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ORIGINAL STUDY

Challenges of the induced-membrane technique in the reconstruction of traumatic tibial defect with limited resources : a cohort study

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This study sought foremost to evaluate the outcomes of applying the induced membrane technique (IMT) for tibia reconstruction within the context of a sub-Saharan Africa trauma center. Second, this study aimed to elucidate the conditions of IMT usage in a limited-resource setting.

A retrospective study was performed among patients treated via IMT for posttraumatic tibial bone defects who had follow-up data available for at least 12 months.

Eleven patients with a mean age of 36 years were included. All presented with an infected multi-tissue defect. The mean length of the tibia defect was 4.4 cm and the mean area of the soft-tissue loss was 32 cm^2. Pedicled flap coverage was required in all cases. At the mean follow-up time of 15 months bone union was achieved in nine of 11 cases, after additional inter-tibiofibular grafting was performed in four cases. Infection recurrence was noted in five of 11 cases. Most patients presented medium-quality soft-tissue coverage and suboptimal function.

IMT may represent a valuable option for tibia reconstruction with limited surgical resources in cases where appropriate infection control and stable soft-tissue coverage can be ensured.

Keywords : Africa ; induced membrane technique ; low resource ; Masquelet technique ; tibia.

INTRODUCTION

The induced membrane technique (IMT), introduced by A. C. Masquelet in 2000, is a well-accepted method for the reconstruction of segmental bone defects related to high-energy trauma, debridement of osteomyelitis, or tumor resection *(1-3)*. IMT is a two-stage procedure : in the first stage, a cement spacer is placed in the bone defect to preserve the reconstruction space and induce a surrounding membrane by way of prompting a foreign-body reaction. In the second stage, the cement spacer

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is removed and a cancellous bone graft is placed within the tube of the induced membrane, which will act as a biological chamber to revascularize the graft and prevent it from suffering resorption *(1,2)*. In comparison with techniques such as bone transport or vascularized transfer, IMT does not require any sophisticated equipment or microsurgical skills and offers a healing time independent from the defect length. Thus, IMT may offer a unique degree of utility in certain resource-scarce situations.

Despite a huge number of recent publications about IMT, few case series have reported on its use in low-resource settings *(4-8)* Posttraumatic bone defects are indeed frequently associated with soft-tissue injury and infection, whose management is particularly challenging, if not impossible, to conduct successfully using limited resources. However, IMT has been used previously for long bone reconstruction related to neglected fractures and Gustilo type IIIB injuries in austere environments *(7,9)*. In such a situation, tibia defects are the most difficult to manage considering the frequent need for flap coverage and the lack of plastic surgeons *(7)*.

In this study, we sought to evaluate the results of IMT for the management of tibial bone loss in a single Senegalese trauma center. We hypothesized that bone union and acceptable functional outcomes can be achieved with IMT despite the limitations inherent in this caregiving scenario. Our second objective was to define the conditions of use of IMT in limited-resource settings.

MATERIALS AND METHODS

A retrospective study was performed including all patients treated at the *Hôpital Principal de Dakar* (HPD) for bone defects using IMT between 2007 and 2012. Eligible individuals included adult patients (1) with posttraumatic bone defects of the tibia related to recent fractures or septic nonunions (2) and a minimum follow-up time of at least 12 months. Conversely, the following were excluded : (1) patients with tibial bone defects related to tumor or osteomyelitis, (2) patients with bone defects in locations other than the tibia, (3) cases involving an incomplete IMT procedure, or (4) cases with an insufficient length of follow-up. This study was approved by the local ethics committee.

Prior to beginning the IMT procedure, radical debridement was performed together with copious irrigation and definitive external fixation. All non-viable soft tissue and infected and necrotic bone were excised down to a healthy surface. Deep samples were taken from the bone defect area and the medullary canal for microbiological analysis. Mono- or multiplanar modular external fixators were adopted according to the size and location of the bone defect.

Stage 1 was initiated once all infected and devitalized tissue was discarded. When needed, flap reconstruction was performed simultaneously by the orthopedic surgeon using local pedicled flaps *(10)*. The bone defect was filled with a polymethyl methacrylate (PMMA) spacer without antibiotics as recommended by Masquelet *(2)*. Broad-spectrum empirical antibiotic therapy was administered after obtaining tissue samples at the time of debridement. All infected cases were treated with a course of antibiotics based on local microbiology tissue sensitivities and drug availability for a minimum period of six weeks.

Stage 2 was performed at least six weeks later in the absence of any clinical or biological signs of infection. The induced membrane was incised carefully, the PMMA spacer was removed by fragmentation, and the cavity was filled with cancellous bone autograft harvested from the iliac crests.

During the following months, patients were mobilized with toe-touch weight-bearing using crutches for eight to 12 weeks and thereafter progressed from partial to full weight-bearing. Once corticalization of the graft became visible on X-rays, the external fixator was dynamized gradually by progressive bar removal. The device was removed after complete healing of the graft and a functional brace with progressive weight-bearing was applied.

The following preoperative data were extracted from patient medicals records : demographics, injury mechanism, injury type (i.e., recent fracture or septic nonunion), and location. Septic nonunions were defined as open fractures lasting for more than three months with persistent bone exposure. Operative data included the time interval between

Table I. — Endpoint assessment based on the Hôpital Principal de Dakar classification

Soft-tissue quality	Type	Lower extremity function
Stable coverage with normal cutaneous trophicity. Flap raising risk-free	A	Walking without aids. Over and underlying joins without significant stiffness
Stable coverage with adhesion, fistula or edema. Flap raising at risk for necrosis	B	Walking using one crush or platform sole. Mild joint stiffness or lameness
Unstable coverage avec ulceration or severe lymphedema. Flap raising impossible	C	Walking using two crushes or long brace. Severe joint stiffness or amputation

Table II. — Patient characteristics and stage 1 parameters

Case	Age	Mechanism	Injury type	Tibial defect location	Defect length (cm)	Soft tissue loss area (cm²)	Injury-T1 time (days)	Flap coverage at T1
1	24	Crash	Gustilo IIIB	Distal third	2	30	23	Distal hemisoleus
2	40	Crash	Nonunion	Middle third	4	16	NA	Prox. saphenous
3	24	Crash	Gustilo IIIB	Middle third	6	72	16	Prox. soleus
4	28	Blast	Gustilo IIIB	Prox. third	4	44	32	MG + prox. saphenous
5	71	Crash	Gustilo IIIB	Distal third	4	14	34	Lateral supramalleolar
6	35	Crash	Gustilo IIIB	Distal third	3	6	50	Distal sural
7	44	Crash	Nonunion	Middle third	3	4	NA	Prox. saphenous
8	48	Crash	Gustilo IIIB	Tibial plateau	3	56	31	MG + prox. saphenous
9	22	Crash	Gustilo IIIB	Distal third	5	30	50	Lateral supramalleolar
10	22	Blast	Gustilo IIIB	Middle third	11	42	41	Prox. soleus
11	45	Crash	Nonunion	Distal third	3	36	NA	Distal saphenous

MD = medial gastrocnemius, NA = not appropriate, Prox. = proximal

injury and the first stage of treatment for recent fractures, length of the tibial bone defect and area of the soft-tissue defect after debridement, flap coverage, and time interval between the first and second stages of treatment. Surgical revisions, such as iterative flap coverage or additional bone healing procedures, were also analyzed. Endpoint assessment was based on the achievement of bone union, residual infection, soft-tissue coverage quality, and functional result. We defined bone union both clinically and radiographically. Clinical healing was defined as pain-free full weight-bearing. Radiographic healing was defined as the observation of bridging callus on three of the four cortices. Soft-tissue coverage quality and functional results were evaluated using the simplified HPD classification system suited for austere environments (Table I) *(7)*.

RESULTS

During the study period, 18 patients were treated using IMT for a long bone defect. Considering the established criteria, 11 patients (eight males and three females) presenting with posttraumatic tibia defects were included with a mean age of 36 years (range : 22-71 years). The mechanism of injury was a road traffic accident in nine cases and a gas explosion in two cases. There were eight Gustilo type IIIB open fractures and three septic nonunions. The bone defect mostly involved the diaphysis (Table II).

Table III. — Distribution of bacterial species

Bacterial species	No.
Gram positive cocci (n=2)	
Staphylococcus aureus	2
Gram negative rods (n=8)	
Pseudomonas aeruginosa	7
Acinetobacter baumannii	1
Enterobacteriaceae (n=5)	
Enterobacter cloacae	3
Escherichia coli	1
Proteus mirabilis	1

The mean time interval between trauma and stage 1 was 34 days (range : 16-50 days) in patients with recent fractures. All wounds were in-

Table IV. — Post-stage 1 parameters and endpoint assessment

Case	Revision after T1	T1-T2 time (weeks)	Revision after T2	Follow-up time (months)	Bone union	Septic recurrence	Soft tissue coverage	Function
1	Lateral supramalleolar flap	15	Tibial nailing	12	Yes	No	B	A
2	-	9	ITF grafting	18	Yes	No	A	B
3	-	8	ITF grafting	12	No	Yes	B	B
4	-	24	-	22	Yes	Yes	B	B
5	-	8	-	12	Yes	No	A	A
6	-	6	FDL flap	12	Yes	Yes	B	A
7	-	11	ITF grafting	12	No	Yes	B	B
8	-	6	-	19	Yes	No	A	C
9	-	11	-	18	Yes	No	B	B
10	Prox. Saphenous flap	16	ITF grafting	12	Yes	No	A	B
11	-	7	-	17	Yes	Yes	C	B

ITF = inter-tibiofibular, FDL = flexor digitorum longus, Prox. = proximal, VAC = vacuum assisted closure

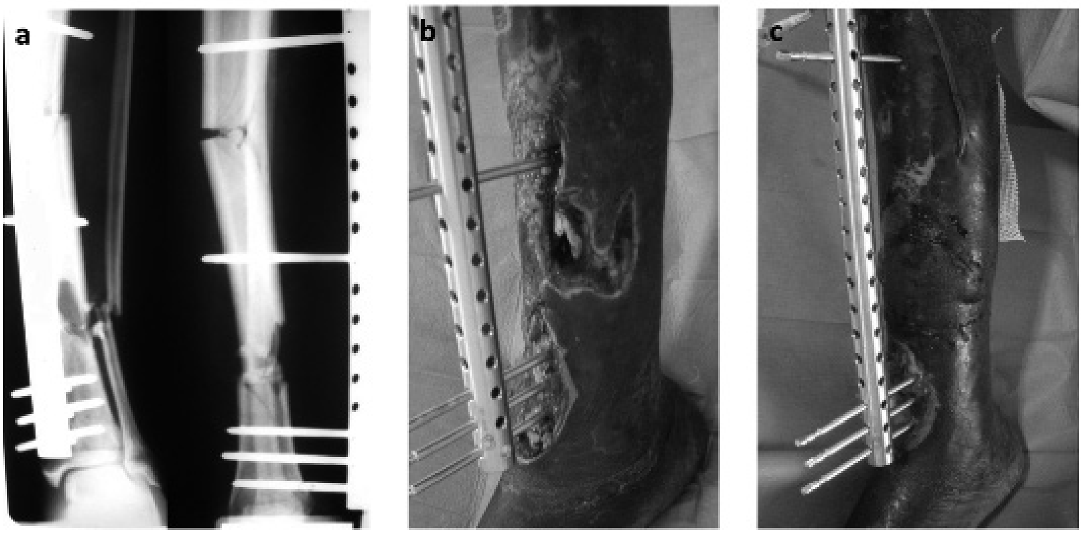

Fig. 1. — **a**, **b** Clinical and radiological aspects before IMT application (case 6). **c** Soft-tissue coverage achieved by distal sural flap placement during stage 1.

fected by nonresistant bacteria (Table III). After debridement, the mean length of the tibia defect was 4.4 cm (range : 2-11 cm) and the mean area of the soft-tissue loss was 32 cm^2 (range : 4-72 cm^2). Flap coverage was required in all cases. Since two patients with large defects were managed by combined flaps, 13 primary pedicle flap transfers were performed, including five muscle flaps and eight fasciocutaneous flaps (Fig. 1). Two cases of partial necrosis of the soleus flap required revision coverage using fasciocutaneous flaps with spacer exchange (Table IV).

The mean time interval between stages 1 and 2 was 11 weeks (range : 6-24 weeks). Marginal loss of the fasciocutaneous flaps occurred in three cases in the aftermath of stage 2. These complications were treated by homemade vacuum-assisted closure (cases 7 and 11) or revision muscle flap transfer (case 6, Fig. 2). Additional bone healing procedures were required in five patients : four were treated with inter-tibiofibular grafting and one underwent intramedullary nailing following external fixator removal (Table IV).

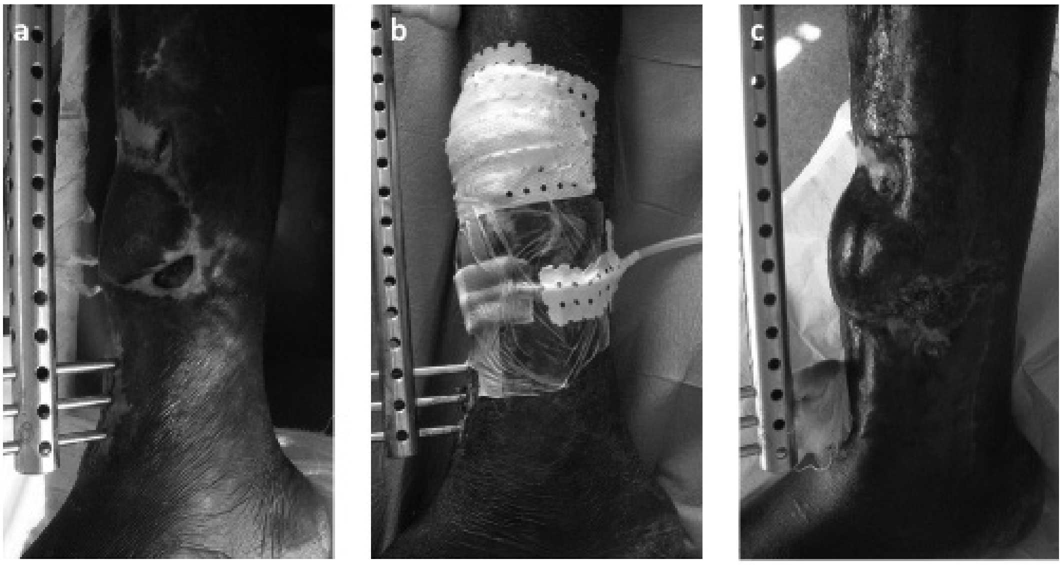

Fig. 2. — **a** Marginal loss of a fasciocutaneous flap with graft exposure in the aftermath of stage 2 (case 6). **b** Temporary coverage using homemade negative pressure wound therapy. **c** Revision coverage achieved by flexor digotorum longus muscle flap.

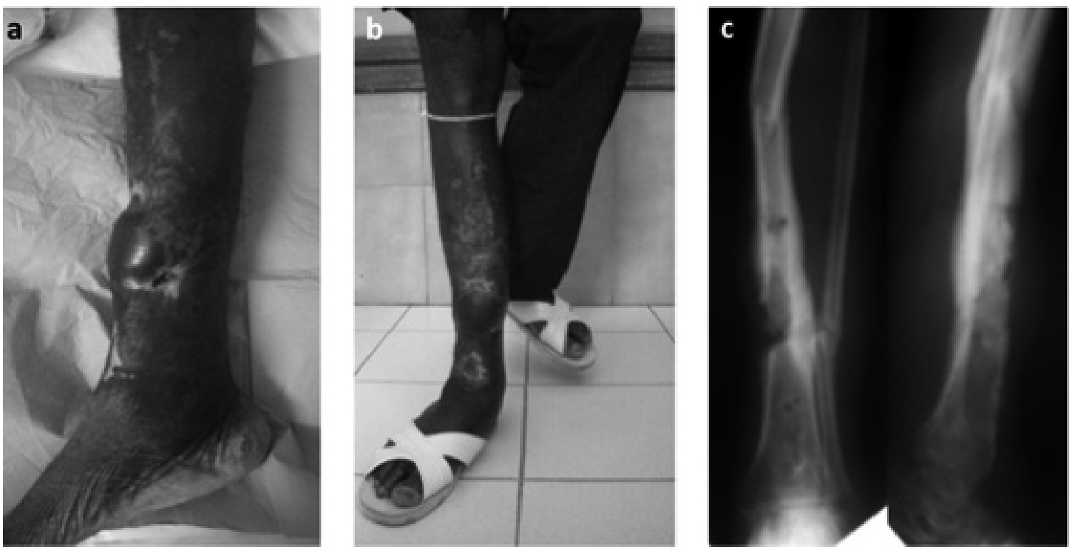

Fig. 3. — **a**, **b**, **c** Type B soft-tissue coverage, type A function, and radiological aspects of bone union present at the time of last follow-up (case 6).

Patients were reviewed at a mean follow-up time point of 15 months (range : 12-22 months). Bone union was achieved in nine of the 11 cases. There was no refracture. Two patients went on to develop nonunion but declined further intervention. Septic recurrence was observed along the reconstructed bone in five cases, including in the two patients with nonunion. Type B coverages and functions were predominant (Table IV). Type B coverages were related to simultaneous flap reconstructions, flap complications, or intermittent pus fistula (Fig. 3). Apart from nonunion, type B functions were mostly due to ankle stiffness or *equinus* deformity. Only one patient showed type C function after knee arthrodesis necessitated by the existence of a tibial plateau defect.

DISCUSSION

The present original study demonstrated that IMT enables the treatment of infected posttraumatic tibia defects in cases with limited surgical resources available. To our knowledge, this is the first series reporting on the use of IMT for long bone reconstruction in a referral African hospital. As compared with procedures involving other locations, tibial bone reconstruction poses specific challenges concerning the adequate achievement of soft-tissue coverage and infection control, which may appear impossible to overcome in precarious conditions *(11,12)*. However, despite the recurrence of infection in five of 11 cases in this study and the attainment of only modest functional outcomes, bone union was achieved in nine of the 11 cases by IMT combined with pedicle flap transfers performed by a single orthopedic surgeon (L. P.).

Fracture infection related to a mean time to flap coverage of 34 days was the major limitation inherent in our patients' management. There were several reasons for this delayed soft-tissue coverage, which is known to be a prognostic factor for open fractures *(13,14)*. First, some patients presented with already infected fractures after being transferred from rural areas or initially managed by traditional bonesetters *(9)*. In addition, following primary debridement, the overcrowding of the operating room due to daily trauma and visceral or obstetric emergencies made it difficult to achieve flap coverage in time. Repeated dressing exchanges were performed in the orthopedic ward, leading to secondary wound contamination. This explains the predominance of *Pseudomonas aeruginosa* over *Staphylococcus aureus* in bacteriological cultures *(15,16)*. Lastly, achieving appropriate antibiotic medication was sometimes challenging because of a limited availability of certain molecules and the existence of cost prohibitions for most patients *(7)*.

The achievement of flap coverage by the orthopedic surgeon alone is another feature of interest in this series. As is the case in most sub-Saharan Africa hospitals, there is no plastic surgeon in the HPD. Thus, only local fasciocutaneous flaps and muscle flaps were used in this series as these methods do not require meticulous pedicle dissection *(10)*. Though such basic flap transfers always permitted limb salvage in this context, we still faced frequent flap complications and obtained soft-tissue coverage only of moderate quality in most cases. Half of the complications recorded occurred in the aftermath of flap-raising during stage 2, indicating unstable soft-tissue reconstruction. Limited secondary exposure of the bone graft was treated successfully by vacuum-assisted closure without revision surgery. Such a treatment approach is comparable to the modified Papineau technique still employed today in small heath care centers of developing countries *(17,18)*. However, while homemade negative-pressure dressing permitted rapid wound healing, mixed results were obtained since some patients went on to develop nonunion or late infection recurrence.

Bone union was achieved in nine of 11 cases, but additional bone healing procedures were required in five of the 11 cases after IMT completion. Inter-tibiofibular grafting was preferred in cases of nonunion of the graft related to insufficient wrapping of the bone ends by the PMMA spacer or resulting from recurrent infection *(2)*. In such cases, we used a posterolateral approach to avoid iterative flap-raising and preserved the interosseous membrane to act as a barrier to the infection site. Moreover, from a mechanical point of view, Masquelet et al. *(1)* recommended systematically performing tibial reconstructions that press upon the fibula and while are reinforced by inter-tibiofibular grafts at both ends of the reconstruction. Contrary to Moris et al. *(12)* we avoided late intramedullary nailing, considering the high risk for infectious complications in our care setting. Lastly, definitive external fixation and poor access to rehabilitation centers explain why many patients returned to full weight-bearing late, which contributed to delayed bone graft healing and suboptimal function.

Taken together, these results illustrate the challenges of conducting posttraumatic tibia defect reconstruction using IMT with limited resources. However, in this context, we dealt with a very difficult group of patients (i.e., who combined bone loss with infection) who often reject the idea of amputation and, for whom, other modern reconstructive methods are unavailable or unsuitable. Vascularized bone transfers are not an option in the absence of plastic surgeons and microsurgeons. Bone transport can be used but requires specialized equipment and extended close monitoring, which are seldom accessible to the average population, especially those living in rural areas. The old Papineau technique remains an attractive alternative when flap surgery is not feasible, but the procedure is limited by delayed wound healing and postoperative scar formation *(17,18)*. Thus, if considering that IMT can be a valuable option in limited-resource settings, our study stresses that its success remains subject to two conditions : (1) an appropriate regimen for bone infection management requiring radical debridement, cultures, antibiograms, and an extended course of antibiotics and (2) the involvement basic soft-tissue coverage skills using simple, reliable and replicable pedicled flaps. We also recommend combining IMT with a systematic inter-tibiofibular grafting *(7,19)*.

This study has the same limitations shared by most of the series published to date about IMT, including a retrospective design, small study cohort, and the heterogeneity of injury subtype *(4,5,11,12,19)*. The HPD functional scale may also be questionable, but we found validated Western scales difficult to apply in this setting. Conversely, most of our patients were young adults with high-energy tibial open fractures who underwent multi-tissue reconstruction at a single African trauma center performed by a single surgeon. This has rarely been reported before. In addition, the major strength of this study is the mean follow-up of 15 months, considering that postoperative follow-up is a well-known obstacle to performing quality orthopedic research in developing countries *(20)*.

To conclude, regardless of the potential need for frequent revision procedures, IMT appears effective in treating infected posttraumatic tibia defects within the limited-resource setting of an African referral hospital. Achieving bone-infection control and stable soft-tissue reconstruction are the main challenges facing isolated orthopedic surgeons intending to use this technique.

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