Clinical Research Report

Journal of INTERNATIONAL MEDICAL RESEARCH

Journal of International Medical Research
2019, Vol. 47(2) 823–835

DOI: 10.1177/0300060518813510
journals.sagepub.com/home/imr
SAGE

Treatment of tumor-like lesions in the femoral neck using free nonvascularized fibular autografts in pediatric patients before epiphyseal closure

Shanchao Luo[1,2,3,*], Tongmeng Jiang[3,4,5,*], Xiaoping Yang[1], Yingnian Yang[1] and Jinmin Zhao[2,3,4]

Abstract

Objectives: Surgical resection of benign bone tumors and tumor-like lesions at the femoral neck presents a difficult reconstructive challenge. However, the safety and efficacy of free nonvascularized fibular autografts (FNFAs) in the treatment of femoral neck tumor-like lesions before epiphyseal closure in young patients remain unknown.

Methods: Sixteen pediatric patients who had not yet undergone epiphyseal closure were treated with FNFAs after resection of tumor-like lesions in the femoral neck from August 2012 to September 2016. All patients underwent supplementary skeletal traction through the supracondylar femur for 4 to 6 weeks after resection. Demographic data were recorded and clinical and radiological outcomes were evaluated during the follow-up.

[1]Yulin Orthopedics Hospital of Chinese and Western Medicine, Yulin, China
[2]Postdoctoral Innovation Practice Base, The Ninth Affiliated Hospital of Guangxi Medical University, Beihai, China
[3]Guangxi Engineering Center in Biomedical Materials for Tissue and Organ Regeneration & Guangxi Collaborative Innovation Center for Biomedicine, Life Sciences Institute, Guangxi Medical University, Nanning, China
[4]Department of Orthopaedics & Guangxi Key Laboratory of Regenerative Medicine, International Joint Laboratory on Regeneration of Bone and Soft Tissue, The First Affiliated Hospital of Guangxi Medical University, Nanning, China
[5]School of Materials Science and Engineering, Zhejiang University, Hangzhou, China

*These authors contributed equally to this work.

Corresponding author:
Jinmin Zhao, Department of Orthopaedics & Guangxi Key Laboratory of Regenerative Medicine, International Joint Laboratory on Regeneration of Bone and Soft Tissue, The First Affiliated Hospital of Guangxi Medical University, Shuangyong Road #22, Nanning 530021, China.
Email: zhaojinmin@126.com

Results: All patients could walk with partial weight bearing 4 weeks postoperative, and full weight bearing was permitted after a mean of 8 weeks. Graft union was attained in all 16 patients at a mean of 2 months. The donor site of the fibular cortical strut showed good regeneration in all patients. The Harris hip score significantly improved from 65% to 95%.
Conclusions: Application of an FNFA is a feasible method in the treatment of tumor-like lesions in the femoral neck before epiphyseal closure in pediatric patients.
Level of Evidence: Level IV.

Keywords
Free nonvascularized fibular autograft, femoral neck, tumor-like lesions, epiphyseal closure, pediatric patients, graft union, Harris hip score

Date received: 12 July 2018; accepted: 24 October 2018

Introduction

Benign bone tumors and tumor-like bone lesions located in the femoral neck can result in osteoarticular deformities, hip strength reduction, pathologic fracture, gait disturbances, and disabling sequelae. Lesions located in the femoral neck are believed to contribute to a high risk of fracture. In addition, bone defects in the femoral neck resulting from surgical resection of benign bone tumors and tumor-like bone lesions present a difficult reconstructive challenge.

Various reconstruction protocols can be employed, each of which has its particular merits and drawbacks. Synthetic bone substitutes are often needed in clinical bone reconstruction and regeneration.[1,2] These substitutes are not at risk of disease transmission, and their quantity may not be limited.[3] Another advantage is their osteoconductive property, which can encourage bone union.[4] However, some potential defects of synthetic bone substitutes include the inability to provide sufficient stability for bone structural reconstruction and the lack of an osteoinductive property.[5] Allografting is one solution for bone defects after tumor resection. However, a high risk of complications, such as infection, nonunion, delayed union, and fracture, is one of the disadvantages of allografting.[6] The structural characteristics of the fibula and minor donor-site morbidity make this bone appropriate in the treatment of bone defects in the limbs.[7,8] The fibular graft provides stabilization as well as osteoinductive and osteoconductive properties that can promote bone union.[9] This graft can also prevent avascular necrosis[10] and collapse of the femoral head.[11] Moreover, it is technically easy to harvest the graft.

To the best of our knowledge, few studies have focused on the safety and efficacy of free nonvascularized fibular autografts (FNFAs) in the treatment of benign bone tumors and tumor-like bone lesions in the femoral neck. Therefore, this study was performed to evaluate the clinical and radiological outcomes of FNFAs in the treatment of tumor-like bone lesions in the femoral neck before epiphyseal closure in pediatric patients.

Patients and methods

Ethical approval

This study was authorized by the Ethics Committee and Institutional Review Board of Yulin Orthopedics Hospital of Chinese and Western Medicine (Yulin, China). It was performed according to the Helsinki Declaration,[12] and written informed consent was provided by each patient's parents. This study was registered at clinicaltrials.gov (NCT03129230).

Inclusion and exclusion criteria

This retrospective study included pediatric patients who had not yet undergone epiphyseal closure and had tumor-like lesions in the femoral neck. No adult patients or pediatric patients who had undergone epiphyseal closure were included in the study. All patients underwent lesion resection followed by application of an FNFA and skeletal traction through the supracondylar femur from August 2012 to September 2016.

Preoperative assessment

The histological types of tumor-like lesions in the femoral neck were aneurysmal bone cysts, bone cysts, and eosinophilic granulomas of the bone (Figure 1). All patients had persistent pain of 1 to 3 weeks' duration in the femoral neck resulting from tumor-like lesions before reconstructive surgery. Clinical assessments before reconstructive surgery included a complete history, physical examination, laboratory tests, conventional radiographs, and magnetic resonance imaging (MRI) of the affected hip. The status of the bone and assessment of the bone defect in the affected hip were evaluated through preoperative X-ray images, computed tomography, and MRI. Biopsy was performed on every patient after the above-described clinical assessment.

Harvesting of fibular grafts

The length of the fibula needed for packing into the bone defect of the affected femoral neck was evaluated from the preoperative MRI scans. Before resection of the tumor-like lesions, the fibular graft was harvested by two posterolateral straight incisions along the fibula. One incision was located in the proximal site of the required fibular segment, and the other was located in the distal site of the required fibular segment. The length of each incision was about 2.0 cm (Figure 2). The fibula was then

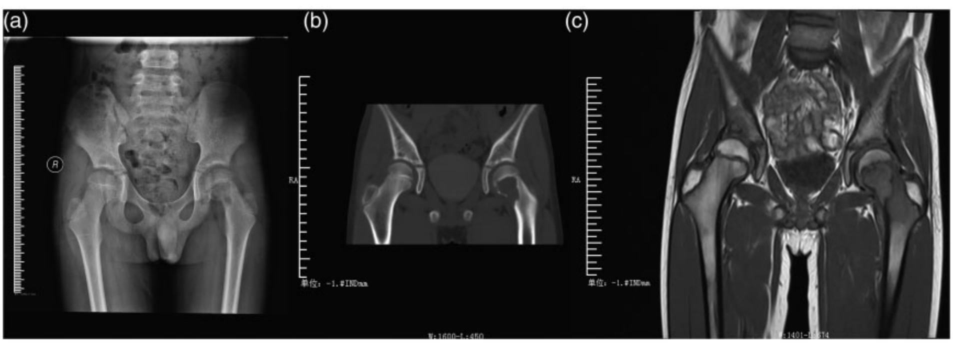

Figure 1. Preoperative (a) radiograph, (b) computed tomography image, and (c) magnetic resonance image in a 9-year-old male patient show eosinophilic granuloma of the bone of the left femoral neck.

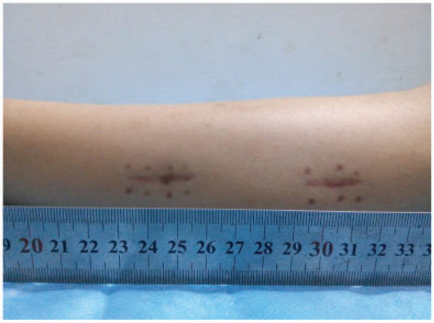

Figure 2. Postoperative photograph shows the proximal and distal skin incisions for free nonvascularized fibula harvesting through a minimally invasive technique (periosteum-preserving technique).

exposed and dissected subperiosteally. The osteotomy procedures were performed at both ends of the required fibular segment using a wire saw. The fibular segment between the two incisions was not exposed. The periosteum of the required fibular segment was carefully detached subperiosteally beginning from the distal end of the required fibula. Next, after rotation of the middle segment of the fibula between the two incisions, the segment of the required fibula (7–10 cm in length) was harvested. The periosteum was closed to facilitate postoperative fibular regeneration, and the incision was closed without drainage. After harvesting of the required fibula, 4 cm of the proximal fibula was preserved to ensure knee stability, and 8 cm the distal fibula was preserved to ensure ankle stability.

Surgical procedure on the hip

Preparation of the affected hip after harvesting of the free nonvascularized fibula was performed by the same team of surgeons. Every patient in the study was placed in the supine position. An anterior approach to the affected hip was employed. A straight incision was made in the anterior hip capsule. The fenestration procedure was performed at the anterior aspect of the affected femoral neck using a high-speed burr or bone chisel. As much pathological tissue as possible, including bone and soft tissue, was removed from the lesion site by curettage. The soft tissue and bone tissue in the affected site was saved for postoperative histopathological examination. The sclerotic bone within the affected site was resected by a high-speed burr, and the surgical wound was washed with a pulse irrigation system. The free nonvascularized fibula (single fibular strut or double fibular strut) was positioned into the femoral neck cavity. If the patient had no pathological fracture either preoperatively or postoperatively or had a low risk of fracture postoperatively, neither end of the fibula was fixed to the recipient's bone by Kirschner wires or screws (Figure 3). If the patient had a pathological fracture either preoperatively or postoperatively or had a high risk of fracture postoperatively, both ends of the fibula were fixed to the recipient's bone by 2-mm Kirschner wires only (Figure 4). Synthetic bone substitute or allograft cancellous bone was then packed into the cavity in the femoral neck around the free nonvascularized fibula. Skeletal traction through the supracondylar femur was conducted on every patient after closure of the hip wound.

Postoperative care

The mean follow-up period was 24 months (range, 7–54 months). During the follow-up, the Harris hip score were used to assess functional outcomes. The clinical assessments were performed using four classes: excellent, no hip pain and a hip rating of >90 points; good, mild discomfort or restriction of hip motion and a hip rating of 80 to 89 points; fair, mild or moderate hip pain with a hip rating of 70 to 79 points and any reduction in the hip score after the operation; and poor, severe hip pain or

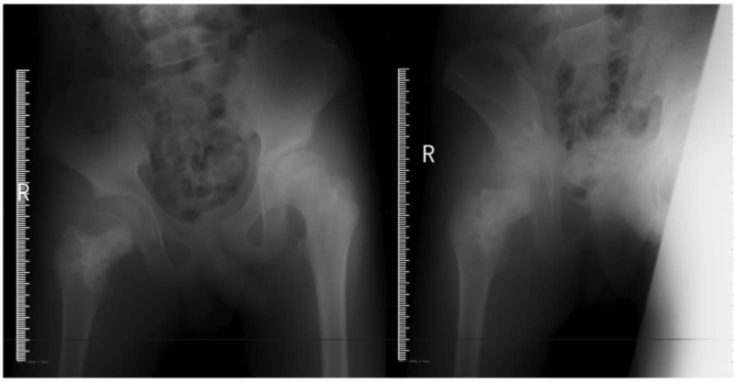

Figure 3. Anteroposterior radiographs obtained 1 day postoperatively show that both ends of the free nonvascularized fibula were not fixed to the recipient bones.

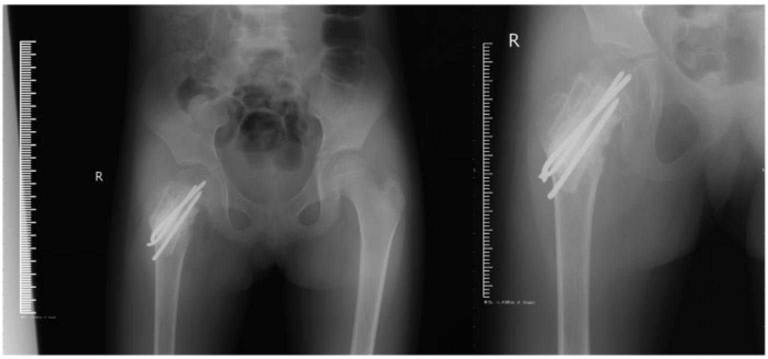

Figure 4. Radiographs obtained 1 week postoperatively in a 9-year-old female patient with an aneurysmal bone cyst show that both ends of the free nonvascularized fibula were fixed to the recipient bones by Kirschner wires.

grossly limited motion and a hip rating of <69 points.

The patients were evaluated with radiographs to assess the evidence of bone union. When radiological bony union between the ends of the fibular graft and the recipient bone was evaluated according to Hsu et al.,[13] bone union was considered to have been obtained. Complications resulting from the fibular autograft and the tumor-like lesions (e.g., infection, fracture, nonunion, local recurrence, early epiphyseal closure, deformity of the proximal femur, and necrosis of the femoral head) were evaluated postoperatively. During the follow-up, free fibular donor site morbidity was evaluated in terms of weakness of the foot evertors and great toe flexors.

Skeletal traction through the supracondylar femur was conducted on every patient for 4 to 5 weeks postoperatively. During skeletal traction through the supracondylar femur, the patient performed ankle pumps, static quadriceps exercises, and knee and hip exercises under the supervision of a physiotherapist. The skeletal traction through the supracondylar femur was removed 4 or 5 weeks postoperatively. Gradual weight bearing of the affected hip was then tolerated for 3 weeks using crutches, followed by full weight bearing. At 7 or 8 weeks after the primary surgery, the Kirschner wire fixed to the fibular graft in patients with pathological fractures was removed, and the patients were then allowed a gradual range of joint movement.

Clinical and radiographic assessments were performed at 4 weeks, 8 weeks, 3 months, 6 months, 12 months, and 24 months following the primary surgery.

Statistical analysis

The Harris hip score was evaluated using Student's test, and a P-value of <0.05 was considered statistically significant.

Results

Patients and reconstructions

Sixteen patients were treated with FNFAs to reconstruct bony defects after resection of tumor-like lesions of the femoral neck. The patients comprised 10 males and 6 females with a mean age of 9.5 years (range, 7.3–13.5 years) at the time of the operation. The primary diagnoses were aneurysmal bone cyst (n = 7), bone cyst (n = 4), and eosinophilic granuloma of the bone (n = 5). The mean length of the bony defect after resection of tumor-like lesions in the femoral neck was 4.0 cm (range, 3.7–5.1 cm). After resection of the tumor-like lesion in the femoral neck, the FNFA (single fibular strut or double fibular strut) was positioned into the femoral neck cavity. Allogeneic cancellous bone or synthetic bone substitute was then positioned around the FNFA.

Clinical outcomes

The mean follow-up period after surgery was 24 months (range, 7–54 months). All patients were asymptomatic within 1 month after surgery. Radiological bone union between the ends of the fibular graft and the recipient bone was achieved in all patients at a mean of 5 weeks (range, 4–6 weeks) (Figure 5). When bone union was obtained, the skeletal traction through supracondylar femur was removed. Partial weight bearing of the affected extremities was then allowed. Full weight bearing of the affected extremities was allowed 7 to 8 weeks postoperatively, when complete bony union between the ends of the fibular graft and the recipient bone was confirmed on radiographs. The Harris hip scores of

Figure 5. (a, b) Radiographs obtained 5 weeks postoperatively in a 12-year-old male patient with an aneurysmal bone cyst show radiological bony union between the ends of the fibular graft and the recipient bone. (c–e) Radiographs obtained 5 weeks postoperatively in a 9-year-old male patient with eosinophilic granuloma of the bone show radiological bony union between the ends of the fibular graft and the recipient bone.

the affected extremities are summarized in Table 1. At the last follow-up (mean of 24 months), the mean postoperative Harris hip score of the affected extremities had significantly improved compared with the mean preoperative Harris hip score of the affected extremities ($p < 0.05$). In 6 of the 16 patients, more than 95% of the length of the fibula in the donor site had regenerated at the last follow-up. In these patients, complete bony union was absent between the proximal fibula and the regenerating fibular segment (Figure 6). In the other patients, the fibular segment in the donor site was completely regenerated, and complete bony union was present between the proximal or distal fibula and the regenerating fibular segment (Figure 7).

Results and complications of treatment

All 16 patients underwent intracapsular curettage in the affected hip. During the follow-up period, 1 of the 16 patients needed additional surgical revisions because of local recurrence of the tumor-like lesion in the affected femoral neck. At the last follow-up, none of the other 15 patients developed local recurrence of the tumor-like lesions in the affected femoral neck. None of these patients developed superficial or deep infection at the donor site or recipient site. During the follow-up period, no patients developed postoperative fractures in the affected femoral neck region. The patients without preoperative epiphyseal injury had no early closure of the epiphysis

Table 1. Mean Harris hip scores before and after surgical treatment.

Tumor-like lesions	Preoperatively	Final follow-up
Aneurysmal bone cyst (n = 7)	65 (50–80)	87 (80–99)
Bone cyst (n = 4)	70 (65–75)	87 (80–95)
Eosinophilic granuloma of bone (n = 5)	71 (55–90)	88 (80–99)

Scores are presented as mean (range).

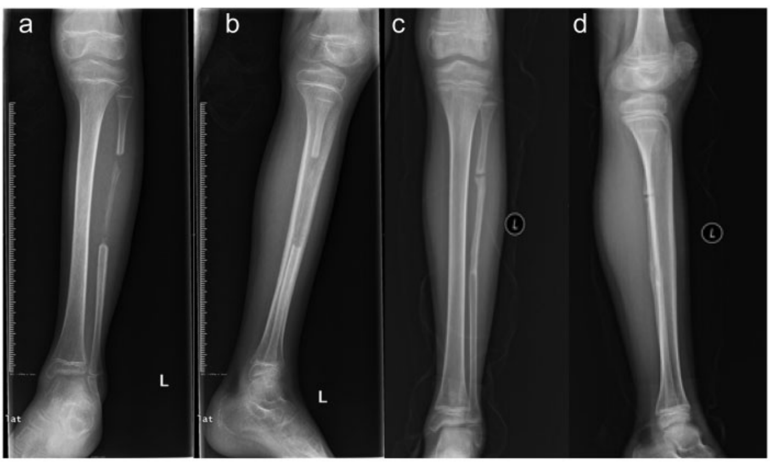

Figure 6. (a, b) Radiographs obtained 8 weeks postoperatively show regeneration of the fibular segment in the donor site in a 10-year-old male patient with eosinophilic granuloma of the bone. (c, d) Radiographs obtained at the last follow-up show that no complete bony union is present between the proximal fibula and the regenerating fibular segment in an 11-year-old male patient with eosinophilic granuloma of the bone.

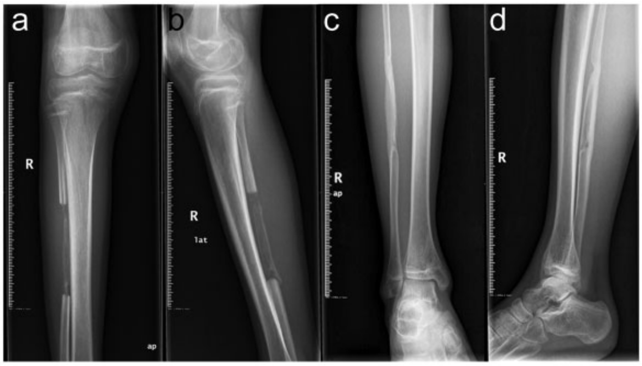

Figure 7. (a, b) Radiographs obtained 8 weeks postoperatively show regeneration of the fibular segment in the donor site in a 13-year-old male patient with an aneurysmal bone cyst. (c, d) Radiographs obtained at the last follow-up show complete regeneration of the fibular segment in the donor site and complete bony union between the proximal fibula and the regenerating fibular segment in a 14-year-old male patient with an aneurysmal bone cyst.

after the surgical revision (Figure 6). Postoperatively, 2 of 16 patients had a slight varus deformity of the affected hip. However, these two patients had exhibited a varus deformity caused by a pathological fracture malunion preoperatively. The other patients without epiphyseal injury or pathological fracture malunion preoperatively did not present a varus deformity or valgus deformity in the affected hip after the surgical revision. During the follow-up period, no patients showed signs of fibula donor site morbidity in the donor extremities (e.g., incisional pain, superficial peroneal nerve or common peroneal nerve injury, deformity of the tibia, deformity of the knee joint, deformity of the ankle joint, knee instability, or ankle instability).

Discussion

The femoral neck is one of the most common sites for benign bone tumors and tumor-like lesions.[14,15] These lesions located in the femoral neck can cause substantial loss of mechanical strength, recurrent pain, deformity, hip joint dysfunction, bone defects, and pathological fractures. Because of their special anatomical structure and biomechanical properties, treatment of benign bone tumors and tumor-like lesions in the femoral neck often poses many formidable challenges. Pathological fracture of the femoral neck is a potentially disastrous complication for the patient. Several therapeutic protocols may be used for benign bone tumors or tumor-like lesions in the femoral neck. These protocols include curettage and bone grafting with or without internal fixation.[16–18] Internal fixation may not be suitable for pediatric patients who have not yet undergone epiphyseal closure because this treatment may cause epiphyseal injury. Every treatment effort in these patients should be directed toward hip joint salvage and should not cause epiphyseal injury. There is no consensus regarding the optimal therapy for femoral neck benign bone tumors or tumor-like lesions in pediatric patients before epiphyseal closure. Some studies have been performed to assess the clinical outcomes of surgical therapy for benign bone tumors or tumor-like lesions in the femoral neck through the use of autogenous cancellous bone grafts, allografts, autogenous cancellous bone and allografts, vascularized or nonvascularized fibular grafts, and fixation of compression hip screws combined with autogenous cancellous bone and allografts.[19–22] One recent study involved treatment of benign bone tumors, including femoral neck lesions, in adults using compression hip screws and synthetic bone substitutes.[23,24] To the best of our knowledge, however, the use of FNFAs in the treatment of femoral neck benign bone tumors or tumor-like bone lesions in pediatric patients before epiphyseal closure has not been reported. In this study, we evaluated the clinical and radiological results of surgical therapy for tumor-like lesions of the femoral neck in pediatric patients before epiphyseal closure using FNFAs in addition to autogenous cancellous bone or allografts or synthetic bone substitutes. George et al.[25] reported the clinical outcomes of nonvascularized autologous fibular grafts in the treatment of benign lesions in the proximal femur. In their study, two patients developed tumor recurrence postoperatively, and none developed pathological fractures postoperatively. In the present study, one patient developed postoperative tumor recurrence. This may have been related to incomplete removal of the lesion in the femoral neck. Therefore, complete removal of the lesion is necessary to prevent postoperative recurrence. Preservation of the epiphyseal segment can afford further growth in children and adolescents. The risk of hip varus or valgus deformities will increase, even if the epiphysis is partially preserved.[26–30] In the present study, two patients with partial epiphyseal injury preoperatively showed hip varus deformities postoperatively. The other patients with or without pathological fractures preoperatively did not develop hip varus or valgus deformities postoperatively. This may have been related to preservation of the integrity of the epiphysis. In our study, the FNFA (single fibular strut or double fibular strut) was positioned into the femoral neck cavity after resection of the lesion without hip compression screw fixation. For patients with preoperative pathologic fractures, internal fixation with a Kirschner wire was performed after the fibula was implanted. All of the above strategies can reduce the risk of epiphyseal injury. Two patients with a preoperative partial epiphyseal injury in addition to a pathological fracture developed early epiphyseal closure postoperatively. The other patients with or without preoperative pathological fractures showed no early epiphyseal closure. No other complications occurred in the recipient site postoperatively, such as superficial or deep infection, pathological fracture, or osteonecrosis of the femoral head. If at least 50% of the bone cortex of the femoral neck is affected by the bone lesion or more than 50% of the diameter of the femoral neck is affected by the bone lesion, surgical reinforcement of the proximal femur after resection of the bone lesion is necessary to prevent postoperative fracture.[31] Some authors have achieved structural reinforcement through compression hip screws in addition to autogenous fibular cortical strut grafts or synthetic bone substitutes after resection of bone lesions. In the present study, however, the FNFA (single fibular strut or double fibular strut) was positioned into the femoral neck cavity after resection of the bone lesion without a compression hip screw. For patients with pathological fractures either preoperatively or intraoperatively, both ends of the fibula were fixed to the recipient bones by 2-mm Kirschner wires only. Skeletal traction through the supracondylar femur was performed on every patient for 4 to 5 weeks. None of the 16 patients showed postoperative fracture or early epiphyseal closure associated with epiphyseal injury. Structural stability of the femoral neck can be obtained by a fibular cortical strut graft combined with skeletal traction through the supracondylar femur. In our study, the postoperative function of the affected extremity in all patients significantly improved compared with the preoperative function of the affected extremity.

Free fibular grafts have been widely used for the reconstruction of bone defects because they can provide mechanical strength and stimulate bone union. Free fibular grafts may be vascularized or nonvascularized. Free vascularized fibular grafts are usually used to reconstruct skeletal defects of >6 cm.[32,33] These grafts offer the potential for more rapid autograft union and have a higher union rate[34] compared with FNFAs. However, free vascularized fibula grafts also have several disadvantages, including the requirement to perform microvascular surgical technique, an increased risk of infection by a prolonged surgery time, the risk of anastomosis failure due to thrombosis, and greater donor-site morbidity.[35] The most common type of donor-site morbidity after application of free vascularized fibular grafts is weakness of the donor leg muscles originating from the fibula.[36,37] However, the FNFA has several advantages over free vascularized fibular grafts. For instance these grafts have a lower technical demand for the surgeon and can reduce donor-site complications.[38,39] Several recent studies have shown that FNFAs harvested by a minimally invasive technique had the same benefits as FNFAs harvested by the periosteum-preserving technique in the treatment of bone defects in children and adults.[40–42] In the above-mentioned studies, complete regeneration of the donor site after FNFA harvesting was obtained in most patients. In the present study, the FNFAs were harvested by the periosteum-preserving technique and positioned into the bone cavity after resection of the tumor-like lesions in the femoral neck. No patients developed donor-site complications such as incisional pain, infection, ankle instability, or peroneal nerve damage. Complete regeneration of the fibula at the donor site occurred within 12 weeks (range, 5–18 weeks) in most patients, which is similar to the results of other studies.[43,44] Bony union between the ends of the fibular graft and the recipient bone was achieved in all patients at a mean of 5 weeks (range, 4–6 weeks), which is similar to the results of another study.[45]

This study had several limitations. Only a small number of patients could be included in the study, the mean follow-up time was relatively short, and there was no control group.

Conclusion

FNFAs harvested by a minimally invasive technique may be an attractive protocol in the treatment of tumor-like bone lesions in the femoral neck before epiphyseal closure in pediatric patients.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

Funding

This work was financially supported by the National Natural Science Foundation of China (Grant No. 81472054), the Guangxi Scientific Research and Technological Development Foundation (Guike AB16450003), the Guangxi Science and Technology Major Project (Guike AA17204085), the Project of Guangxi Medical and Health (Grant No. Z20170955), and the Innovation Project of Guangxi Graduate Education (Grant No. YCSZ2015108).

ORCID iD

Tongmeng Jiang http://orcid.org/0000-0002-6902-1980

Jinmin Zhao http://orcid.org/0000-0002-1047-8820

References

1. Kim BS, Kang HJ, Yang SS, et al. Comparison of in vitro and in vivo bioactivity: cuttlefish-bone-derived hydroxyapatite and synthetic hydroxyapatite granules as a bone graft substitute. *Biomed Mater* 2014; 9: 025004.
2. Tang D, Tare RS, Yang LY, et al. Biofabrication of bone tissue: approaches, challenges and translation for bone regeneration. *Biomaterials* 2016; 83: 363–382. DOI: 10.1016/j.biomaterials.2016.01.024.
3. Sanmartin de Almeida M, Fernandes GVO, de Oliveira AM, et al. Calcium silicate as a graft material for bone fractures: a systematic review. *J Int Med Res* 2018; 46: 2537–2548. DOI: 10.1177/0300060518770940.
4. Behzadi S, Luther GA, Harris MB, et al. Nanomedicine for safe healing of bone trauma: opportunities and challenges. *Biomaterials* 2017; 146: 168–182. DOI: 10.1016/j.biomaterials.2017.09.005.
5. Hao Z, Song Z, Huang J, et al. The scaffold microenvironment for stem cell based bone tissue engineering. *Biomater Sci* 2017; 5: 1382–1392. DOI: 10.1039/c7bm00146k.
6. Ferrari S, Smeland S, Mercuri M, et al. Neoadjuvant chemotherapy with high-dose ifosfamide, high-dose methotrexate, cisplatin, and doxorubicin for patients with localized osteosarcoma of the extremity: a joint study by the Italian and Scandinavian Sarcoma Groups. *J Clin Oncol* 2005; 23: 8845–8852. DOI: 10.1200/JCO.2004.00.5785.
7. Arai K, Toh S, Tsubo K, et al. Complications of vascularized fibula graft for reconstruction of long bones. *Plast Reconstr Surg* 2002; 109: 2301–2306.
8. Tu YK, Yen CY, Yeh WL, et al. Reconstruction of posttraumatic long bone defect with free vascularized bone graft: good outcome in 48 patients with 6 years' follow-up. *Acta Orthop Scand* 2001; 72: 359–364. DOI: 10.1080/000164701753542014.
9. Korompilias AV, Beris AE, Lykissas MG, et al. Femoral head osteonecrosis: why choose free vascularized fibula grafting. *Microsurgery* 2011; 31: 223–228. DOI: 10.1002/micr.20837.
10. Li Z, Chen W, Su Y, et al. The application of closed reduction internal fixation and iliac bone block grafting in the treatment of acute displaced femoral neck fractures. *PloS One* 2013; 8: e75479. DOI: 10.1371/journal.pone.0075479.
11. Kainth GS, Yuvarajan P, Maini L, et al. Neglected femoral neck fractures in adults. *J Orthop Surg (Hong Kong)* 2011; 19: 13–17. DOI: 10.1177/230949901101900104.
12. World Medical A. World Medical Association declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA* 2013; 310: 2191–2194. DOI: 10.1001/jama.2013.281053.
13. Hsu RW, Wood MB, Sim FH, et al. Free vascularised fibular grafting for reconstruction after tumour resection. *J Bone Joint Surg Br* 1997; 79: 36–42.
14. Shih HN, Cheng CY, Chen YJ, et al. Treatment of the femoral neck and trochanteric benign lesions. *Clin Orthop Relat Res* 1996; 328: 220–226.
15. Kundu ZS, Gogna P, Sangwan SS, et al. Benign lytic lesions of the femoral neck: mid-term results of extended curettage and sartorius muscle pedicle bone grafting. *Arch Orthop Trauma Surg* 2013; 133: 457–462. DOI: 10.1007/s00402-013-1687-8.
16. Jaffe KA and Dunham WK. Treatment of benign lesions of the femoral head and neck. *Clin Orthop Relat Res* 1990; 257: 134–137.
17. Jaffe KA, Launer EP and Scholl BM. Use of a fibular allograft strut in the treatment of benign lesions of the proximal femur. *Am J Orthop (Belle Mead NJ)* 2002; 31: 575–578.
18. Enneking WF and Gearen PF. Fibrous dysplasia of the femoral neck. Treatment by cortical bone-grafting. *J Bone Joint Surg Am* 1986; 68: 1415–1422.
19. Shih HN, Chen YJ, Huang TJ, et al. Treatment of fibrous dysplasia involving the proximal femur. *Orthopedics* 1998; 21: 1263–1266.
20. Bryant DD, 3rd, Grant RE and Tang D. Fibular strut grafting for fibrous dysplasia of the femoral neck. *J Natl Med Assoc* 1992; 84: 893–897.
21. Guille JT, Kumar SJ and MacEwen GD. Fibrous dysplasia of the proximal part of the femur. Long-term results of curettage

and bone-grafting and mechanical realignment. *J Bone Joint Surg Am* 1998; 80: 648–658.
22. Shih HN, Chen YJ, Huang TJ, et al. Semistructural allografting in bone defects after curettage. *J Surg Oncol* 1998; 68: 159–165.
23. Nishida Y, Tsukushi S, Hosono K, et al. Surgical treatment for fibrous dysplasia of femoral neck with mild but prolonged symptoms: a case series. *J Orthop Surg Res* 2015; 10: 63. DOI: 10.1186/s13018-015-0208-6.
24. Nakamura T, Matsumine A, Asanuma K, et al. Treatment of the benign bone tumors including femoral neck lesion using compression hip screw and synthetic bone graft. *SICOT-J* 2015; 1: 15. DOI: 10.1051/sicotj/2015009.
25. George B, Abudu A, Grimer RJ, et al. The treatment of benign lesions of the proximal femur with non-vascularised autologous fibular strut grafts. *J Bone Joint Surg Br* 2008; 90: 648–651. DOI: 10.1302/0301-620X.90B5.20330.
26. Ceruso M, Taddei F, Bigazzi P, et al. Vascularised fibula graft inlaid in a massive bone allograft: considerations on the biomechanical behaviour of the combined graft in segmental bone reconstructions after sarcoma resection. *Injury* 2008; 39: S68–S74. DOI: 10.1016/j.injury.2008.05.014.
27. San Julian Aranguren M, Leyes M, Mora G, et al. Consolidation of massive bone allografts in limb-preserving operations for bone tumours. *Int Orthop* 1995; 19: 377–382.
28. Thompson RC, Jr, Garg A, Clohisy DR, et al. Fractures in large-segment allografts. *Clin Orthop Relat Res* 2000; 370: 227–235.
29. Fuchs B, Ossendorf C, Leerapun T, et al. Intercalary segmental reconstruction after bone tumor resection. *Eur J Surg Oncol* 2008; 34: 1271–1276. DOI: 10.1016/j.ejso.2007.11.010.
30. San-Julian M and Canadell J. Fractures of allografts used in limb preserving operations. *Int Orthop* 1998; 22: 32–36.
31. Gunther KP, Hartmann A, Aikele P, et al. Large femoral-neck cysts in association with femoroacetabular impingement. A report of three cases. *J Bone Joint Surg Am* 2007; 89: 863–870. DOI: 10.2106/JBJS.F.00885.
32. Zelenski N, Brigman BE, Levin LS, et al. The vascularized fibular graft in the pediatric upper extremity: a durable, biological solution to large oncologic defects. *Sarcoma* 2013; 2013: 321201. DOI: 10.1155/2013/321201.
33. Kalra GS, Goel P and Singh PK. Reconstruction of post-traumatic long bone defect with vascularised free fibula: a series of 28 cases. *Indian J Plast Surg* 2013; 46: 543–548. DOI: 10.4103/0970-0358.122013.
34. Eward WC, Kontogeorgakos V, Levin LS, et al. Free vascularized fibular graft reconstruction of large skeletal defects after tumor resection. *Clin Orthop Relat Res* 2010; 468: 590–598. DOI: 10.1007/s11999-009-1053-x.
35. Puri A, Subin BS and Agarwal MG. Fibular centralisation for the reconstruction of defects of the tibial diaphysis and distal metaphysis after excision of bone tumours. *J Bone Joint Surg Br* 2009; 91: 234–239. DOI: 10.1302/0301-620X.91B2.21272.
36. Lee KS and Park JW. Free vascularized osteocutaneous fibular graft to the tibia. *Microsurgery* 1999; 19: 141–147.
37. Youdas JW, Wood MB, Cahalan TD, et al. A quantitative analysis of donor site morbidity after vascularized fibula transfer. *J Orthop Res* 1988; 6: 621–629. DOI: 10.1002/jor.1100060502.
38. Wuisman P, Gohlke F and Witlox A. Allografts in reconstruction of osseous defects in primary malignant bone tumors. *Orthopade* 2003; 32: 994–1002. DOI: 10.1007/s00132-003-0580-5.
39. Patwardhan S, Shyam AK, Mody RA, et al. Reconstruction of bone defects after osteomyelitis with nonvascularized fibular graft: a retrospective study in twenty-six children. *J Bone Joint Surg Am* 2013; 95: e56, S51. DOI: 10.2106/JBJS.K.01338.
40. Mukherjee AN, Pal AK, Singharoy D, et al. Harvesting the free fibular graft: a modified approach. *Indian J Orthop* 2011; 45: 53–56. DOI: 10.4103/0019-5413.73657.
41. Lucas G, Lopez J, Fraisse B, et al. Minimally invasive harvesting of nonvascularized fibular graft in children. *Orthop Traumatol Surg Res* 2015; 101: 515–518. DOI: 10.1016/j.otsr.2015.02.006.

42. Agarwal A and Kumar A. Fibula regeneration following non-vascularized graft harvest in children. *Int Orthop* 2016; 40: 2191–2197. DOI: 10.1007/s00264-016-3233-0.
43. Abuhassan FO and Shannak A. Non-vascularized fibular graft reconstruction after resection of giant aneurysmal bone cyst (ABC). *Strategies Trauma Limb Reconstr* 2010; 5: 149–154. DOI: 10.1007/s11751-010-0093-9.
44. Xin ZF, Kim KH and Jung ST. Regeneration of the fibula using a periosteum-preserving technique in children. *Orthopedics* 2009; 32: 820. DOI: 10.3928/01477447-20090922-14.
45. Tripathy SK, Sen RK and Goyal T. Nonvascularized fibular grafting in nonunion of femoral neck fracture: a systematic review. *Indian J Orthop* 2016; 50: 345–351. DOI: 10.4103/0019-5413.185587.