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The regeneration at non vascularized fibular harvest site and development of ankle valgus in donor leg-investigations done over two time points

Anil Agarwal*

Specialist, Department of Paediatric Orthopaedics, Chacha Nehru Bal Chikitsalaya, Geeta Colony, 110031, Delhi, India

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ABSTRACT

Introduction: We retrospectively observed the fibular regeneration in non vascularized harvest in children and development of ankle valgus at 2 time points to find any possible relationship between them.
Material and methods: A 6 month period was chosen as the first time frame to assess regeneration and ankle valgus. Radiographs at this time and a subsequent follow up were studied for regeneration, lateral distal tibial ankle (LDTA) and fibular station. The donor sites were divided into complete and incomplete regeneration groups and compared statistically.
Results: There were 12 patients with 18 harvested fibulae. Ten out of 18 fibulae (56%) had complete longitudinal regenerate at 6 months. Two fibulae underwent delayed union. Of 8 incomplete regenerates at 6 months, 6 (75%) were also incomplete beyond a follow up of 2.75 years. Incomplete group had radiological ankle valgus in 6 legs (75%) at 6 months increased to 7 at follow up. Further, LDTA for incomplete group was significantly lower than complete group ($p = 0.025$) at 6 months.
Conclusions: More than half of harvested legs (56%) had complete longitudinal fibular regeneration at 6 months. Of incomplete regenerates at 6 months, three fourth remained so beyond 2.5 years. Ankle valgus was found strongly related to long standing fibular non regeneration. Radiological ankle valgus developed early in the incomplete regenerate group.

1. Introduction

Both vascularized and non vascularized fibular harvesting are established procedures in pediatric orthopedics. In regions where microvascular surgical expertise and infrastructure is limited, non vascularized fibula is commonly utilized.[1] An added advantage of non vascularized fibular harvest is it's regeneration potential. Therefore lesser donor site complications are related to this technique.[1–4] Although many series have indicated the approximate regeneration time for the harvested fibula (approximately 5–16 months), there is no dedicated research on the above aspect.[2–4] Of the various complications associated with fibular harvest procedure, development of ankle valgus in the donor leg is the most feared one and is more commonly seen following gaps in fibular regeneration.[5,6] Yet the timing of development of ankle valgus in non vascularized fibular harvest and its relationship to incomplete fibular regenerate has never been elicited in detail.[6]

The timing of fibular regeneration and development of ankle valgus following harvest, if any, is therefore a matter of much interest. This determination makes sense since this can guide to appropriate early interventions for an impending ankle deformity. It is also important to prognosticate patients regarding outcomes at the donor site and safety of this procedure. Sometimes, the limited number of autogenous bone graft sites in the pediatric age group may compel a repeat fibular harvest which also necessitate knowledge of fibular regeneration.[3] We therefore took up this evaluation to observe the longitudinal fibular regeneration at two time points of 6 months and an available further follow up. The study also investigated development of ankle valgus in donor legs at above periods, if any, and its relationship with incomplete fibular regenerate.

2. Material and methods

The retrospective study was conducted at a pediatric health care

* Corresponding author. 4/103, East End Apartments, MayurVihar Ph-1 Ext., 110096, Delhi, India.
E-mail address: anilrachna@gmail.com.

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centre located in suburb of a low income country. Patient's case records (2001–2017), who underwent an autogenous full length diaphyseal (sparing approximately 10% of total length at either ends) non vascularized fibular harvest (unilateral or bilateral), were examined. Additional prerequisite for the study was availability of a standardized standing donor lower limb radiograph at 6 months. These patients were called for a follow up to obtain a similar recent x-ray. We excluded patients with neuromuscular or bony pathology in the donor leg. Also excluded were smaller sized fibular harvests or osteoarticular grafts. Patient's and parent's consent was obtained for the publication of results.

Our methodology included observation of longitudinal fibular regenerate and radiological ankle valgus and comparing these parameters at two time points of 6 months and the recent available follow up.

The selection of an initial time point of 6 months for evaluation of regenerated fibula was based on our previous experience (discussed later).[4] The fibular harvest sites were classified into two groups - complete or incomplete longitudinal regenerate and statistically compared. The radiological evaluations were based on the standardized anteroposterior standing x-rays. The radiological ankle valgus was quantified using *lateral distal tibial angle* (LDTA, the angle between the tibial mechanical axis and the distal tibial joint surface; normal range, 84–92°) and *fibular station* (Malhotra grade 0: fibular growth plate at the level of the talar plateau, Grade 1: fibular growth plate between the top of the talus and the distal tibial growth plate, Grade 2: fibular growth plate in line with the distal tibial growth plate, Grade 3: severe migration with fibular growth plate proximal to the distal tibial growth plate).[7,8] We had previously documented fibular station of 1 as a normal finding in children.[7] The radiological ankle valgus was therefore quantified as either LDTA< 84° or fibular station >1 or presence of both for the purpose of this study.

The statistical evaluation was done using the online software www.socscistatistics.com. Student *t*-test was used to compare parametric data (age, follow up, LDTA). Mann-Whitney *U* Test was used for non parametric Malhotra grades. A p value of <0.05 was taken as significant.

3. Results

There were 12 patients with 18 harvested fibulae (6 bilateral) satisfying the inclusion criteria (Table 1). Total follow up available was 2.76 ± 1.98 years. There was no statistical difference in the patient's age (5.80 ± 2.18 versus 5.59 ± 2.87 years; p = 0.864) or duration of follow up (2.95 ± 2.10 versus 2.53 ± 1.93 years; p = 0.668) in complete or incomplete regenerates (Table 2).

3.1. Regenerate at 6 months and follow up (Figs. 1–3)

Ten out of 18 fibulae (56%) had complete longitudinal regenerate at 6 months. Two fibulae had delayed regeneration at 3 and 1.5 years (patient 7 and 9) making an overall of 12 complete regenerates (66%) at final follow up. The regenerated fibulae were however irregular and nonuniform (incomplete remodeling). Of 8 incomplete regenerates at 6 months, 6 (75%) were also incomplete beyond 2.75 years..

3.2. Ankle valgus in the harvested legs (Figs. 1–3)

At 6 months, LDTA was <84° in one (patient 12) and fibular station >1 in 2 legs (patient 5 and 7) in the complete group (n = 10) at 6 months. At follow up, LDTA <84° was observed in 1 (patient 4) leg only. Thus, just 3 legs at 6 months and 1 leg at recent follow up had radiological ankle valgus in the complete group. At 6 months in the incomplete group (n = 8), LDTA was <84° in 2, fibular station >1 in 2 and both were abnormal in 2 more legs. At the later follow up, LDTA was <84° in 3, fibular station >1 in 2 and both were abnormal in 2 more legs. Going by radiological criteria, incomplete group had ankle valgus in 6 legs (75%) at 6 months and 7 at the recent follow up. The odds ratio for development of radiological ankle valgus in incomplete compared to complete group at 6 months was 7 (95% CI − 0.86 to 56.84; p = 0.0687) but increased to 63 (95% CI − 3.32 to 1194.79; p = 0.0058) at final follow up. Two legs in the incomplete group had both normal LDTA and fibular station at 6 months (patient 8 and 12), but these parameters deteriorated in follow up. Contrarily, in two legs where the regeneration was delayed (patient 7 and 9), LDTA improved upon union. In one leg (patient 7), even the fibular station improved.

3.3. Other observations

The mean LDTA in the incomplete group at 6 months was significantly less than the complete group (p = 0.025) (Table 2). Intragroup LDTA comparison in the complete group at 6 months and recent follow up was non significant (86.90 ± 2.02 versus

Table 1
Patient data showing the regeneration status and radiological ankle valgus at 6 months and subsequent follow up.

S.no.	Age at surgery (years)	Follow up (years)	Side	Bilateral	Incomplete longitudinal regenerate, if any, at 6 months		Incomplete longitudinal regenerate, if any, at subsequent follow up		LDTA at 6 months		LDTA at subsequent follow up		Fibular station at 6 months		Fibular station at subsequent follow up	
					Right	Left	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
1.	3.5	6.5	Left	-	-	Yes	-	Yes	-	70	-	70	-	3	-	3
2.	7	6	Right	-	No	-	No	-	87	-	88	-	1	-	0	-
3.	10	5	Right	-	No	-	No	-	87	-	85	-	0	-	0	-
4.	4.25	5.75	Right	-	No	-	No	-	87	-	80	-	0	-	0	-
5.	3.25	1.75	-	Yes	Yes	No	Yes	No	87	88	85	84	2	2	2	1
6.	6	0.5	-	Yes	Yes	No	Yes	No	82	87	82	87	1	0	1	0
7.	3	3	-	Yes	Yes	No	No	No	83	90	85	85	2	2	1	1
8.	11.5	1.5	Right	-	Yes	-	Yes	-	84	-	73	-	1	-	1	-
9.	6	1.5	Left	-	-	Yes	-	No	-	84	-	90	-	2	-	2
10.	7.5	1.5	-	Yes	No	Yes	No	Yes	84	82	85	82	0	1	0	1
11.	6.5	1	-	Yes	No	No	No	No	88	88	86	86	1	1	1	1
12.	4	4	-	Yes	No	Yes	No	Yes	83	87	84	82	1	1	1	2

Abbreviations: LDTA-lateral distal tibial angle.

Table 2
Complete and incomplete regenerate group comparisons.

Characteristics	Complete (n = 10)	Incomplete (n = 8)	P value[a]
Patient's age at index procedure (years)	5.8 ± 2.18	5.59 ± 2.87	0.864
Follow up (years)	2.95 ± 2.10	2.53 ± 1.93	0.668
LDTA at 6 months (degrees)	86.90 ± 2.02	82.38 ± 5.37	**0.025**
LDTA at subsequent follow up (degrees)	85 ± 2.16	81.13 ± 6.56	0.096

[a] Unpaired *t*-test.

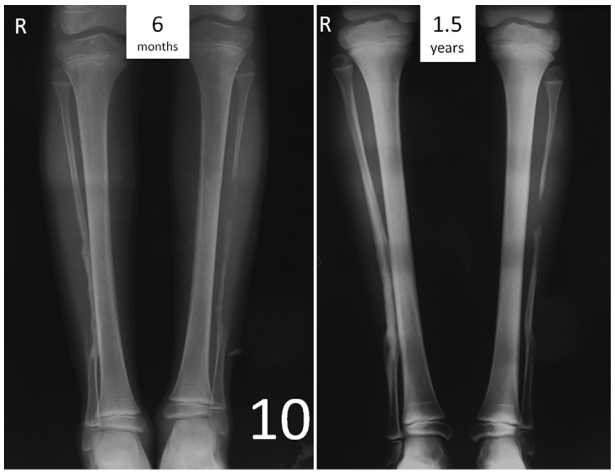

Fig. 1. The harvested fibula can longitudinally regenerate within a 6 months period as illustrated in this bilateral case (patient 10). The right side was a complete regenerate at 6 months (LDTA = 84 and fibular station 0). There was no ankle valgus on this side. Ankle valgus (LDTA <84 and fibular station 1), however, developed at the same time point on the contralateral left side with incomplete regenerate. It persisted at a follow up of 1.5 years, when fibular continuity was still not restored.

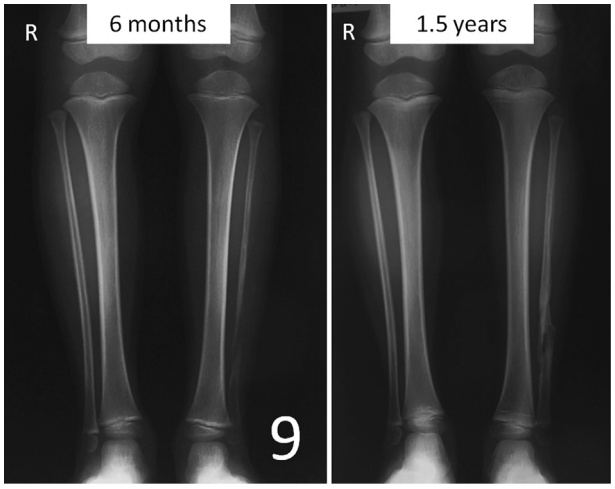

Fig. 2. The dynamic relationship between the fibular gap and radiological ankle valgus illustrated in a unilateral case with delayed union occurring at 1.5 years (patient 9). The harvested left side had incomplete regeneration at 6 months. The radiological ankle valgus improved following restoration of fibular continuity and LDTA improved from 84 to 90°. Fibular station recovery however was delayed. Note that a fibular station of 1 is sometimes a normal radiological finding as obvious on the non intervened right side.

85.00 ± 2.16°; p = 0.058). For incomplete group too, comparison at 6 months and recent follow up, the LDTA did not change significantly (82.38 ± 5.37 versus 81.13 ± 6.56°; p = 0.50).

The fibular stations were not different for complete and incomplete group at 6 months (p = 0.068) but became significantly

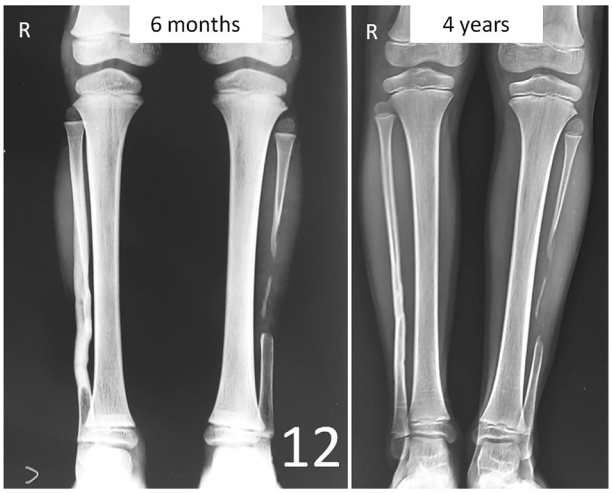

Fig. 3. The dynamic relationship between fibular gap and radiological ankle valgus further illustrated in a case with bilateral harvest (patient 12). The right side had regenerated at 6 months and did not have any ankle valgus. Contrarily, the contralateral left incomplete regeneration had developed ankle valgus within the same time span. The left side remained ununited at follow up of 4 years. Both LDTA and fibular station deteriorated further on this side in the patient.

altered at subsequent follow up (p = 0.008). The intra faction comparisons in both groups for fibular station at 6 months and follow up were again non significant (complete group p = 0.470; incomplete group p = 0.960).

4. Discussion

Ankle valgus is the most feared complication after fibular gaps.[5] This morbidity has most frequently been reported from the vascularized fibular harvest series, where regeneration of donor fibular does not occur.[9–11] However, even with a regeneration potential, the non vascularized harvest is not immune from this problem.[2,5,6,12] What still remains unknown is the regeneration timing of fibula and ankle valgus development, if any, for incomplete regenerates. The further behavior of ankle valgus in delayed union/incomplete regenerated fibula is also not documented.

Indirect evidence for timing of regeneration at fibular donor site in children has emerged from several series (Steinlechner and Mkandawire approximately 5 months; Bettin et al. 8–16 months).[2,3] We made the initial assessment at a time point of 6 months period based on our previous experience wherein a longitudinal fibular regenerate was restored in 71% (15 out of 21) legs at a similar time frame.[4] According to various reports, the main process of fibular regeneration takes place within the first 1.5–2 years.[2,13] Our current study supports these findings. Eighty three percent of the harvested fibulae (i.e. 10 out 12) which were to possibly regenerate, did so within the 6 months period. The retrospective analysis also showed that 6 fibulae with incomplete regeneration at above time point, remained so in the further follow up of 2.76 years. Incomplete regenerates beyond 6 months

therefore need a careful watch for healing process and also ankle valgus. Thus, radiographic evaluation of harvest site at 6 months can give a fair idea of 'at risk' legs.

Kang specifically evaluated fibular gaps/psuedarthrosis in 19 children.[5] Seven were following fibular harvest. In all cases, early closure of the lateral part of the distal tibial physis, upward migration of the lateral malleolus, unstable valgus deformity of the ankle joint developed during a mean follow-up of 11 years (range, 5–21 years).[5] Nathan et al. investigated the timing of development of ankle valgus in vascularized fibular harvests.[10] Children were first noted to have ankle deformity 32 months (range, 20–38 months) after their primary surgical procedures. In an earlier series involving 30 non vascularized fibular harvests from our institution, 33% (10) ankles had ankle valgus at a mean follow up of 39.4 months (range, 24–83 months) after the index procedure.[6] In present series, we specifically focused on the relationship of ankle valgus to incomplete fibular regenerates. The non regeneration was weakly associated with development of ankle valgus (odds ratio = 7) at 6 months but at subsequent follow up, the odds ratio heightened to 63. Another finding was an abnormal LDTA ($82.38 \pm 5.37^{\circ}$) at 6 months in the incomplete group, a behavior quite different from LDTA ($86.90 \pm 2.02^{\circ}$; $p = 0.025$) of the complete group. Furthermore, there was persistence of the deteriorated LDTA in subsequent follow up in this group. This indicated that ankle mechanics are altered quite early in non regenerates. Abnormal LDTA may as well indicate future fibular gaps and therefore need serial monitoring. On the other hand, the normality of LDTA was maintained throughout the follow up for the complete group.

The commonly accepted postulate for ankle valgus following fibular shortening is the mechanical theory.[5,14,15] Fibula acts a lateral pillar and supports weight transmission through ankle which results in balanced growth of lower tibial epiphysis. In fibular gaps, the ankle is eccentrically loaded altering the lower tibial mechanics. In fact, fibular gaps, lateral wedging of the distal tibial epiphysis, and talar tilt at the ankle mortise are supposed to be closely related.[7] The findings of the current study lend further support to this theory. LDTA appeared to be an earlier radiological marker for ankle valgus compared to fibular migration as judged by Malhotra grading. LDTA deteriorated early in the incomplete group and persisted during follow up. Vis a vis, when fibular stations were matched for complete and incomplete group at 6 months, changes were insignificant ($p = 0.068$). It was only on later follow up that the station alterations became significant for the incomplete regenerates ($p = 0.008$). This may be interpreted as delayed when compared to LDTA changes. The LDTA and fibular station improved when delayed union occurred for two patients. It appears that fibular pillar might be dynamically linked to lower tibial epiphysis growth and fibular stations (LDTA>fibular station).

Our study had a small sample size and obvious statistical limitations. The observation methodology, retrospective nature of the study and the non consecutive case collection were other drawbacks. Malhotra stations are ordinal scale data and hence not very sensitive to change. This study is however one of the first to indicate a direct relationship between incomplete fibular regeneration and radiological ankle valgus. It also critically examined the timing of regeneration and development of ankle valgus for the non vascularized fibular harvests. Our study was fairly consistent in several parameters-harvests were obtained from healthy legs only,[5,12] an adequate residual distal fibular remnant was ensured,[10] no substitute was added at the donor site to enhance regeneration.[16] Six patients in our study had bilateral harvests offsetting variations of age, health and other anatomical considerations for fibular regeneration. It is therefore reasonable to infer that a standing radiograph of donor leg at 6 months post harvest can hint the development of incomplete regeneration and future ankle valgus. Having said that, it must however be emphasized here that children have intense growth and regeneration potential and there is a possibility that incomplete regenerates might unite in future. It is therefore essential to keep these patients in long term observation.

5. Conclusions

More than half of harvested legs (56%) had complete longitudinal fibular regeneration at 6 months. Of incomplete regenerates at 6 months, three fourth remained so beyond 2.5 years. Ankle valgus was found strongly related to long standing fibular non regeneration. Radiological ankle valgus developed early in the incomplete regenerate group.

Compliance with ethical standards.

Research involving human participants and/or animals

Retrospective study.

Informed consent

Yes.

Financial conflicts

Nil.

Conflicts of interest

Nil.

Financial conflicts

Nil.

Disclosure of potential conflicts of interest

Nil.

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jcot.2019.03.017.

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