG) have been described in the last decades in the management of severe wounds of the lower extremities. Although the use of ADM appears to offer a viable option in extremity wounds with exposed tendon, bone or joint and it has been widely described, Iorio ML et al systematically reviewed the literature on this issue and observed that the comparative efficacy of vascularized tissues to ADM and STSG has no yet been elucidated.

In this article, we present four cases of severe crush injuries with extensive deglovement of the plantar surface of the foot that were successfully treated by a combined use of NPWT, ADM and skin grafts with a long-lasting result both from a morphological and functional point of view.

Patients and Methods

Patients

A retrospective study was performed in our Department during the period from March 2010 to July 2012. Four patients were treated for severe deglovement of the plantar surface with denuded tendons, muscles and bones caused by...
trauma of great magnitude. Tissue defects were evaluated at admission according to Arnez classification of soft-tissue degloving in limb trauma [11]. A combination of NPWT (Wound V.A.C., KCI, Inc., San Antonio, TX), bilayer acellular dermal matrix (Integra®, Plainsboro, NJ) and subsequent STSG were used in all the patients.

Surgical Procedure

In every case the treatment protocol included the bone fracture fixation (if necessary), radical wound debridement to remove devitalized tissues and a conservative management with V.A.C. device (KCI, Inc., San Antonio, TX) with a level of subatmospheric pressure of 125 mmHg and serial delayed excisions in order to gradually evaluate the vascularity and viability of injured skin. V.A.C. dressings were changed every 5 days. This staged management was continued until the wound bed was debrided and vascularised, an adequate coverage of bone and tendon exposure and culture-negative wound were obtained. Only patients with positive wound culture received an antibiogram-guided antimicrobial intravenous therapy during their hospital stay. After that the bilayer dermal matrix was tightly anchored by suturing or stapling along the wound edges (Figure 1); small multiple incisions were performed on the superficial silicone layer in order to prevent fluid accumulations. The matrix was then circumferentially covered with a compressive poliuretane foam dressing to provide firm adhesion of the graft to underlying structures and a iodopovidone ointment was copiously applied on template’s edges to minimize the risk of template infection/contamination. Adequate off-loading, immobilization and posterior below-knee splinting regimens were applied and dressings were removed every 3 days to better inspect the matrix engraftment process step by step. After a variable period of 3 to 4 weeks (until a well vascularised tissue bed is observed under the silicone sheet), the engraftment of Integra® was evaluated and the second surgical stage was then performed with a STSG to cover the regenerated dermis. As standard procedure, after silicone layer removal, a further meticulous debridement of the regenerated recipient site by high-pressure water with VersaJet (Smith & Nephew Medical Limited, Hull HU3 2BN England) was performed to obtain bleeding and well cleaned tissues to improve the skin engraftment that was evaluated on the fourth postoperative day in all the cases.

Once patients completely healed they were followed every 3 months; occurrence of complications such as skin ulcerations, breakdown or blisters was observed and walking/weight-bearing ability was detected.

Results

A total of 4 patients were treated for devastating deglovement of the plantar surface during 2,5 years. All of them were Caucasian men with a mean age of 45,2 years (range, 29-55 years). Two patients referred a motorcycle high speed accident, while the other two were victims of work accidents. According to Arnez classification of soft-tissue degloving in limb trauma, three patients reported a type 2 pattern of wound (in this pattern most of the skin is still present either as a flap or as an area of wide undermining and the level of avulsion is mainly confined to a unique layer, Figure 3), while one patient reported a type 3 lesion (circumferential individual plane degloving, Figure 2). All patients reported wound bed infections; the most common isolated microorganisms were Pseudomonas Aeruginosa (2 patients), Methicillin-Resistant Staphylococcus Aureus and
Acitenobacter Baumannii. A wide surgical debridement was always performed at the admission. A conservative management with serial excisions and NPWT was then applied for a mean period of 23.2 days (ranging from 19 to 29 days). The bilayer acellular dermal matrix (Integra®, Plainsboro, NJ) appeared well incorporated after a mean period of 21 days (ranging from 19 to 23 days). A stable complete healing was obtained in all the patients after a mean time of 63 days (ranging from 58 to 71 days).

Follow-up ranged from 31 to 61 months (mean follow-up, 51.3 months). All patients were able to walk using orthopaedic shoes and they didn’t have immediate postoperative complication such as template infection or unsuccessful STSG/dermal matrix engraftment (Table 1-2). Only a patient reported the late occurrence of a small skin ulceration on the reconstructed heel after a subsequent superficial trauma, that healed in two weeks with conservative management.

Discussion

The heel fat pad is a highly specialized adipose-based structure that protects the rear foot and the lower extremities from the stress generated during the heel-strike and the initial support phase of locomotion; then its cushioning efficiency is the result of its structure, shape and thickness. Biomechanical studies demonstrated that under the loads occurring during normal walking, the peak plantar pressures occurred in the region immediately below the calcaneal tuberosity. An appropriate knowledge of the heel anatomy and distribution is mandatory and can guide the plastic and orthopedic surgeons to a more effective reconstruction [3, 12].

Several pathological conditions such as burns, pressure sores, diabetic foot, vascular diseases, malignant tumors and trauma can lead to extensive soft tissue defects of the whole heel and sole foot. Among trauma of great magnitude, degloving lesions may be a serious challenge because torsional and compressive forces affect several levels of the subcutaneous tissue and fascia leading to separation and tearing of the skin from the deep fascia with devascularization of avulsed tissues with resulting skin necrosis. The straightforward treatment for this condition in emergency is the repositioning and suturing of avulsed flap back into their original position, but it is quite well-known that total or partial necrosis of the repositioned flap occurs frequently. Despite several pharmacological agents and non-invasive techniques are currently available, determination and improvement of the viability of avulsed
flap are still difficult [13, 14].

Considering the unique anatomical properties of the heel and the problems related to flap viability after degloving injuries, it is usually difficult for the surgeon to decide the most appropriate surgical management. In reconstructing the plantar aspect of the foot, the ideal replacement should provide durable, glabrous and thick skin to resist the shearing force encountered in standing and walking durability, adequate sensibility, relative soft-tissue fixation to the underlying structures, a satisfactory appearance with anatomic contour allowing the patient to wear normal shoes [15, 16]. A review of the literature demonstrated three main approaches for the management of heel and sole foot injury: local flaps, free flaps and skin grafts, each of them has its advantages and disadvantages. Several local flaps have been described such as the medialis pedis flap [17], instep flap (medial plantar flap) [18], lateral calcaneal flap [19], dorsalis pedis [20], reverse sural artery [21] and flexor digitorum brevis muscle [22]. Local tissues have been advocated by several authors as a first choice for heel reconstruction due to their versatility, reliability, constant vascular anatomy pattern, immediate restoration of sensation and their similarity with the unique physical properties of the weight-bearing surface of the foot thus following the golden rule of reconstruction: “replace like with like” [5]. On the contrary other authors believe that these flaps are generally limited to the reconstruction of relatively uncomplicated small defects as they can provide a small amount of tissue; furthermore their dissection is usually difficult, which leads to the sacrifice of one of the nutrient arteries of the already injured foot and they are usually located within the trauma zone [23, 24].

Table 1. Patients data

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age</th>
<th>Tissue defect (Arnez ZM et al., 2010)</th>
<th>Ethiology</th>
<th>NPWT (days)</th>
<th>Wound bed infection</th>
<th>Days from ADM application to STSG</th>
<th>Complete Healing (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>Type 2 (heel)</td>
<td>Motorcycle accident</td>
<td>24</td>
<td>Pseudomonas Aeruginosa</td>
<td>20</td>
<td>58</td>
</tr>
<tr>
<td>2</td>
<td>49</td>
<td>Type 3 (heel, sole, left ankle and dorsum)</td>
<td>Work accident</td>
<td>21</td>
<td>Pseudomonas Aeruginosa</td>
<td>22</td>
<td>63</td>
</tr>
<tr>
<td>3</td>
<td>29</td>
<td>Type 2 (heel and sole)</td>
<td>Motorcycle accident</td>
<td>29</td>
<td>Methicillin-Resistant Staphylococcus aureus</td>
<td>19</td>
<td>71</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
<td>Type 2 (heel)</td>
<td>Work accident</td>
<td>19</td>
<td>Acinetobacter Baumannii</td>
<td>23</td>
<td>60</td>
</tr>
</tbody>
</table>

NPWT, negative pressure wound therapy; ADM, acellular dermal matrix; STSG, split thickness skin graft

Table 2. Patients follow-up data

<table>
<thead>
<tr>
<th>Patient</th>
<th>Immediate postoperative complications</th>
<th>Long-term complications</th>
<th>Walking/weight-bearing</th>
<th>Follow-up (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>None</td>
<td>Yes</td>
<td>55</td>
</tr>
<tr>
<td>2</td>
<td>None</td>
<td>None</td>
<td>Yes</td>
<td>61</td>
</tr>
<tr>
<td>3</td>
<td>None</td>
<td>Skin ulceration</td>
<td>Yes</td>
<td>31</td>
</tr>
<tr>
<td>4</td>
<td>None</td>
<td>None</td>
<td>Yes</td>
<td>58</td>
</tr>
</tbody>
</table>

Free tissue transfers have been widely adopted for complex heel or sole foot reconstruction: radial forearm flap, posterolateral thigh flaps, skin grafted muscle flaps such as latissimus dorsi and gracilis muscle flaps [23-25]. They seem to be the best solution for large complicated defects. Nevertheless microsurgical tissue transfer is more time consuming, it needs a specialized microsurgical team, it has higher postoperative risks and requires more postoperative care with higher costs both for the patient and for the medical centre [5].

Another controversy exists as to concern the use of fasciocutaneous or muscle flaps. Skin grafted muscle flaps are more useful for deep irregular defects and seems to be more stable because flap tailoring under good tension in the recipient area is possible thus preventing too much shifting; moreover they can fill dead spaces and are suitable in case of infected wounds with osteomyelitis [23]. On the other hand they are often bulky precluding the use of normal shoes thus requiring secondary debulking and revision procedures due to excessive muscle volume [16], they show recurrent ulcerations [26], they are incapable of innervations and display dryness and cracking of the skin graft, and they seems to not tolerate prolonged pressure [2] showing remarkable atrophic changes clinically and a high incidence of muscle necrosis was significantly observed in the animal studies [27]. Fasciocutaneous flaps are more suitable for superficial defects, provide better sensibility [23], they provide thick and pliable tissue, excellent aesthetic results and good anatomical contour allowing patients normal footwear [2]. Nevertheless they cause more donor site deformity and are more prone to shearing force [23], that act tangentially to the surface and have been suggested as important pathogenic factors in the
development of plantar ulcers. Despite the current literature reported several available technique, a systematic review recently reported that an ideal flap for reconstruction of the weight-bearing heel has not yet been elucidated.

Skin graft seems do not meet the requirements of this particular area and has always been considered vulnerable to trauma and pressure and its use was limited for suprafascial avulsions or adipofascial and free-muscle flaps coverage. Some authors presented the immediate replacement of the avulsed flap as a defatted full-thickness graft with good results and others described the use of STSG for foot sole reconstruction. Nevertheless Nicoletti et al. recently demonstrated that often foot sole reconstruction with STSG inexorably requires secondary surgical correction with lipofilling as skin grafts are usually unstable in the long term and undergo retraction with subsequent foot deformity, chronic pain and recurrent ulcerations.

Furthermore several authors used NPWT to facilitate coverage of exposed ungraftable structures with granulation tissue and subsequent skin graft to cover the defect. However has been observed that skin graft alone applied directly over bone or tendon with an overlying granulation bed did not provide stable long-lasting coverage leading to recurrent breakdown and reexposure of underlying structures.

In the last decades with the advent of tissue engineering, the use of ADM appears to be a useful adjunctive option in extremity wounds that have exposed tendons, bones and joints and they are expanding rapidly in many fields. Among the currently available dermal substitutes Integra® (Integra Life Sciences, Plainsboro, NJ) is one of the most used and a majority of clinical studies focus on this product; it is a bilaminate dermal replacement system composed of bovine collagen and shark chondroitin-6-sulfate with a superficial protecting silicone layer. It is an acelarral and nonviable template that requires different phases of dermal regeneration histologically demonstrated: it works as a scaffold for patient’s own fibroblasts and endothelial cells ingrowth which are gradually replaced by collagen of the host leading to new dermal formation (i.e. the neodermis) that usually occurs at 4 weeks. Despite these observations, from a systematic review of the literature (Iorio et al., 2012) emerged that a comparative efficacy of vascularized tissues to ADM and STSG has not yet been elucidated.

An accurate analysis of the current literature revealed that only a few studies exist describing the combined use of ADM and skin grafts for foot injuries reconstruction and most of them are small case series. Menn et al. reported 4 cases of lower extremity wounds managed with Integra and NPWT; nevertheless only in one case a weight-bearing area (heel) was involved and follow-up data are lacking. Pu LL described 2 cases but only one affected the heel with only 5 months of follow-up period. Chen X et al. illustrated 15 cases of complex wounds with bone exposure but only 2 patients had calcaneus defects; of these cases one failed for template infection and the other one had a short follow-up period (4 months). Onesti et al. described a single case report of plantar reconstruction in a pediatric patient with 36 months of follow-up but the aetiology of the defect was a malignant neoplasm and not a trauma. Fraccalvieri M et al. reported 7 cases of osteomyelitis involving the heel with a mean follow-up period of 22.3 months; however even in this study the aetiology of the defect was not a trauma. This is a very important factor determining the choice of the more appropriate management for heel reconstruction due to the massive involvement of soft tissues after a great magnitude degloving injuries with the above mentioned problems regarding avulsed flap viability. Kuro et al. recently described a single case report with the combined use of artificial dermis and topical NPWT to treat a complex wound of the leg; nevertheless the aetiology was a cellulitis of the lower limb without heel involvement and with a short follow-up period (3 months).

To our knowledge the current study is the first to describe several cases of weight-bearing reconstruction after complex degloving trauma of the foot with a combined use of ADM, NPWT and STSG with a long follow-up period (mean period, 51.3 months). Furthermore the overall complication rate was really encouraging and only one patient reported a late occurrence of skin ulceration that healed in a few weeks with conservative management.

However this study has some important limitations such as the small casuistic of patients. Furthermore it is not a comparative study and a functional assessment of locomotor recovery (e.g. gait analysis) is lacking.

Conclusions

Soft tissue reconstruction after degloving trauma of the heel usually poses an important challenge for the plastic and orthopedic surgeon and sometimes conventional treatment such as local flaps or microvascular tissue transfer are not available. Despite the initial concerns about the use of acellular dermal matrices and skin grafts for this kind of injuries and the paucity of available literature, dermal substitutes seems to be a simple and safe alternative for weight-bearing reconstruction of the degloved foot. We believe that our study yields more useful information and represents an important reassurance about their long-term reliability. Further investigations with a larger patient
casuistic will be necessary to better clarify the functional outcomes and comparative studies with flap coverage would be suitable.

Financial disclosure

None of the authors has a financial interest in any of the products, devices, or drugs mentioned in this article.

Funding

None

Authors Contributions

AS and LG performed the surgical procedures, paricipated to the study design and the writing of the manuscript. MT led the study design, the analyses of the literature and the writing of the manuscript. GDB participated to the study design and coordination, and drafted the manuscript. All authors read and approved the final manuscript.

References


