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Distal femoral bone defect treatment using an engineered hydroxyapatite cylinder scaffold made from rattan wood

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SUMMARY

Distal femoral non-union presents significant challenges, often requiring complex treatment strategies to achieve bone healing. In this case, a young male patient with an open fracture of the distal femur developed an atrophic non-union, 9 months after initial fixation. The patient underwent surgical intervention with debridement, leading to a 2.2 cm bone defect and placement of a cylindrical synthetic bone graft (b.Bone), combined with bone marrow aspirate concentrate. This approach aimed to provide structural support and enhance biological healing. The choice of the cylindrical graft was due to its optimal fit and support for the anterior femoral cortex. Postoperative outcomes were favourable, with successful bone healing, confirmed radiologically, and restoration of function. This case demonstrates the potential of synthetic bone substitutes augmented with biological agents as a promising alternative to traditional grafts in managing complex non-unions.

BACKGROUND

Fracture non-union after the fixation of distal femoral fracture remains a challenging problem to treat, associated with increased morbidity and prolonged disability.[1] The overall incidence of this complication has been reported to be up to 8.6% and can be affected by the fixation method.[2] Open injuries, segmental bone loss, increased body mass index and inadequate fixation during the initial treatment have been highly associated with impaired bone healing.[3] Of note, septic non-unions represent a more complex situation as the presence of infection complicates the management and alters the prognosis.[4]

The increased mechanical demands of the femur and the potential poor biological environment, especially after open fracture, make the treatment of distal femoral non-unions notoriously difficult.[5] The traditional approach includes adequate reconstruction and the use of autografts or allografts after debridement of non-viable bone. However, autografts have been correlated with donor site morbidity, insufficient structural integrity and increased surgical time, while allograft use has been related to increased cost and possible immune reactions.[6] Synthetic bone substitutes, on the other hand, have osteoconductive properties and offer a promising alternative for gap filling and facilitation of bone healing.[7]

Recently, an innovative biomimetic and bioactive bone substitute was developed from rattan wood because of its intrinsic structure which mimics human bone. Based on a unique physical and chemical process, the rattan wood is biomorphically transformed into a biomimetic bone substitute designed to facilitate the regeneration of the host bone. The b.Bone synthetic substitute is available in different shapes including blocks, wedges and cylinders.[8] Here, we present a case of an atrophic distal femoral non-union which was managed with a b.Bone cylinder graft for the bone defect created after debridement of the necrotic avascular bone edges at the non-union site.

CASE PRESENTATION

A male patient in his early adolescence was transferred to the emergency department of our hospital after a motorcycle accident. At presentation, he was haemodynamically stable. The imaging studies revealed Gustilo-Anderson type IIIA open fractures of the distal femur (intra-articular, AO 33-C1.1) and the patella (simple, transverse) on the left lower limb. There was no neurovascular deficit. The patient was taken to the theatre for emergent wound debridement and open reduction and internal fixation of both fractures. An anatomical locking plate (NCB-DF Zimmer Inc., Winterthur, Switzerland) was used in the distal femur, and,

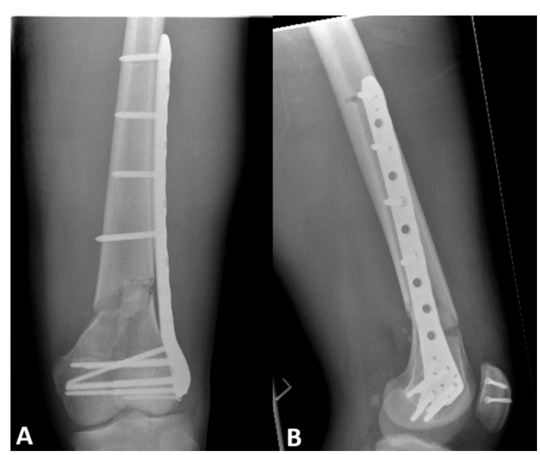

Figure 1 Postoperative X-rays of the left distal femur and patella. Open reduction and internal fixation of the distal femur with an anatomical plate and screws, with compression of the intra-articular fracture component and bridging of the metaphyseal fracture. Fixation of transverse patella fracture with two compression screws. (A) Anteroposterior view. (B) Lateral view.

Figure 2 X-rays of the left distal femur at 9 months postoperatively. The fracture line of the distal femur is still visible. Fracture healing has been achieved only at the posterior cortex. (A) Anteroposterior view. (B) Lateral view.

following reduction, two cannulated screws were placed for patella fracture fixation (figure 1).

The wound healing was uncomplicated. However, at 9 months, the patient was still symptomatic. He experienced pain at the distal femur with weight bearing, and there was tenderness on palpation of the fracture site.

INVESTIGATIONS

The radiological investigation at 9 months, including plain X-rays and CT, confirmed incomplete bone healing at the fracture site (figures 2 and 3).

The patient at that stage was afebrile and there was absence of signs indicative of infection. Biochemical investigations showed no evidence of elevated inflammatory markers.

TREATMENT

A surgical intervention to address the left distal femoral fracture non-union was decided. In the theatre, the site of non-union

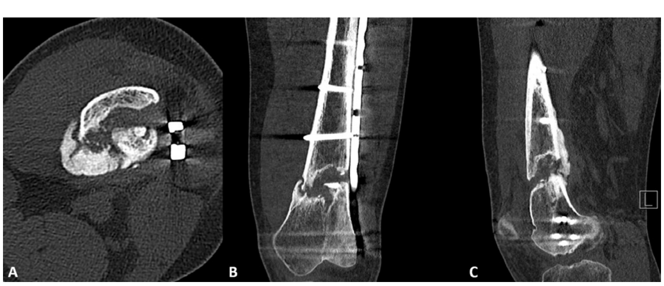

Figure 3 CT images of the left distal femur at 9 months postoperatively. There was a thin column of callus formation to the posterior aspect of the distal femoral fracture. There was no evidence of union across the fracture, identified with sclerotic margins consistent with an established non-union. (A) Axial view. (B) Coronal view. (C) Sagittal view.

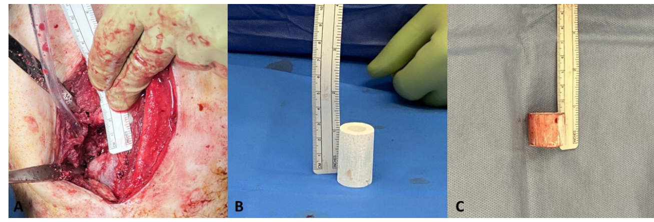

Figure 4 Intraoperative images. (A) After debridement of the avascular, necrotic bone of the left distal femur through a lateral approach, the bone gap was measured. (B) The size of the intact cylinder synthetic graft was measured. (C) The cylinder synthetic graft is cut at the size of the bone gap.

was exposed, the proximal and distal ends were meticulously trimmed down to the bleeding bone and a cylinder of synthetic bone (b.Bone, GreenBone ORTHO S.p.A, Faenza, Italy) was placed to fill the gap (figures 4–6).

Bone marrow aspirate concentrate from the left iliac crest was also injected at the site of intervention. The surgery was uneventful, and the patient tolerated the procedure well.

OUTCOME AND FOLLOW-UP

Postoperative care protocol involved toe-touch weight-bearing for the initial 4 weeks, followed by partial weight-bearing for another 4 weeks and a subsequent gradual progression to full weight-bearing activities.

At the 1-year follow-up, the patient exhibited painless full weight-bearing capacity, absence of tenderness on distal femur palpation and 110° of knee motion with complete extension recovery. The surgical wound had healed well. Radiological

Figure 5 Intraoperative image of the left distal femur through a lateral approach. The bone ends have been trimmed down to the bleeding bone, and a cylindrical synthetic graft has been placed into the gap.

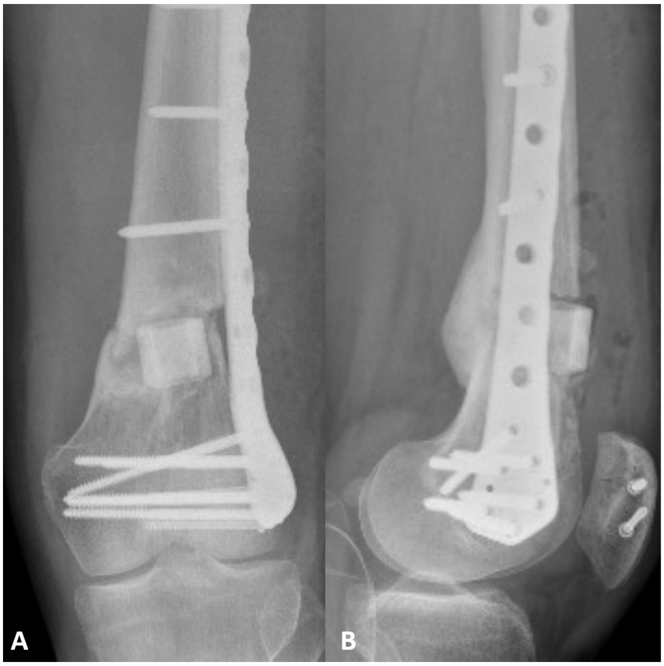

Figure 6 Postoperative X-rays of the left distal femur after the intervention at the site of non-union. A cylindrical synthetic graft has been placed to fill the bone gap after non-union tissue debridement. (A) Anteroposterior view. (B) Lateral view.

assessment confirmed successful bone healing and integration of the synthetic graft (figure 7).

At the 2-year follow-up, the patient had fully resumed daily and sports activities, experiencing only minimal discomfort following prolonged exercise. The patient demonstrated full range of knee motion with painless weight-bearing and reported complete satisfaction with the functional outcome. The radiographs at the final visit demonstrated promotion of graft integration (figure 8).

Figure 7 X-rays of the left distal femur at 1 year after the intervention at the site of non-union. There is obvious integration of the synthetic substitute with good bone healing medially, laterally and anteriorly and bone remodelling posteriorly, compared with the previous X-rays. (A) Anteroposterior view. (B) Lateral view.

Figure 8 X-rays of the left distal femur at 2 years after the intervention at the site of non-union. There is advancement of graft integration compared with the X-ray of the 1-year follow-up. (A) Anteroposterior view. (B) Lateral view.

DISCUSSION

Distal femoral non-unions necessitate a multifaceted approach, including mechanical stabilisation, replacement of bone loss and biological enhancement of healing.[9]

In the absence of a stable fixation, revision of the osteosynthesis is necessary to provide the stability required for bone union.[10] This issue was not encountered during the revision surgery, as there was no evidence of osteolysis of the metal work. The challenges were the extensive bone loss coupled with a deficiency in the local biological factors necessary to promote the healing process.

In this case, the bone loss encountered was secondary to the debridement of the devitalised non-union edges of the distal femur due to the previous open fracture sustained. In such cases, the resultant defect can be addressed in a single stage or multiple stages. The single-stage approach involves filling the defect with structural autografts, allografts or synthetic materials. Alternatively, staged management may involve techniques such as distraction osteogenesis using an external fixation device or the Masquelet technique.[11] When the bone loss is minimum, corticocancellous autografts, allografts or synthetic substitutes can be employed to fill the gap.[7 12 13]

Autografts possess osteoconductive, osteoinductive and osteogenic properties, making them ideal for promoting bone regeneration. In contrast, allografts and synthetic bone materials primarily offer osteoconductive scaffolding, facilitating bone growth on their surfaces.[14] To enhance their efficacy, these materials are often combined with mesenchymal stem cells or growth factors, such as bone morphogenetic proteins or platelet-rich plasma, to augment their osteoinductive potential and improve clinical outcomes.[15]

Here, a synthetic bone substitute was used to provide immediate structural support and facilitate new bone growth. The b.Bone is a ceramic resorbable scaffold (a framework that allows cell adhesion, proliferation and differentiation) available in variable forms.[16] In contrast to previously reported cases, the cylindrical shape for the bone substitute was selected, due to its ability to optimally fit the gap between the two bone fragments and provide support to the anterior femoral cortex.[17 18] Furthermore, the bone marrow aspirate concentrate, which contains mesenchymal stem cells and growth factors, was added to stimulate the healing process.[19] In vitro, it has been proven that the combination of b.Bone and stem cells has the potential to provide vasculature to the repair area.[20] The injection of stem cells at the site of synthetic scaffold implantation is a commonly employed strategy to enhance the scaffold's osteogenic potential.[21] In this case, no additional growth factor was used, as this synthetic material has an indirect osteoinductive property by design.[22]

The b.Bone is synthesised through the biomorphic transformation of rattan wood structures, featuring a distinctive, highly interconnected, porous 3D structure that mimics the hierarchical architecture and morphology of natural human bone.[8] The transformation process includes five steps: pyrolysis of rattan wood, to yield carbon templates; carburisation, to form calcium carbide; oxidation, to yield calcium oxide; carbonation, to form calcium carbonate; phosphatisation, to achieve the final hydroxyapatite phase.[23] The final product is composed of hydroxyapatite and beta-tricalcium phosphate along with metal ions (CO_3^{2-}, Mg^{2+}, Sr^{2+}), a combination that has the capacity to induce overexpression of genes associated with osteogenesis and facilitate interaction between osteoblasts and fibroblasts to stimulate angiogenesis.[24] In experimental studies, the implantation of b.Bone in structural defects has been observed to promote cellular infiltration and vascularisation, macroscopic new bone formation and remodelling and gradual microscopic scaffold bioresorption and integration.[25 26]

This synthetic scaffold was preferred over allogenic bone, as it is less expensive and combines the properties of both cortical and cancellous bone in a single ceramic graft.[27] b.Bone has been successfully used to fill bone gaps, providing structural support and promoting bone healing. However, being a new biomaterial, the clinical evidence demonstrating its effectiveness remains limited. Tosounidis and Pape[17] presented three cases with Schatzker II or III tibial plateau fractures treated with open reduction and internal fixation, with b.Bone implanted at the metaphyseal area. At follow-up, no reduction loss was observed, demonstrating the material's effectiveness in supporting the depressed joint line. Furthermore, b.Bone has been used to address bone loss in the iliac crest following tricortical autograft harvesting. Alt *et al*[18] and Mofori *et al*[28] reported nine cases and one case, respectively, where b.Bone was effectively used to repair iliac crest defects.

The use of a cylindrical bone substitute combined with bone marrow aspirate concentrate in the management of distal femoral non-union was associated with successful clinical and radiographical outcomes in this case. At the 2-year follow-up, both radiological union and clinical union were present. Interestingly, the density of the scaffold was still present on the radiographs, indicating that there is a slow process of complete transformation of the scaffold towards becoming natural bone. However, this finding is not uncommon as it has been reported for other types of synthetic bone substitutes.[29 30] It is believed that the mineral phase of the synthetic scaffold (hydroxyapatite and tricalcium phosphate) is responsible for this phenomenon of slow resorption. This approach offers a viable alternative to traditional bone grafting techniques, providing structural support, promoting biological healing and sparing the morbidity of harvesting autologous bone grafts. Further research is desirable to establish the broader applicability of this technique and to optimise patient selection criteria.

Patient's perspective

2-year follow-up

Before the operation, I was hardly walking, as I could not bear weight on my left leg. The pain I experienced was usually 10 out of 10. I could not participate in sports. I was isolated from my friends, and I had no social life. I was feeling down.

Today, 2 years after the operation, I can do all the things I did prior to the accident. I have tried climbing, cycling and football without any concern. I am looking forward to returning to my sports activities. Then and again, I have minimal pain now, but it is OK. I am very happy, I am really independent and I am not feeling a burden on my family anymore.

Learning points

- Cylindrical synthetic bone grafts can provide effective structural support in complex non-union cases with moderate to severe bone loss.
- Cylindrical synthetic bone substitutes offer a promising alternative to structural autografts and allografts, having limited drawbacks and potentially improved outcomes.
- The combination of a cylindrical synthetic bone substitute, which has osteoconductive properties, with bone marrow aspirate concentrate, which promotes osteoinduction and osteogenesis, presents an effective option to promote healing in cases of atrophic non-union.
- Careful patient selection and comprehensive preoperative planning are essential for optimising outcomes with cylindrical synthetic bone substitutes.

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