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Original Article

Efficacy of Non-Vascularized Fibular Grafts in the Reconstruction of Large Long Bone Defects in the Paediatric Population

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Abstract

Background: Management of large long bone defects in the paediatric population remains a significant challenge in orthopaedic surgery. These defects often arise secondary to chronic osteomyelitis, high-energy open fractures, or resection of benign and malignant bone tumours. Various reconstructive strategies have been employed, including cancellous bone grafting, free vascularized fibular grafting (FVFG), and bone transport using external ring fixators. Although non-vascularized fibular grafts (NVFG) have demonstrated promising outcomes in adults, their utility in children is less clearly defined due to limited data on safety, efficacy, and long-term outcomes.

Objectives: This study aims to evaluate the clinical and radiological outcomes of non-vascularized autologous fibular grafts in the management of large long bone defects (> 4cm) in children, with specific focus on graft incorporation, time to union, preservation of the physis, and functional recovery.

Methods: An observational study was conducted on 20 children presenting with large long bone defects exceeding 4 cm. All patients underwent reconstruction using autologous non-vascularized fibular strut grafts. Grafts were fixed via internal fixation (plates or nails) or external fixation based on the bone affected, soft-tissue condition, and stability needs. Patients were followed for a minimum period of 6 months. Outcome measured included radiological union, graft resorption or remodeling, limb-length discrepancy (LLD), joint range of motion (ROM), and complications (graft fracture, non-union, physeal injury).

Results: Of the twenty children, radiographic union was achieved in 18 by a mean of 9.4 ± 2.1 weeks (range: 7–13 weeks). Two cases demonstrated delayed union; one of which required an additional surgical procedure (revision grafting and fixation) to achieve union. At final follow-up, most patients regained full joint function; minor complications included one graft fracture, one physeal separation, and one implant failure. All patients were ambulatory and pain-free, with no recurrence of infection or graft failure.

Conclusion: Non-vascularized fibular grafting, when employed in conjunction with rigorous infection control and suitable fixation, is a safe, effective, and technically feasible reconstructive option for large bone defects in children. There is relatively rapid incorporation of the graft with high union rates and low donor-site morbidity. Special caution is needed in larger defects and some cases may require revision.

Keywords: Non-vascularised fibular graft, Paediatric gap non-union

Introduction

Large defects of long bones represent one of the most challenging issues in paediatric orthopaedic practice. These defects result from various pathologies such as osteomyelitis, open fractures, or tumor resections. They pose different challenges

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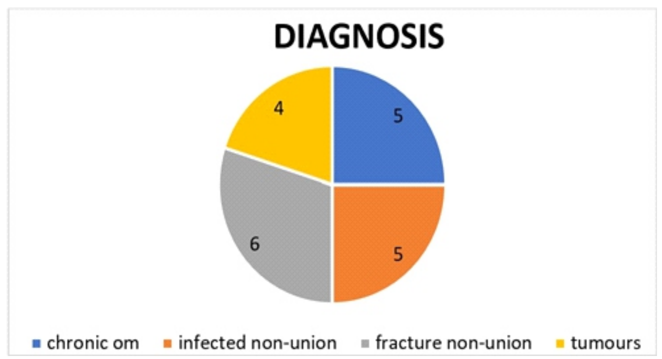

Figure 1: Etiologies for infected gap non-union in our case series

based on the primary pathology like persistent infection or altered local anatomy and their treatment should address these challenges. Various surgical options are available for treatment of these bone defects, including cancellous bone grafting, free vascularized fibular grafting (FVFG), and bone transport using an external ring fixator [1].

Non-vascularized fibular grafts were first introduced in the early 20th century and remained the gold standard for biological reconstruction for over six decades. In comparison to vascularized autografts, non-vascularized fibular grafts offer several advantages, including the potential for donor site remodeling, a technically less demanding procedure, and shorter operative time [2].

Autologous fibular grafts offer both biological and mechanical benefits. Biologically, they possess osteoconductive properties and the capacity for remodeling via creeping substitution. Mechanically, they offer significant structural support and contribute to load-sharing at the reconstruction site. Moreover, it is well-documented that preserving the periosteal sleeve during graft harvest promotes early regeneration of the donor site, thereby reducing the risk of complications [3].

In this study, we aim to evaluate the role and outcomes of non-vascularized fibular grafts in the management of paediatric long bone defects. By reviewing existing literature and assessing clinical outcomes, we seek to determine the effectiveness, potential complications, and limitations of this technique in children.

Materials and Methods

This observational study was performed in the Department of Paediatric Orthopaedics at a paediatric tertiary care hospital. Ethical approval was obtained from the Institutional Ethics Committee, and all procedures adhered strictly to institutional protocols governing human research.

Children aged between 2 to 16 years who presented with gap non-unions measuring 5cm and more, secondary to trauma, chronic osteomyelitis, or tumour resection were included in the study. Informed consent was obtained from parents or legal guardians before enrolment.

In cases of osteomyelitis, the eradication of local infection was prioritized. They underwent aggressive debridement and sequestrectomy where needed. Following resolution of infection in terms of clinical healing, normalization of the soft-tissue envelope, and normal inflammatory markers; fibular grafting was performed. Some of these children underwent Masquelet technique which helped in maintaining the length and in local antibiotic delivery. The mean time from debridement to grafting in our series was approximately six months, which aligns with the studies conducted by Loro et al. [4].

In case of tumours, grafting was scheduled after completion of adjuvant chemotherapy and when the patient was in remission. In our cohort, this corresponded to a mean interval of 3 – 4 months post–chemotherapy. This interval was chosen based on the studies conducted by Sheridan et al. [5].

To ensure the validity and safety of our cohort, we excluded patients presenting with florid infection at the time of surgery and those with underlying pathological bone disorders such as osteogenesis imperfecta, pseudarthrosis or metabolic disorders.

Graft Harvesting and Surgical Technique

Non-vascularized fibular grafts (NVFG) were harvested through a minimally invasive, periosteum-sparing technique from either the ipsilateral or contralateral fibula. Contralateral fibular graft was preferred, in view of anticipated complications in ipsilateral grafting, such as instability, lack of regenerate and the influence of local pathology. The graft was deliberately sized to exceed the defect by approximately 1 cm, ensuring adequate overlap and stability. After measuring the required graft length, the periosteum was meticulously elevated circumferentially using a periosteal elevator, preserving tissue continuity particularly along the interosseous border, thereby preserving the periosteum at the donor site. Distal fibular segments close to the ankle and proximal segments near the fibular head were preserved to maintain ankle stability and

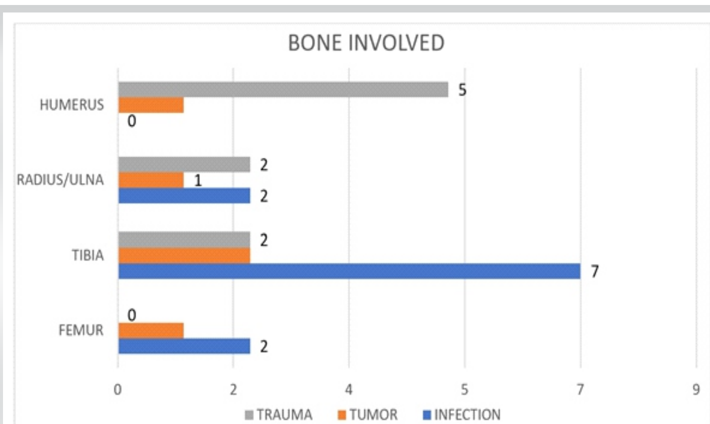

Figure 2: Bone involvement in our series

protect the peroneal nerve. Although 6 cm from both the fibular head and the ankle joint is generally accepted in adults [6], this metric is not directly applicable to children due to significant age-related anatomical variability. Accordingly, in this study the harvest distance was not standardized but tailored to each child's specific anatomy. Once the periosteum was fully elevated, the graft was gently freed and delivered, taking care to maintain periosteal integrity at the donor site to promote fibular regeneration. The graft was then inserted into the recipient site and secured with appropriate internal or external fixation.

Post-operative care & follow-up

The limb was immobilized in a plaster slab, followed by serial wound care and suture removal. Regular follow-ups were conducted at 2 weeks, 4 weeks, and monthly until radiological confirmation of union. Following radiological union, the slab was removed and the patient was started on gentle range-of-motion exercises. At each visit pain assessment, range of motion (ROM) of adjacent joints, limb length discrepancy, presence of deformity, and integrity of the overlying skin were checked. Minimum follow-up of 12 months was ensured.

Results

A total of 20 children (11 males, 9 females) were reviewed (Table 1), with ages ranging from 2 to 16 years (mean±SD: 6.9±3.2 years). The diagnoses included infected gap non-union (n=5), chronic osteomyelitis (n=5), benign tumours (n=3), Malignant tumours (n=2) and fracture non-unions (n=5) (Fig. 1).

The mean defect length was 6.64 cm (range: 5 – 13 cm). Affected bones mainly included the tibia (n=10) and femur (n=3) (Fig. 2).

Radiographic union was achieved in all patients, with bridging callus formation and blunting at the proximal and distal graft–host junctions by 8.8±1.3 weeks (range: 7–12 weeks) (Fig. 3). In the two patients with malignant tumours, union was delayed but ultimately achieved by 4 months.

Seventeen out of 20 patients demonstrated full joint ROM post-union. Three patients exhibited stiffness, which included a case of tibia adamantinoma, osteosarcoma of the proximal tibia and a proximal humeral cyst. Remodeling of the fibular graft to match the parent bone was noted in 16 cases.

Among 20 patients with available measurements, LLD ranged from 1.0 to 3.6 cm (mean±SD: 2.3±0.7 cm). (Fig. 4)

Complications noted include, fracture at graft site occurred with proximal tibial plating following minimal trauma. Another child had physeal separation at proximal graft end. In this case the graft was taken from ipsilateral fibula, which led to instability at the proximal tibia which further lead to physeal separation. One of the patients who underwent fixation of the fibular strut graft by screw fixation had implant failure and revision surgery was done with ex-fix application.

Discussion

A gap non-union is characterized by a persistent inter-fragmentary bone defect (typically ≥3 mm), where healing is impaired due to inadequate mechanical contact and disruption of biological continuity, often leading to atrophic ends or pseudarthrosis [7].

Gap non-union represents a failure of the "diamond concept" of bone healing [21], where all necessary components —mechanical stability, osteogenic cells, scaffold, growth factors—must be in place. Any deficit in these areas disrupts

Figure 3: (a) Clinical photograph demonstrating extrusion of the sequestrum through the skin;
(b) Pre-operative radiograph showing a segmental defect with gap non-union;
(c) Intra-operative images from the first stage procedure following thorough debridement and placement of an antibiotic-impregnated cement spacer;
(d) Immediate post-operative radiograph confirming appropriate position of the cement spacer;
(e) Second-stage reconstruction with a non-vascularized fibular graft stabilized using a long reconstruction plate;
(f) Final follow-up radiograph demonstrating satisfactory incorporation of the graft and progression towards union.

the healing cascade:

· Mechanical strain above ~10% impairs blood vessel formation, preventing callus even when biology is intact [8].

· Biological impairment (e.g., low vascularity, comorbid conditions) inhibits bone formation at the fracture gap, resulting in atrophic non-union [9].

· Infection can lead to altered biomechanics and local destruction which interplay to perpetuate the non-union

Nutritional deficits play a role in non-union particularly those affecting calcium balance and vitamin D metabolism, further compromising osteogenesis. Additionally, several pharmacologic agents known to interfere with bone metabolism—such as corticosteroids, diuretics, antiepileptics, opioids, and anticoagulants—have been associated with an elevated risk of non-union [10].

All patients in our series were evaluated preoperatively for nutritional deficiencies (including vitamin D and calcium levels) and treated appropriately before undertaking the reconstructive surgery. Thus, any potential compromise in bone metabolism due to malnutrition was addressed, reducing the risk of impaired fracture healing.

Children possess a richly-vascular periosteum and active growth plates, which significantly enhance bone healing through robust callus formation and remodeling capacity. However, when non-union or bone loss occurs—particularly involving the physis—these same growth mechanisms can paradoxically result in long-term deformity. Damage to the growth plate may disrupt longitudinal bone growth, leading to limb length discrepancies (LLD) and angular deformities [11].

Our study was undertaken to assess the effectiveness of non-vascularized fibular grafts as a reliable method for reconstructing large long bone defects in children, regardless of the underlying etiology.

In the study conducted by Komalporn et al., segmental long bone defects secondary to open fractures and infected non-unions around the elbow were evaluated and treated with open reduction internal fixation with fibular graft and plate or external fixation (ex-fix). In contrast, Lenze et al. limited their investigation to osseous neoplasms involving the metaphyseal and diaphyseal regions of long bones, which were treated in with open reduction internal fixation with plate/ex-fix. Our study, however, incorporates a more comprehensive range of etiologies leading to non-union, including post-traumatic, infectious, and neoplastic causes, with all major long bones considered in the analysis [1,2].

In our cohort, the predominant indication for surgical intervention was chronic osteomyelitis and infected non-unions, accounting for 65% of cases. This is in concordance with existing literature from developing regions, where infection remains a leading cause of paediatric bone loss. A two-stage management protocol was employed: Masquelet technique, beginning with aggressive debridement and insertion of an antibiotic-loaded cement spacer to control infection, followed by delayed definitive reconstruction using bone grafting techniques. Our methods were similar to the study conducted by Tarng et al, where 27 cases of mixed adults and adolescents with chronic osteomyelitis were managed by a two-stage process of debridement first followed by definitive fixation [12].

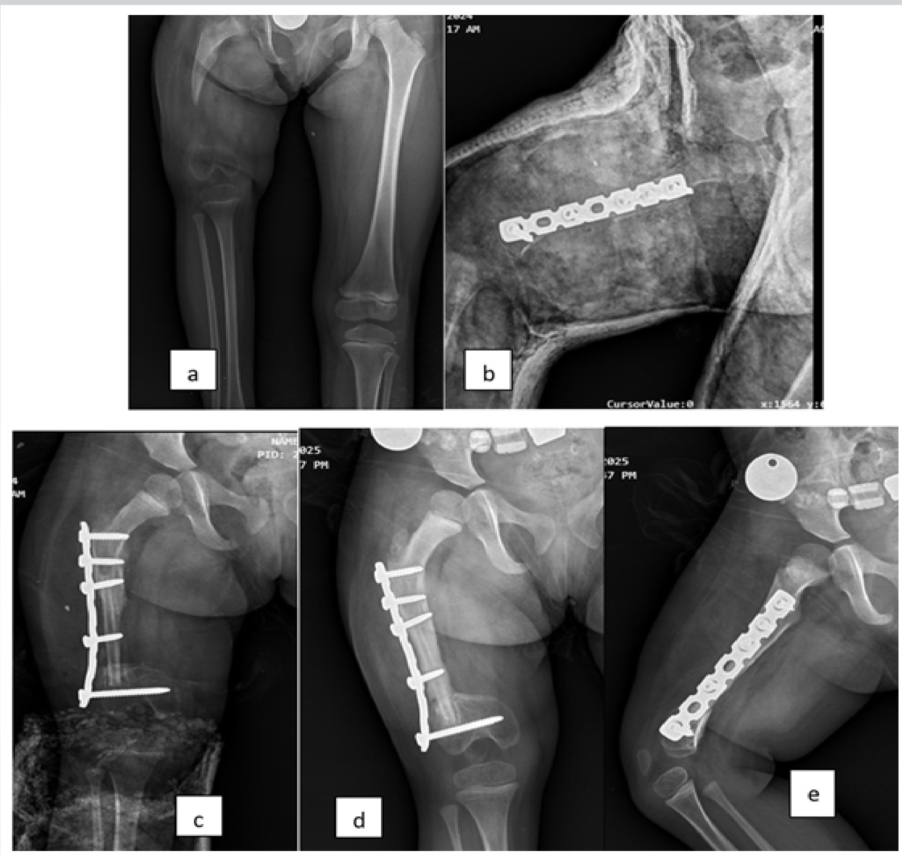

Figure 4: A 6-year-old female with a right femur gap non-union:
(a) Pre-operative radiograph demonstrating a segmental defect with a blunted proximal femur and isolated distal condylar segment, consistent with gap non-union;
(b) Immediate post-operative radiograph following thorough debridement and reconstruction using an 8 cm non-vascularised fibular graft with stable internal fixation;
(c) Four-week follow-up radiograph showing early callus formation at the proximal interface with satisfactory implant position and stability; and
(d–e) Three-month post-operative anteroposterior and lateral radiographs demonstrating good graft incorporation, consolidation, and remodelling of the graft to resemble native femoral bone with proximal and distal graft uptake.

Sl.No	SEX	AGE	DIAGNOSIS	AFFECTED BONE	LENGTH OF DEFECT [In cm]	FIXATION METHOD	TIME TO UNION [In weeks]	COMPLICATION	LIMB LENGTH DISCREPENCY [in cm]
1	F	14	DIAPHYSEAL ADAMANTINOMA	RIGHT TIBIA	6	ILLIZAROV	12	STIFFNESS+	3
2	F	9	INFECTED GAP NON-UNION	RIGHT DISTAL RADIUS	5	Plating	8	-	-
3	M	5	INFECTED GAP NON-UNION	LEFT FEMUR	5	Rush nail	7	-	2.5
4	F	1.6	INFECTED GAP NON-UNION	LEFT TIBIA	8	-	8+	Physeal separation	1.5
5	M	8	CHRONIC OSTEOMYELITIS	RIGHT TIBIA	7	Plating	8	-	1
6	M	10	CHRONIC OSTEOMYELITIS	LEFT TIBIA	9	Plating	10	Fracture of graft	2.1
7	F	2	CHRONIC OSTEOMYELITIS	RIGHT TIBIA	5	Screws followed by Ex fix	9	Implant Failure	1.7
8	M	2.1	CHRONIC OSTEOMYELITIS	RIGHT TIBIA	6.2	LRS	9	-	2.7
9	F	4	INFECTED GAP NON-UNION	RIGHT FEMUR	7.4	Plating	7	-	3
10	F	3	CHRONIC OSTEOMYELITIS	RIGHT TIBIA	7.5	Plating	10	-	1.6
11	M	8	OSTEOSARCOMA	RIGHT PROXIMAL TIBIA	8.1	Plating	12	JOINT STIFFNESS	3.6
12	F	11	ANEURSYMAL BONE CYST	RIGHT PROXIMAL HUMERUS	6.3	Plating	8	JOINT STIFFNESS	-
13	M	10	NEGLECTED MONTEGGIA	RIGHT	5.4	Plating	7		-
14	M	8	SIMPLE BONE CYST	LEFT PROXIMAL FEMUR	5.2	Plating	9		2.4
15	F	6	NEGLECTED MONTEGGIA	RIGHT FOREARM	5.5	Plating	8		-
16	M	8	ANGIOMATOSIS	RIGHT RADIUS	5.2	Plating	13	STIFFNESS	-
17	M	13	NEGLECTED MONTEGGIA	LEFT	7.4	Plating	7		-
18	F	9	INFECTED NON-UNION	RIGHT DISTAL FEMUR	6.3	Plating	9		2.9
19	M	8	FRACTURE NON-UNION	RIGHT TIBIA	8.2	Plating	8		3
20	M	10	FRACTURE NON-UNION	LEFT TIBIA	9.2	Plating	11		1.8

Table 1: Patient Demographics, Defect Characteristics, and Treatment Outcomes

While some authors perform bone grafting as early as 6 – 8 weeks post-debridement once soft tissue and local environment appear favorable, we adopted a more conservative approach and waited for a 6-month interval to ensure stable soft tissues and infection-free status before grafting. We acknowledge that this longer interval may not be standard. A recent retrospective series in children reported a mean interval of 12 weeks (range 2–34 weeks) between debridement and autograft insertion [13].

There were no cases of infection recurrence during the follow-up period. These findings reinforce established treatment algorithms that emphasize complete eradication of infection as a prerequisite for successful osseous reconstruction.

Our cohort utilized different fixation strategies (internal fixation with plates or nails; external fixator) depending on bone involved, soft-tissue condition, defect location, and anticipated load-bearing. Plate or intramedullary fixation was chosen for bones where soft tissue was adequate and internal support feasible; external fixation was reserved where soft-tissue compromise, risk of infection, or poor skin condition precluded plating — similar to recommendations in paediatric osteomyelitis reconstruction by Loro et al. For example, in the collective experience of post-osteomyelitis bone defects in children, external fixation alone (without plating) was used successfully in some cases, highlighting that rigid internal fixation is not always mandatory.4 The choice of fixation therefore reflects a tailored approach rather than a one-size-fits-all method.

The favorable outcomes observed in our cohort, with radiographic union achieved in all patients, emphasize the effectiveness of non-vascularized fibular grafts in managing paediatric gap non-unions.

Although vascularized fibular grafts are often regarded as the gold standard for reconstruction of large bone defects—particularly in adults—our findings support the use of non-vascularized grafts in the paediatric population, owing to their robust healing capacity and the biological activity of the periosteum. Bridging callus formation and remodeling at the graft–host junction was typically observed within 8 to 10 weeks, which is approximately 2 to 3 weeks earlier than the union times reported by Patwardhan et al. [13].

Our study achieved 100% union by approximately 8 – 9 weeks except in malignancy, matching the results of Kaewpornsawan 1 (around 9 weeks) and outperforming Thakkar (80%)14 and Tarng (93%)12.

Smaller defects (<7 cm) in our series and that of Tarng et al had excellent outcomes, while the larger defects (≥9 cm in Kaewpornsawan; ≥12 cm in Lenze) remain manageable but held a higher risk of mechanical issues. We noticed a fracture in a patient with a graft size longer than 9 cm despite fixation with internal fixation.

Although union was delayed in cases involving malignant lesions, this is likely attributable to the effects of chemotherapy on bone metabolism and healing. Notably, no instances of tumour recurrence, infection or persistent non-union were observed, in contrast to the findings reported by Lenze et al. [2]

Donor site morbidity was minimal. None of the patients reported pain or functional impairment at the donor site, and there were no fractures of the donor fibula. These findings reinforce existing literature suggesting that careful harvest while preserving the periosteum allows for fibular regeneration and minimizes complications.

Table 2: Comparison of Clinical Outcomes Across Published Studies

STUDY	SAMPLE SIZE	MEAN DEFECT SIZE	INDICATIONS	MODE OF FIXATION	UNION RATE	TIME TO UNION	COMPLICATIONS	DONOR OUTCOMES
OUR STUDY	20	7.3cm	osteomyelitis (10), malignant (2), benign tumours (3), non-union fractures (4).	ORIF/EX-FIX	90%	8 weeks	Graft fracture, implant failure	excellent
Kaewpornsawan & Eamsobhana (2017)	9	9.3cm	infected non-union	ORIF /ex-fix	100%	9 weeks	Graft hypertrophy	excellent
Lenze et al. (2017)	36	12cm	tumour resection	plate fixation	94%	23 weeks	graft fracture, recurrence	good
Thakkar & Sangada (2018)	20	8cm	infected non-union, fracture non-union	ORIF/ ex-fix	80%		Stress fracture, superficial infection, nonunions	excellent
Tarng & Lin (2019 Injury)	27	6cm	infected non-union	ORIF/ex-fix	92.60%		non-union, graft hypertrophy	good
Patwardhan et al. 2013	26	6cm	infected non-union	ORIF/ex-fix		>6 weeks,51 ± 6.7	delayed unions, infection, LLD	excellent

ORIF – Open reduction and internal fixation.

A limb length discrepancy of mean±SD: 2.3±0.7 cm was observed in the lower limbs of our patients, consistent with the findings reported by Patwardhan et al., who documented limb length discrepancies ranging from 2 to 4 cm in all patients with lower limb involvement. These discrepancies were managed conservatively with shoe lifts and close observation, without the need for further surgical intervention [13].

The limitations of our study include a relatively small sample size and the absence of a control group using alternative reconstruction methods. Additionally, while functional outcomes were favorable, objective measures such as validated pediatric functional scores were not employed. Longer follow-up will be necessary to assess potential long-term effects of fibular harvest on limb alignment, growth, and joint function.

Conclusion

Non-vascularized fibular strut grafting is a safe and effective technique for the reconstruction of pediatric gap non-unions involving significant bone loss. It offers excellent rates of union with low donor site morbidity and acceptable functional outcomes, making it a valuable option in resource-limited settings where microsurgical capabilities for FVFG may be restricted.

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Declaration of patient consent : The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given the consent for his/ her images and other clinical information to be reported in the journal. The patient understands that his/ her names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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