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Treatment of finger degloving injury with acellular dermal matrices: Functional and aesthetic results

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Degloving injuries;
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Summary *Introduction:* Finger degloving injuries (FDIs) represent a challenge in hand surgery. When replantation is not possible, several techniques including loco-regional flaps, pocket abdominal flaps and free flaps have been described as methods to provide skin cover and avoid finger shortening. The aim of this study is to present our experience with acellular dermal matrices (ADMs) in the treatment of FDI.
Materials and methods: We retrospectively reviewed the charts of 18 patients who presented with FDI and were treated with ADM between December 2015 and July 2017. Surgical outcomes including complications were analysed, and patient-centred assessments were performed at 12 months of follow-up.
Results: The follow-up period ranged from 10 to 20 months. All patients showed good integration and vascularisation of the ADM. All the fingers covered with ADM were firm and soft, with a slim and satisfactory appearance at a mean follow-up of 12 months. No limitations in tendon sliding were observed at dynamic sonography one year after surgery.
Conclusion: ADMs could be regarded as a viable option when dealing with FDIs, if replantation is not possible and finger length is to be preserved. On the basis of these results, the surgical

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treatment of FDI with ADM is a viable option that produces good functional outcomes and cosmetic appearance.
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Introduction

Finger degloving injuries (FDIs) represent a unique challenge in hand surgery. The irreplaceable quality of the skin that has been lost, together with the need for functional recovery, explains why skin avulsion is a particularly significant trauma when the hand is affected[1,2]. The ideal treatment should focus on providing thin, pliable and sensate skin; prevent stiffness and contracture; promote a quick healing process, hence resulting in early mobilisation; prevent painful neuromas and obtain a cosmetically acceptable result.

Several reconstructive options have been described to provide soft tissue coverage when replantation or revascularisation is possible because the degloved skin has been crushed or the vascular pedicle is unsalvageable[2]. Heterodigital flaps, a subcutaneous distant pocket and free tissue transfer, have been commonly advocated when skeletal shortening is not desired[3-5].

In the last few decades, there have been a good number of products created with the purpose of helping manage soft tissue injuries[6,7] These products range from purely synthetic compounds to both cellular and acellular materials obtained from human and animal sources[6]. They can provide effective protection to the tissues, hence preventing infection and promoting the formation of granulation tissue. The use of acellular dermal matrices (ADMs) has evolved in hand surgery during the past 15 years to become the treatment of choice for many conditions affecting the hand, wrist and forearm, as well as for use as a temporary cover after skin tumours excision[8,9].

The use of ADMs to treat traumatic digital injuries including FDIs has not been extensively documented, and the purpose of this paper is to present our experience with the use of ADMs in the treatment of FDIs. Functional outcomes and surgical complications were evaluated to assess the effectiveness of the final reconstruction.

Materials and methods

Patient selection

This is a retrospective analysis of a database prospectively collected between December 2015 and July 2017. The manuscript was prepared according to the STROBE guidelines[10]. Inclusion criteria were patients affected by FDI (Figure 1), when the degloved skin had been crushed, and the vascular pedicle was unsuitable for either replantation or revascularisation. Patients presenting with associated tendon apparatus injury and/or bone exposure were excluded. Minor and major comorbidities were not considered as exclusion criteria, as all surgical procedures required local anaesthesia. All patients were treated using a PELNAC® (Gunze Corp., Osaka, Japan) dermal regeneration template (DRT), followed by the stepwise healing process, and an informed consent was obtained before surgery. Our study was performed in accordance with the ethical standards set out in the Declaration of Helsinki, as amended in Tokyo in 2004.

Surgical technique

Surgical procedures were all performed under local anaesthesia. After physical examination, aggressive debridement and irrigation of the involved finger was performed. A PELNAC® DRT was used to cover the injured area (Figures 2 and 7). PELNAC® regeneration templates consist of two layers: a porcine tendon-derived atelocollagen sponge layer, approximately 3 mm thick, and an outer reinforced meshed silicone film layer, for better wound conformity and drainage. A PELNAC® DRT is prepared by freeze-drying and does not require washing before use. The regeneration template was rehydrated in saline solution for 10 min before application, and it was fixed with intermittent resorbable 4-0 sutures. Considerable care was taken in making the template adhere to the wound bed, and compressive dressing was applied to facilitate dermal matrix integration. The patients were discharged the day after the first surgical procedure, and after that, they were followed weekly in the clinic and trained in gradual mobilisation by our occupational therapy (OT) team.

After removal of the silicone layer (21 days after its application), the extent and depth of the wound bed were evaluated clinically. If epithelialisation was seen at the edges and/or epithelial islands were observed within the lesion, the dermo-epidermal skin graft was not performed (ten patients). In these cases, the wound was treated with advanced dressings (sodium carboxymethyl cellulose layer containing silver ions) and showed complete re-epithelialisation with time ranging from 35 to 59 days of use. Eight patients underwent a second surgical step, which consisted of covering the lesion with a full-thickness skin graft (FTSG). The FTSG was harvested from the volar side of the wrist or the volar surface of the arm, depending on the size of the skin surface needed.

Perioperative administration of 2 g cefazolin was done to all patients during both surgical procedures, and 3 g/day amoxicillin/clavulanate was prescribed for 6 days after their discharge from hospital. Occupational therapy was started from 1 to 2 weeks later, according to wound healing status, with the aim to maintain range of motion (ROM) in the affected finger. Massage was used to soften scar tissue at the surgical area and control oedemas in the fingers during the rehabilitation process.

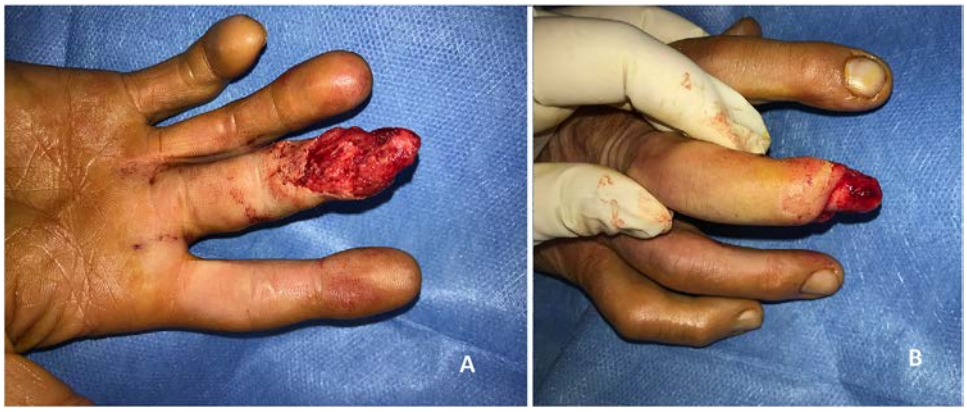

Figure 1 Case no. 1. Degloving injury of the middle finger of the right hand. (A) Volar view, (B) Dorsal view.

Figure 2 Case no. 1. Application of PELNAC^{TM} layer. A loop created around the finger with suture thread promotes the adhesion of the matrix to the wound bed.

Outcomes

The time needed for dermal matrix integration and complete wound healing after the surgical procedures was recorded. We re-evaluated patients after 3, 6 and 9 months. Surgical outcomes including complications were evaluated, and patient-centred assessments were performed at 12 months of follow-up.

Patient-centred assessment

Patients were asked to complete the 30-item DASH questionnaire, and the raw score was transformed to the quoted DASH percentage score, wherein 0 points indicated normal, pain-free function and no disability, and 100 indicated maximal impairment.

Observer assessment

Range of motion (ROM)

Active and passive ROM were assessed for each patient at the metacarpophalangeal (MCP), proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints using standard goniometers at both the injured and the contralateral finger. The results were classified according to the total active motion (TAM) ratings proposed by the American Society for Surgery of the Hand[11] (ASSH).

Grip and pinch strength

Grip strength was measured using a Martin Vigorometer with a medium size bulb. Both hands were measured three times. The average strength of these three measurements was calculated. Normal grip strength was predicted from the normal hand. For right hand-dominant individuals, the 10% rule was applied, and for left hand-dominant individuals, grip strength was assumed to be the same in both hands. Pinch strength was measured using a Jamar Pinch Gauge. Tip pinch, i.e. the strength exerted between the fingertip of the involved finger and the fingertip of the thumb, was also measured.

Sensory

Superficial touch/deep pressure perception in fingers was evaluated using the monofilament test (the Semmes-Weinstein monofilament, or SWM), and the fine tactile

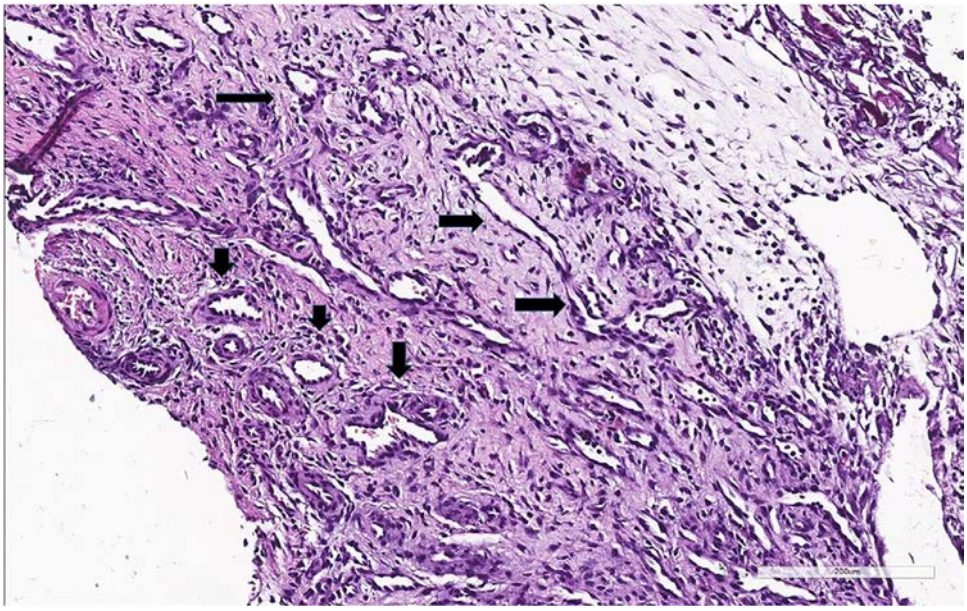

Figure 3 Case no. 2. Histological aspect shown in the lesions by numerous newly formed blood vessels (marked by black arrows). Scale Bar: 200 μm.

discrimination sensation was evaluated using static and dynamic 2-PD tests. All studies were repeated on the contralateral normal finger to match each parameter with a control value of the same patient. The following SWM test values were used in the interpretation: green filament, size 2.83 (normal); blue filament, size 3.61 (diminished light touch); purple filament, size 4.31 (diminished protective sensation) and red filament, size 6.65 (loss of protective sensation). A 2-PD score of 6 mm or less was excellent, 7–15 mm was good and 16 mm or higher was considered poor. The 10-point verbal rating scale (VRS: 0 = no pain and 10 = extreme pain) was used to evaluate subjective pain intensity in the involved finger. The VRS has been shown to correlate with the visual analogue scale (VAS).

Scar appearance

The modified Vancouver Scar Scale (VSS) was used for scar appearance evaluation. Four scar characteristics were tested: height (0–4), pliability (0–4), vascularity (0–3) and pigmentation (0–3).

Sonography evaluation

Dynamic sonography was used to evaluate tendon sliding under the repaired soft tissue according to the following rating scale (0= total impairment; 1= partial impairment; 2= normal sliding). Fibrous reconstructive tissue thickness and quantity were also determined (Video 1).

Biopsy samples and histological analysis

When the silicone layer was removed, biopsy samples were taken from the central area of the wound bed using a 3 mm punch. Specimens were fixed for 2 h in 2% paraformaldehyde and then processed with standard procedure for embedding in paraffin wax. Five-micrometre-thick sections were cut using a microtome and stained with haematoxylin and eosin using a routine protocol (Figure 3).

Results

From December 2015 to July 2017, a total of 35 patients were analysed. Eighteen patients met the inclusion criteria. The mean age of patients was 42.17 years old (range 19–66 years). Six cases involved the index, 4 cases involved the middle finger, 4 cases involved the ring finger, 2 cases involved the thumb and 2 cases involved the little finger. All injuries resulted from machine-related damage. The paratenon was preserved in 13 out of 18 patients. Accompanying fingertip-bone amputation was observed in 3 patients. The majority of traumas occurred during work, which were caused by automatic machinery in motion. The most frequent comorbidity was mild to moderate arterial hypertension. The mean follow-up was 17.4 months (range 12–24 months). The total area of dermal matrix application ranged from 2 cm^2 to 18 cm^2, the largest single site measuring 12 cm^2. ADM placement was performed on average 0.5 days after injury (range 0–2 days), and the second surgical step was performed on average after 21.3 days (range 20–25 days) later. All patients showed good integration and vascularisation of the ADM as borne out by histological analysis (Figure 3), except for 2 fingers with tips damaged by crushing and bone exposure, which required further surgical revision. Complete (100%) skin graft incorporation was observed in 6 patients; in 2 patients, a small area of graft was lost but did not require further local wound care. Ten patients who did not need a skin graft for reconstruction showed complete re-epithelisation with advance dressing after the silicon layer was removed (Figures 4 and 5). Complete healing was observed at a mean time of 40.2 days since injury (Table 1).

At a mean follow-up of 12 months, all the fingers covered with ADM were firm and soft, with a slim and satisfactory finger appearance. No ulcers and no bone/tendon infections were observed at 12 months of follow-up. In more

Figure 4 Case no. 1. The figure shows the newly formed granulation tissue after removal of the matrix silicon layer.

than half the patients (12), TAM (Kleinert and Verdan, 1983) was excellent or good as shown in Table 2. Normal tendon sliding evaluated with dynamic sonography was observed in 15 out of 18 patients. Grip strength ratio was >0.75 in all cases. Pinprick static and moving two-point discrimination tests showed partial recovery: more than 65% of patients maintained protective sensation. Michigan Hand Outcomes Questionnaire was submitted to patients, with the average result 4–5.

Discussion

Wound coverage after a complete degloving injury of fingers remains a very challenging procedure for hand surgeons. Optimal management criteria should include the need to preserve finger length, early, good-quality (thin, pliable) skin cover, and an early return to function. Ideally, replantation or revascularisation should be attempted, whenever possible. Both procedures require microsurgical skills and have unique features[12]. It may sometimes be possible to use the degloved skin as a graft, but most cases present with partial or complete structural damage. Alternative treatment options include the use of local flaps, abdominal flaps, fascial free flaps, anterolateral thigh skin flaps[13-15], latissimus dorsi skin flaps, medial arm free flaps and cutaneous free flaps[3,5,15]. Abdominal skin flaps are advantageous, as the abdominal area can provide a large amount of skin, but the flap is thicker and denser than normal finger soft tissue and multiple secondary thinning procedures are needed[2]. The use of a cutaneous free flap can offer a one-stage reconstruction with a good post-operative thickness and sensation, especially when thin flaps are harvested (e.g., dorsalis pedis flap, dorsal toe flap)[16]. The limit can be the

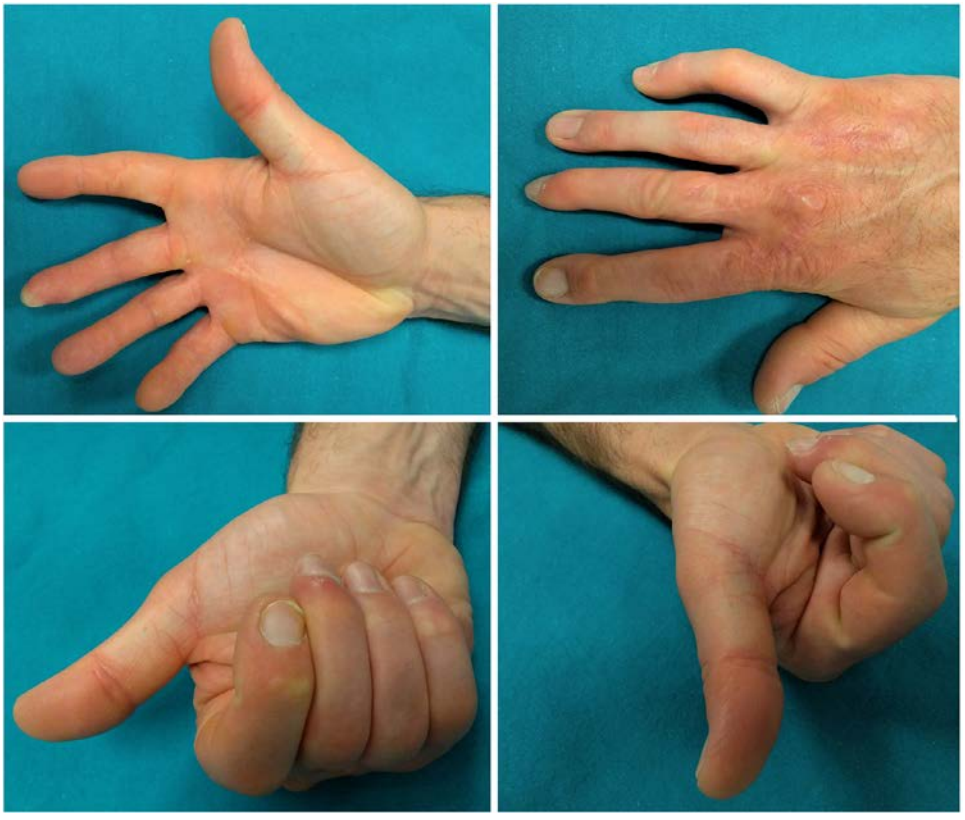

Figure 5 Case no. 1. Results after 3 months with excellent aesthetic and functional results. No skin graft was needed to achieve the complete healing. (A) Volar view, (B) Flexion of the fingers, (C) Dorsal view.

Table 1 Patients' demographics and surgical data.

Patient (*n*)	Age	Hand Finger	ADM placement (days after injury)	Silicon layer removal (days)	Need for skin graft (yes/no)	Wound healing (days)	Follow-up
1	42	R II	1	21	Yes	35	15
2	66	R II	0	20	No	40	12
3	45	L III	2	22	Yes	31	20
4	56	L IV	1	25	Yes	34	24
5	29	R II	0	21	No	35	19
6	48	R III	0	21	Yes	40	14
7	30	R I	1	23	No	42	22
8	59	L II	0	21	No	56	15
9	24	L IV	1	20	No	43	12
10	36	L IV	0	21	Yes	35	12
11	42	R V	0	21	Yes	33	20
12	51	L III	0	21	No	38	18
13	32	R I	0	21	No	44	12
14	38	R II	1	21	No	59	18
15	34	R V	1	20	No	45	21
16	19	L IV	0	22	Yes	34	23
17	47	L III	1	21	Yes	40	18
18	61	R II	0	23	No	40	19
Mean (±SD)	42.17±13.18	-	0.5 ± 0.62	21.39±1.24	-	40.22±7.48	17.44±3.97

Table 2 Patients' outcome (evaluated at a mean follow-up of 12 months).

	TAM (%)				2PD test			SWM test			
	Excellent (normal)	Good (>75)	Fair (75-50)	Poor (<50)	Excellent (6 mm)	Good (7-15 mm)	Poor (>16 mm)	Normal	Decreased Light touch	Decreased Protective sensation	Loss of protective sensation
No. of patients (%)	3 (16.7)	9 (50)	4 (22.2)	2 (11.1)	2 (11.1)	15 (83.3)	3 (16.7)	5 (27.8)	7 (38.9)	5 (27.8)	1 (5.5)

Dynamic sonography			DASH score				Total VSS score			
2 (normal)	1 (partial impairment)	0 (total impairment)	0-25	25-50	50-75	75-100	>9	9-7	7-4	<4
15 (83.3)	3 (16.7)	—	17 (94.4)	1 (5.5)	—	—	3 (16.7)	4 (22)	8 (44)	3 (16.7)

TAM (total active motion) = total active flexion - total extension deficit (MCP, PIP, DIP);% = TAM of the injured finger/TAM of the contralateral finger.
2PD test: 2-point discrimination test.
SWM test: Semmes-Weinstein monofilament test.
DASH score: Disabilities of the Arm, Shoulder and Hand score.

availability of a microsurgical team, long surgical recovery time and donor site morbidity.

ADMs in hand surgery were used initially as a skin replacement in the treatment of burns[17]. Since then, hand surgeons have used ADMs for skin coverage after various surgical procedures, such as radial forearm flap harvest, basal joint reconstruction and rotator cuff repair[18,19]. Nevertheless, a literature search yields only few articles on the use of ADMs for FDIs. Moreover, no comparative studies evaluating dermal matrix versus alternative treatment options (free tissue transfer) can be found. Taras and colleagues[20] described their experience with ADM on 17 patients; their study, which included digital injuries with soft tissue defects, showed how their approach was effective in treating cases with tendon, bone and joint exposure. Azzena et al.[21] presented a single case of FDI treated with ADM and a full-thickness skin graft, achieving satisfactory range of motion recovery and a cosmetically acceptable result. In addition, we found some case reports of degloving traumas to other parts of the body successfully treated with dermal matrices[22,23].

To our knowledge, this paper is one of the largest case series on the use of ADM for FDI. The outcomes evaluated through objective assessment tools show quite encouraging results (Figures 6-8). First, the use of ADM enables the surgeon to cover the large circumferential soft-tissue defects typically associated with FDIs, without donor site morbidity. The final digital coverage is not too bulky and does not interfere with finger function. Second, no limitation of tendon sliding was observed in our case series and was

Figure 6 Case no. 2. Degloving injury of the index finger and the thumb of the left hand. (A) Dorsal view, (B) Volar view.

Figure 7 Case no. 2. Application of PELNAC™ layer.

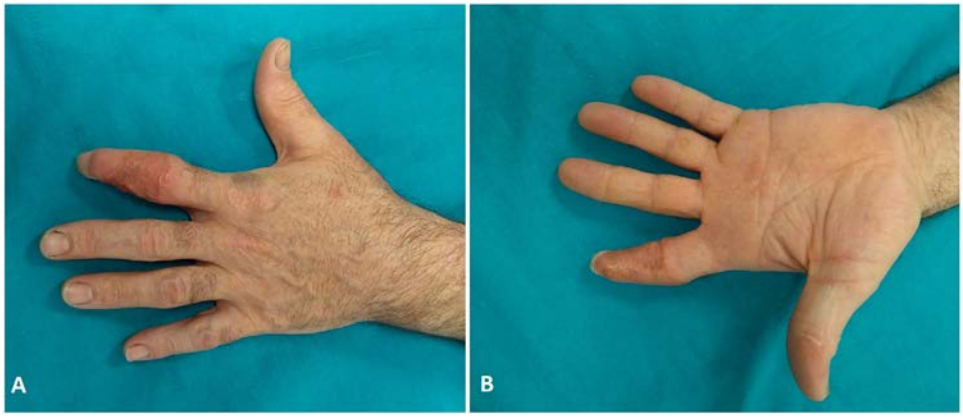

Figure 8 Case no. 2. Results after 3 months.

confirmed by dynamic ultrasonography. This evidence suggests that the acellular dermal template forms an intermediate space where the extensor and flexor tendons are able to slide. This finding was described by Carothers in an oncology case, in which the palm of a hand with nerve and flexor tendon exposure was treated with the acellular dermal regeneration template; they attributed the excellent sliding results obtained to the favourable immunologic response of host tissue to the bovine collagen and condroitin-6-sulphate[24]. Although it is true that at 12 months of follow-up, only 11.1% of patients had excellent results in the 2-PD test, and only 27.8% achieved complete recovery as determined through surface wound mapping (SWM), but surgeons should have expected this result, as no direct nerve repair had been performed, and the patients should have been informed before surgery.

However, the patients' high satisfaction level in our case series may be justified by the optimal functional results achieved (Table 2) and the possibility of a fast recovery time and a prompt return to work and one's normal daily activities.

The main advantage of using ADM is that this surgical approach can be performed in cases of trauma patients with life-threatening injuries, which preclude major surgery on the hand in emergency situations. Moreover, prolonged anaesthesia is not necessary, as both surgical procedures require only local anaesthesia, enabling all patients to undergo finger reconstruction, irrespective of old age and complex comorbidities. The cost of the ADM may represent a concern in defining the surgical treatment plan, but this cost may be offset by reduced operating room time and the avoidance of hospitalisation.

This study has some limitations, such as the lack a control group and limited sample size. Comparative prospective studies are needed to best evaluate the long-term benefits of ADM reconstruction for FDIs in terms of functional outcomes and cost-effectiveness. We did not take into consideration degloving injuries involving multiple fingers (DIMF), which should be addressed separately on account of the relatively large areas of injured skin.

Conclusions

ADMs should be viewed as a viable option for the treatment of FDIs. The surgical treatment of FDIs with ADMs is easy to perform, and when carefully performed, it ensures a satisfactory functional outcome and limited donor site morbidity compared with loco-regional or free flaps. This technique should be taken into consideration, especially when other surgical techniques cannot be used.

Acknowledgements

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Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjps.2019.05.029.

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