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Reconstruction with customized, 3D-printed prosthesis after resection of periacetabular Ewing's sarcoma in children using "triradiate cartilage-based" surgical strategy:a technical note

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ABSTRACT

Background: Surgery for Ewing sarcoma involving acetabulum in children is challenging. Considering the intrinsic structure of immature pelvis, trans-acetabular osteotomy through triradiate cartilage might be applied. The study was to describe the surgical technique and function outcomes of trans-acetabular osteotomy through triradiate cartilage and reconstruction with customized, 3D-printed prosthesis.

Methods: Two children with periacetabular ES were admitted to our hospital. The pre-operative imaging showed the triradiate cartilage was not penetrated or wholly affected by tumor. After neoadjuvant chemotherapy, the tumor was excised by trans-acetabular osteotomy basing on "triradiate cartilage strategy" and the acetabulum was reconstructed with the customized, 3D-printed prosthesis. The prosthesis was designed in Mimics software basing on the images from CT, optimized by topology technique, and examined in FE model. After implantation, the oncological and functional outcomes were evaluated with radiography, CT, and MSTS score.

Results: The operation time and intra-operative blood loss in these two children were 3.5h, 2.5h and 300 ml, 600 ml, respectively. The postoperative specimen showed the tumor was en bloc removed with safe margin. In the latest follow-up (48 months and 24 months), both patients were free of disease and had satisfactory function according to MSTS score. The radiography indicated the prosthesis fit the defect well without loosening.

Conclusion: The customized, 3D-printed prosthesis could provide optimal reconstruction of pelvic ring and satisfactory hip function after trans-acetabular osteotomy in children.

The translational potential of this article: This study provides promising results of implantation of customized 3D printing prosthesis in children's pelvic sarcoma, which may bring a new design method for orthopaedic implants.

Introduction

Ewing sarcoma (ES) is a small round-cell tumor, which is the second most common malignant bone tumor in children/adolescents and the fourth most common overall [1,2]. The pelvis is the second most common bony site of ES, accounting for 19.9% in the Mayo clinic series [3]. The pelvic ES resections are classified by tumor location and extension according to Enneking and Dunham [4]: Type I refers to resection of the ilium, type II to resection of the peri-acetabular region, type III to resection of the pubis or ischium, and type IV to resection of the lateral mass of the sacrum.

Pelvic tumor resection can result in substantial functional impairment, especially when acetabulum is involved. Various reconstructive options including biological reconstruction, iliofemoral arthrodesis, hip transposition, and prosthetic reconstruction have been established [5]. However, results showed high incidence of early and late complications, especially in type II resection [6,7].

Unlike type I and type III resection, type II usually requires excision of whole acetabulum in adults to get safe margin, which severely impairs hip function. However, in skeletally immature children, the acetabulum has its own intrinsic structure: the triradiate cartilage (tri-flanged hyaline cartilage). The triradiate cartilage usually fuses at 15–18 years of age [8]. It is generally believed that hyaline cartilage could impede the tumor extension, although it is not an impenetrable barrier. The reasons could

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be that chondrocytes may retard tumor invasion by secreting potent anti-angiogenic factors [9].

Considering the special acetabular structure in children, trans-acetabular osteotomy through triradiate cartilage can be performed to excise tumor. This surgical strategy can maximally retain the unaffected acetabulum to get better functions as well as the growth potential of residual acetabulum. Winkelmann et al. [10] removed the iliac sarcoma at the triradiate cartilage level and leaved more than 2/3 of the acetabulum in three children. After transposition of the remaining acetabulum to the lateral side of sacrum, the hip joint could be preserved. However, the patients' gait was substantially influenced by leg length discrepancy. Ozaki et al. [11] treated four children with pelvic Ewing's sarcoma involving the acetabulum close to the triradiate cartilage. Three patients underwent a hip transposition after the resection of the ilium and the upper acetabular part. One patient underwent no skeletal reconstruction. Functional evaluation showed one was excellent, and three were fair. Sales de Gauzy et al. [12] resected the tumors which were located at the pubic ramus with an extension to the acetabulum (type II + III) in 2 children. The trans-acetabular resection through triradiate cartilage was performed without reconstruction. The follow up results showed prolonged hamstring activity at the middle stance phase and Trendelenburg limping gait. Therefore, the acetabular reconstruction is highly needed. We previously used similar surgical strategy to perform trans-acetabular osteotomy in 8 children with open triradiate cartilage [13]. The periacetabular tumor was removed and allograft was used for reconstructions. Nevertheless, the following problems still exist with allograft reconstruction: 1) owing to the limited availability of pediatric allografts, the allografts from bone bank were over-size and required cutting or trimming to fit the defects; 2) the immunogenic response and insufficient osteogenic ability of allograft continue to be a significant concern. The reported potential advantages, indications, clinical results, complications, limitations and potential future development for children undergone trans-acetabular osteotomy were summarized in Table 1.

Recently, the Ti–6Al–4V (TAV) prosthesis manufactured by 3D-printing technique have been extensively used in orthopedic surgeries including revision arthroplasty, spine surgery, and reconstruction after tumor excision [14–18]. The 3D-printing technique can achieve precise manufacturing, complex shape, and appropriate micropores for osteointegration. We previously designed and implanted customized 3D-printed prosthesis to reconstruct shoulder and hip joints after sarcoma resection [19]. All patients could achieve better functions in long-term follow up. Considering the aforementioned drawbacks of allograft and unique advantages of 3D-printing technique, we hypothesize that implantation of customized, 3D-printed prosthesis can reconstruct acetabulum and restore hip function after trans-acetabular osteotomy through triradiate cartilage in children.

To our knowledge, there were few reports on customized, 3D-printed prosthesis of reconstruction after trans-acetabular osteotomy in children. We report two cases of periacetabular ES treated by trans-acetabular osteotomy through triradiate cartilage followed by customized, 3D-printed prosthesis reconstruction, aiming to describe the design of prosthesis, the surgical technique, and clinical/functional outcome of the patients.

Materials and methods

Patient characteristics

In June 2016 and January 2018, two children (age: 6 and 8) with periacetabular ES were admitted to our hospital. The pre-operative imaging showed the triradiate cartilage was not penetrated or wholly affected by tumor. According to our reported classification [13], these two children had type I + IIA lesions. Bone scan and chest CT indicated that there was no evidence of distant metastasis. All patients received neoadjuvant chemotherapy with VAC (vincristine + doxorubicin + cyclophosphamide) alternating with IE (ifosfamide + etoposide) for at least 12 weeks prior to surgery. Thereafter, the tumors were excised by trans-acetabular osteotomy basing on "triradiate cartilage strategy" [13]. This surgical technique was illustrated in Fig. 1, it can maximally preserve the unaffected acetabular component. Then, the customized, 3D-printed prostheses were subsequently implanted to reconstruct acetabulum. The study was approved by the institutional review board of Xi-Jing Hospital, Air Force Military Medical University.

Design and manufacture of prosthesis

The patients were scanned by thin section CT with a slice thickness of 0.625 mm. The CT data in DICOM form was imported into Mimics software (16.0, Materialise Inc., Leuven, Belgium) to construct the pelvic model. According to our reported method [20], inhomogeneous material properties were rendered to the pelvic model according to the corresponding grey scale value. The ischium, pubic, and sacrum were assigned various Young's Modulus to construct finite element (FE) model of pelvis. Under virtual condition, the tumor was simulated to be excised with safe margin and prosthesis was designed to fill the defect. The prosthesis was designed to transfer the loading from acetabulum to sacrum. The interface to sacrum and residual acetabulum was porous structure for bone ingrowth. The loading on prosthesis was examined when pelvis is under loading conditions of six daily activities including walking, single leg standing, standing up, sitting down, ascending stair, and descending stair in FE model. The topology optimization technique was used to reduce the weight/volume of the prosthesis by removing the unnecessary material from the region with zero loading to bear. The final design data were imported into EBM S12 system (Arcam AB, Sweden). Then, the TAV alloy powder was melted layer by layer in the EBM system to manufacture prosthesis. Thereafter, the residual powder in prosthesis was removed by acid treatment and ultrasonic cleaning. Finally, the prosthesis was sterilized and packed for further use. The prosthesis was tested according to the National Standard of Implants for Surgery in China. It took two days to design prosthesis, three to four days for printing, packaging and shipping prosthesis. The lead-time required about a week from the request to the implant availability.

Surgical procedure

The surgery was performed in the lateral decubitus position. An extended ilioinguinal incision and a vertical incision toward the great trochanter was used for tumor resection. The retroperitoneal iliac vessels and femoral nerve were dissected and protected. The glutei are mobilized to expose the sciatic notch and sciatic nerve was protected. The resection was performed with the aid of computer assisted navigation system (CANS; Stryker Pacific, Ltd., Hong Kong, China). The preoperative image data from CT, MRI and bone scan were integrated in CANS. Based on these images, a 3D pelvic model was reconstructed. The pelvic model was used for preoperative planning and navigation-guided resection as reported previously [21]. With the assistance of CANS, the patients underwent precise resection through the sacroiliac joint and triradiate cartilage. The upper component of acetabulum and neighboring ilium (type I + IIA) was meticulously removed. After tumor removal, a customized, 3D-printed prosthesis which precisely matched the bony defect was implanted. The upper microporous surface was pressed fit in lateral mass of sacrum, the lower microporous surface was intimately attached to residual part of pubis and ischium, and the lower smooth surface joined the residual acetabulum to form the acetabular fossa. The two screws passed through the holes in the upper portion of prosthesis into the S1 and S2 vertebral body. Another two screws passed the holes in lower portion of prosthesis into the residual part of pubis and ischium, respectively. The residual joint capsule was sutured to small holes in the peripheral rim of prosthesis to prevent hip dislocation. The residual abductor muscles were reattached to the implant by suturing. Partial weightbearing was started six to eight weeks after operation, but full weightbearing was not allowed until three months.

Table 1
Clinical data of children undergone trans-acetabular osteotomy for tumor excision.

Study/Year	Pelvic zone involved (pts No.)	Age (year)	Indications	Recon. (pts No)	FU (month)
Ozaki et al. [11] /1998	Ilium and acetabulum close to TRC (3); pubis and acetabulum close to TRC (1)	7.8	Open TRC and no tumor crossing	None (1); hip transposition (3)	21
Sales et al. [12] /2014	Ilio-pubic and ischio-pubic part close to TRC (2)	8	1) Open TRC and no tumor crossing 2) intact ilio ischiatic ramus	None	144 (1); 36 (1)
Fan et al. [13]/2017	Ilium and partial acetabulum (3); pubis and partial acetabulum (4); ischium and partial acetabulum (1)	12	Open TRC and no tumor crossing	Allograft and plate (12)	39
Current study	Ilium and partial acetabulum (2)	7	Open TRC and no tumor crossing	Customized 3D printing prosthesis (2)	48 (1); 24 (1)

TRC: triradiate cartilage; pt: patient; CAS: computer-assisted surgery; Recon.: reconstruction, FU: follow up; ANED: alive with no evidence of disease; DOD: died of disease; AWD: alive with disease

Post-operative management

Patients were asked to undergo non-weight-bearing ambulation for the first 6–8 weeks post-operatively. Partial weight-bearing ambulation using crutches or a walker was encouraged between weeks 9 and 12, and full weight-bearing ambulation was not allowed until osteointegration was achieved at implant–bone interface in CT scans.

Follow-up

The patients had regularly scheduled follow-up, they were assessed at 2 weeks, 1 month and 3 months after surgery, and every 3 months thereafter for the first 2 years, then every 6 months between 2 and 5 years. Radiological examination (radiograph or CT scan) of the pelvis and physical examinations were performed at each follow-up appointment. To assess for metastatic disease, chest CT was performed every 3 months for the first 2 years after surgery and every 6 months thereafter.

Results

Case presentations

Case 1

A 6-year-old child had right iliac pain and lameness without clear reason. A core needle biopsy showed the diagnosis of Ewing sarcoma in right ilium. Pelvic radiograph and CT images revealed a large, permeative destructive lesion in right ilium with soft tissue mass (Fig. 2A and B). The 3D reconstructed CT images might assist the surgeons in locating expandable osteolytic lesion with soft-tissue invasion (Fig. 2C). The coronal and sagittal CT images showed the tumor extended from the ilium to the upper component of acetabulum adjacent to the triradiate cartilage (Type I + IIA). The tumor did not penetrate the triradiate cartilage (Fig. 2D). The patient received neoadjuvant chemotherapy with VAC/IE for 12 weeks prior to surgery.

Based on the images from CT and MRI, a 3D tumor model was reconstructed in CANS. The model was used for preoperative surgical planning and intraoperative guiding resection. After topology optimization and FEA in the implant design, the final data was used to manufacture 3D printing prosthesis (Fig. 3). Before operation, the customized, 3D-printed prosthesis was simulated to be implanted after tumor excision in pelvic model. This procedure was to check initial integration between the bone and the implant (Fig. 4A and B). With the help of CANS, the right ilium and upper component of the acetabulum was precisely excised en bloc (Fig. 4C). The prosthesis was implanted to fill the bone defect by fixation on sacrum and residual pubic/ischial ramus with screws. Because the poor bone quality was found in operation, a plate was also used to reinforce the initial stability (Fig. 4D). It took around 3.5 h to complete the surgery and intraoperative blood loss was about 300 ml.

The patient was required to have partial weight-bearing activity at 6–8 weeks and full weight-bearing at 12 weeks postoperatively. She was followed up for 48 months and there was no recurrence or metastasis (Fig. 5). At the latest follow-up, she was event-free and presented a painless gait with a mild right-sided lurch. Radiographs showed that the femoral head had slightly lateral protrusion (Fig. 5A). It did not lead to any obvious symptom. The patient acquired good hip functions including weight-bearing position, flexion, internal/external rotation, and abduction (Fig. 6). According to the Musculoskeletal Tumor Society (MSTS) score, the result was excellent (27, 90.0%).

Case 2

An 8-year-old child developed slowly progressive pain and swelling in the left hip for 3 months. After the patient was referred to our hospital, the tenderness with a palpable mass was obvious in left pelvis. Pelvic radiographs and MRI showed a mixed lyticsclerotic lesion on the left ilium. The tumor had high signal intensity on T2-weighted MRI. It involved the left ilium and juxta-acetabular bone close to triradiate cartilage (Fig. 7A and B). The CT scan revealed the tumor did not cross the triradiate cartilage (Fig. 7C and D). The biopsy confirmed the diagnosis of pelvic Ewing sarcoma. After 12 weeks of new adjuvant chemotherapy, the patient underwent surgery. The 3D printing prosthesis was designed and manufactured after topology optimization and finite element analysis (FEA) (Fig. 8). The 3D reconstructive CT images helped

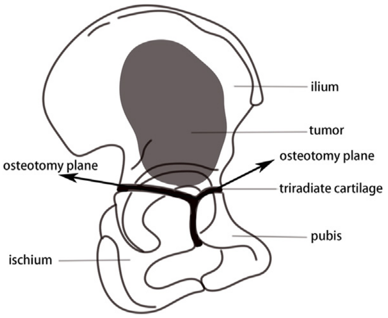

Fig. 1. The tumor was located in the ilium and infiltrated the acetabulum close to the triradiate cartilage (TRC). And the osteotomy could be performed through TRC to maximally preserve the un-affected acetabular component.

Functional score (MSTS)	Status (pts No)	Complications	Potential advantages	Limitations	Future development
Excellent (1); Fair (3)	ANED (2); DOD (1); AWD (1)	Major leg-length discrepancy (7–9 cm)	Limb salvage	Arthrosis caused by hip transposition needs further surgery	Solve the problem of postoperative limb deformity
Excellent (100%; 90%)	ANED (2)	Medial subluxation; abnormal gait; Trendelenburg limping gait; loss of hip flexion	Limb salvage; preserve partial acetabular development	Not applicable for children with tumor involving upper acetabular component	CAS to increase the safety and accuracy of procedure.
Excellent (90%)	ANED (6); DOD (1); AWD (1)	Wound healing; leg-length discrepancy (2 cm); screw loosening	Limb salvage; preserve partial acetabular development	Allografts: limited availability; over-size; risk of disease transmission; immunoreaction	To match the growth potential between femoral head and reconstructed acetabulum
Excellent (93%; 90%)	ANED (2)	Slightly lateral protrusion of femoral head	Limb salvage; preserve partial acetabular development; Geometrical adaptiveness for irregular bone defect	Complex surgical technique and rich surgical experience needed	To match the growth potential between femoral head and reconstructed acetabulum

the surgeon understand the spatial location of tumor (Fig. 9A). The prosthesis was simulated to be implanted in pelvic model before operation to verify the matching (Fig. 9B). All image data were imported into CANS for 3-D tumor model reconstruction and navigation-guided excision. After appropriate registration and calibration, the surgeons could locate the bone cutting plane with navigation tools. Then, the trans-acetabular resection through triradiate cartilage was performed according to preoperative plan. Thereafter, the tumor was removed en bloc and prosthesis was implanted to reconstruct pelvic ring (Fig. 9C). The prosthesis was fixed to the sacrum and residual pubis/ischium with screws (Fig. 9D). The reconstruction plate was not needed in this case since the bone quality was good and screws could provide immediate stability. The duration of surgery was 2.5 h and blood loss was 600 ml. The postoperative radiograph showed the placement of prosthesis was

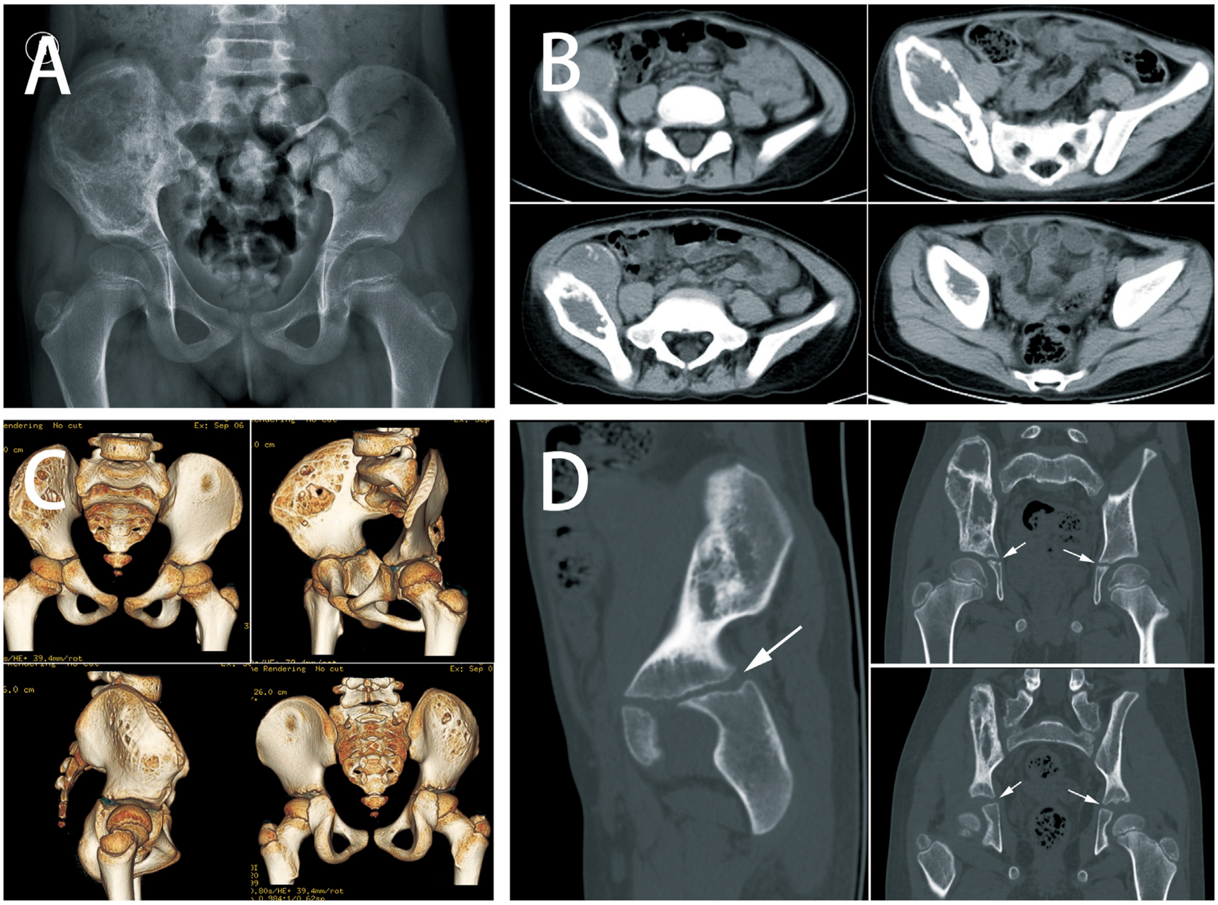

Fig. 2. **(A)** Pelvic radiograph showed a large osteolytic lesion in the right ilium. **(B)** Axial CT images showed a large destructive lesion in the right iliac wing with soft tissue mass. **(C)** The 3D reconstructed CT images showed the expandable osteolytic lesion with soft-tissue invasion. **(D)** The coronal and sagittal CT images showed that the tumor did not penetrate the triradiate cartilage. (indicated by white arrow).

satisfactory (Fig. 10A). Adjuvant chemotherapy was continued after operation. Partial weight-bearing activity started at 3 months after surgery and full weight-bearing was allowed at 6 months. The patient was followed up for 24 months. At the latest follow-up, the patient was event-free. The patient had a Trendelenburg limping gait and the hip range of motion was normal. There was no leg length discrepancy. The result was excellent according to MSTS score (28, 93.3%). The radiograph and CT image at 24-month follow-up showed the femoral head was well centered (Fig. 10A and B). The 3D reconstruction of CT images indicated the femoral head had adequate coverage (Fig. 10C and D).

Discussion

With the advancement of multidisciplinary treatment, the outcomes of pelvic ES have improved. However, the excision and reconstruction of pelvic ES involving acetabulum remain challenging [1,22]. In immature pelvis, trans-acetabular osteotomy through triradiate cartilage was reported to preserve unaffected acetabulum as much as possible [10]. Anatomy study showed the acetabular cartilage complex was composed of epiphyseal growth-plate cartilage adjacent to the ilium, ischium, and pubis. All growth plates were centrally confluent with triradiate cartilage, which caused the hip socket to expand during growth [23]. In children, these three bones are separated by triradiate cartilage, which was considered to be the barrier of tumor invasion. It may allow performing a wide resection while maximally preserving the acetabulum, although the growth plate is a relatively safe margin [10,24]. Consequently, the prerequisite for this osteotomy strategy is an open triradiate cartilage (non-ossification) without tumor invasion. MRI is the preferred method to show the relationship between tumor and growth plate with 90.3% accuracy rate [25]. In these 2 cases, MRI images showed the triradiate cartilage was not infiltrated by tumor. The ilium and upper component of acetabulum were safely removed.

Although various reconstructions including allograft, autograft, hip transposition, and prosthetic replacement have been reported, periacetabular reconstruction is still challenging due to high rate of complications and limited functional outcomes, especially for immature pelvic tumor [6,7,26,27]. In aforementioned methods, prosthetic reconstruction has been paid more and more attention with the development of 3D-printing technology. The most significant advantage is that the customized prostheses can be fabricated to match the irregular bone defect perfectly. The bone-implant interface also can be processed to porous structure imitating the trabecula, which can facilitate bone in-growth and offer the long-term mechanical stability [14,18,28]. The screws through the holes of prosthesis are used to fix the implant to the residual pelvic bone for immediate stability. Liang et al. [14] also introduced a 3D-printed screw-rod connected hemi-pelvic prosthesis. It was a modular prosthesis, which could provide more flexibility at the time of the reconstruction. Nevertheless, it was not fitful for the reconstruction in children with partial acetabular resection. In current study, the customized prosthesis required precise excision to achieve accurate reconstruction. This also means that the surgeon must perform the osteotomy according to the pre-operative plan and cannot make timely adjustments. The sacrum contacting surface of our prosthesis is designed with a wrapping-edge structure, which is beneficial to press-fit. Compared to other customized acetabular prosthesis [29], this implant has lower weight and more remarkable strength after finite element analysis.

The prerequisite for precise placement of customized prosthesis is

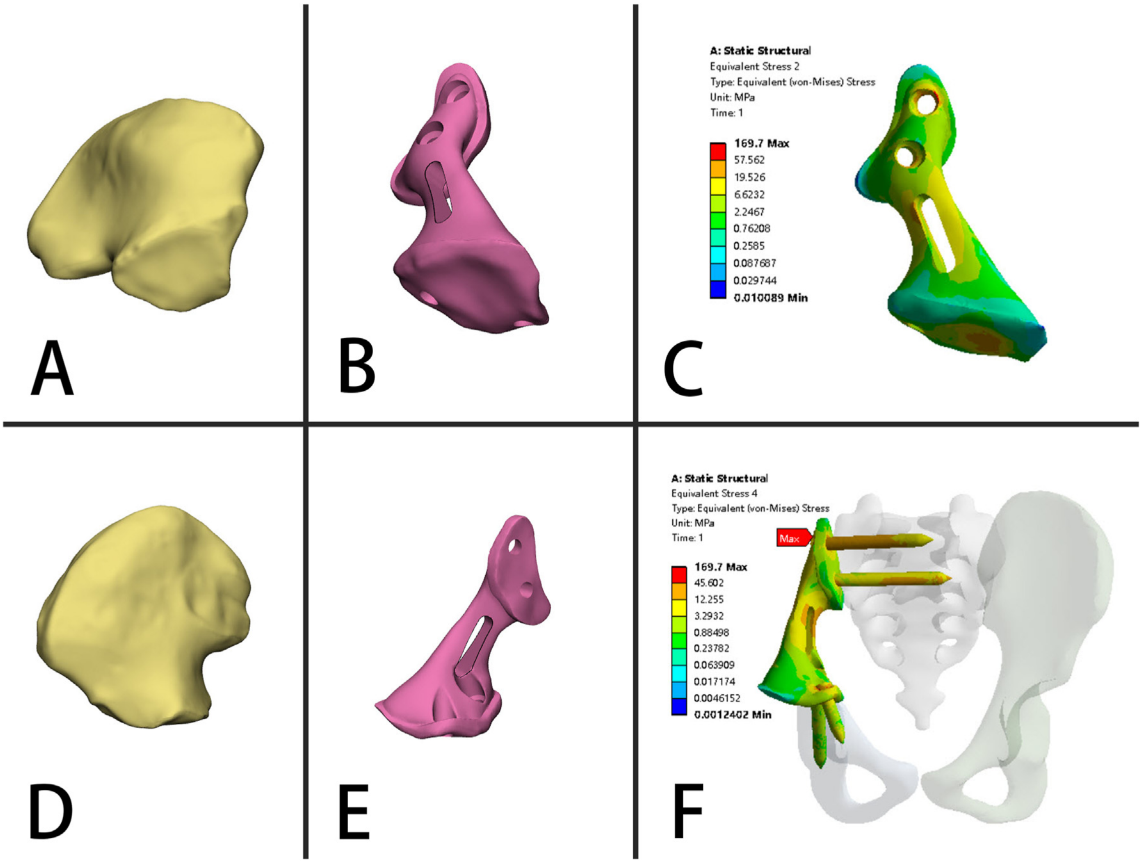

Fig. 3. (A, D) The A-P and lateral view of the prosthesis that was designed to mimic pelvic anatomical structure basing on CT data by Mimics software. (B, E) The A-P and lateral view of the prosthesis with reduced volume after topology optimization. (C) The loading on prosthesis was examined in finite element (FE) model to determine the proper design. (F) The prosthesis was simulated to install on pelvic model.

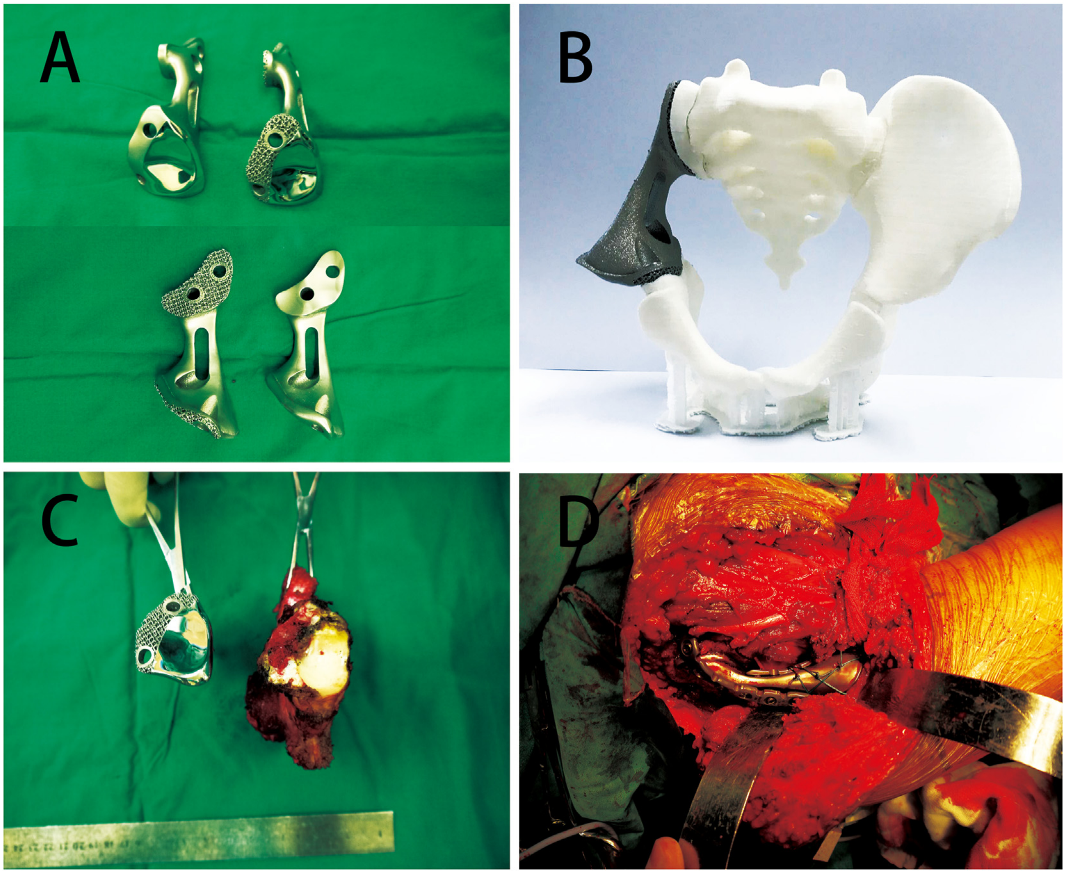

Fig. 4. **(A)** Gross photography of 3D-printed prostheses **(B)** Preoperative simulated reconstruction was performed in pelvic model to verify the matching between prosthesis and residual bone. **(C)** The comparison image of excised tumor and the prosthesis. **(D)** The 3D-printed prosthesis was implanted after tumor excision.

accurate resection according to surgical planning. Studies indicated that navigation-assisted surgery in tumor excision was an efficient technique with less complication and better oncological outcome [30,31]. Considering the soft tissue involvement, both MRI and CT image data were input into navigation system to reconstruct fusion images and 3D tumor model. This technique could keep surgeons aware of the suitable extent of resection to achieve safe margin. In this study, the tumor was en bloc removed with safe margins with the help of navigation system. Compared with traditional surgical technique, experimental study showed that navigation system could significantly improve cutting accuracy during simulated pelvic osteotomy, averaging 2.8 mm as compared to 11.2 mm for the free-hand cutting procedure [32]. In patients, navigation-guided surgery could reduce intralesional resection rate for pelvic and sacrum tumors with the registration error$<$1 mm [30]. In a retrospective study of 21 patients, the disease-free survival was significantly better with navigation-assistance [31]. Moreover, the precision of intra-operative installation of customized prosthesis could be improved three to five times compared with the non-navigated [33].

In the first case, the bone quality was not good at the time of intra-operative inspection because of long-term bed rest. Therefore, the reconstruction plate was used to reinforce immediate stability. After 4-year follow-up, the patient had no recurrence and metastasis. The hip function was good and the patient was able to walk without crutches. However, the patient presented a painless gait with a mild right-sided lurch. Other relevant study showed the femoral head could migrate superiorly and laterally after upper acetabular component excision without reconstruction in children. The degree of displacement was associated with the age at diagnosis and the length of follow-up [34]. In this study, the patient's height increased rapidly. At the most recent follow-up, the femoral head slightly displaced laterally in radiograph although the

Fig. 5. **(A)** Pelvic radiograph at 48 months postoperatively; **(B)** CT indicated that the bone was tightly bound to the prosthesis at the interface 48 months postoperatively; **(C)** Radiograph of the full length of both lower limbs at 48 months postoperatively.

Fig. 6. (A) Weight-bearing position of the patient. (B) Flexion position of the patient. (C) External position of the patient. (D) Internal position of the patient. (E) Abduction position of the patient.

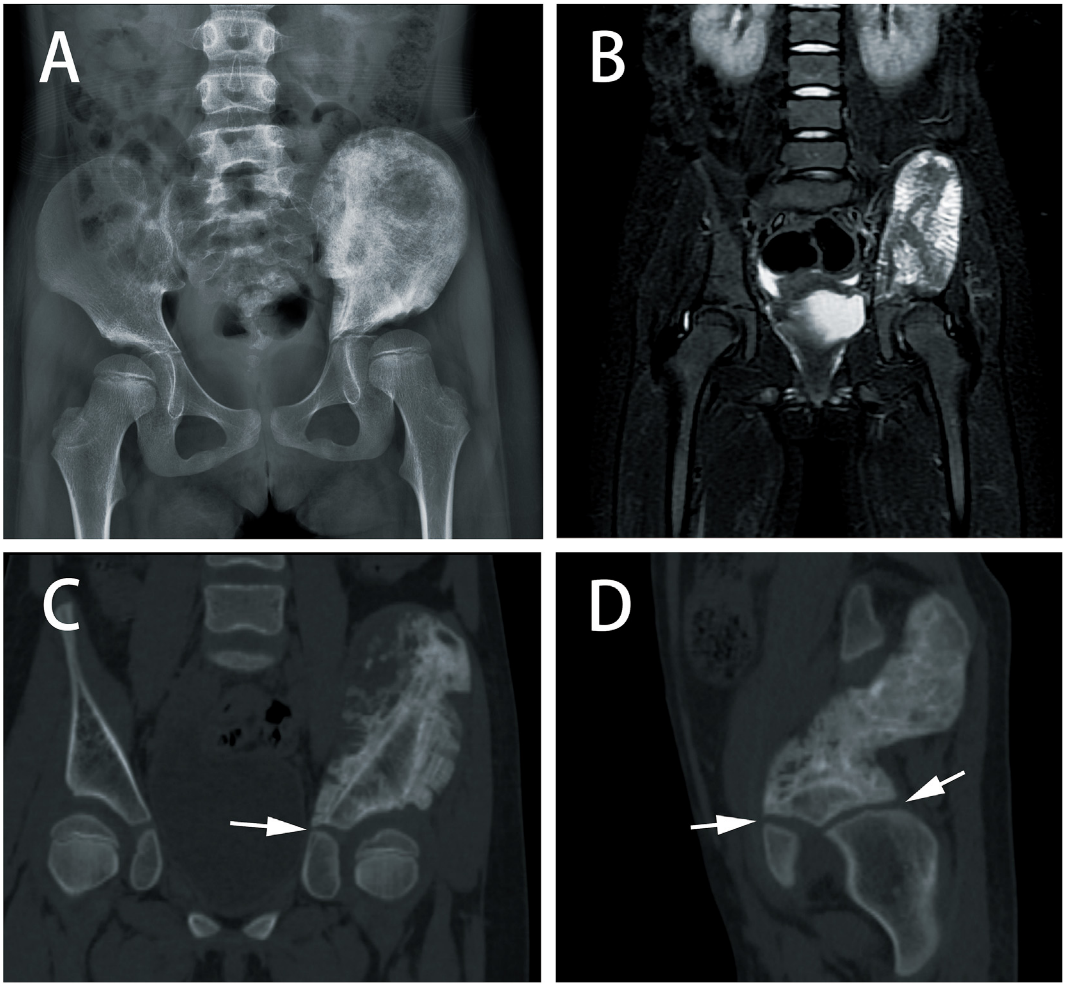

Fig. 7. (A, B) The X-ray and MRI of pelvis indicated the lesion of left ilium and upper acetabular component with soft tissue mass. (C, D) The coronal and sagittal CT images showed the tumor did not penetrate the triradiate cartilage (indicated by white arrow).

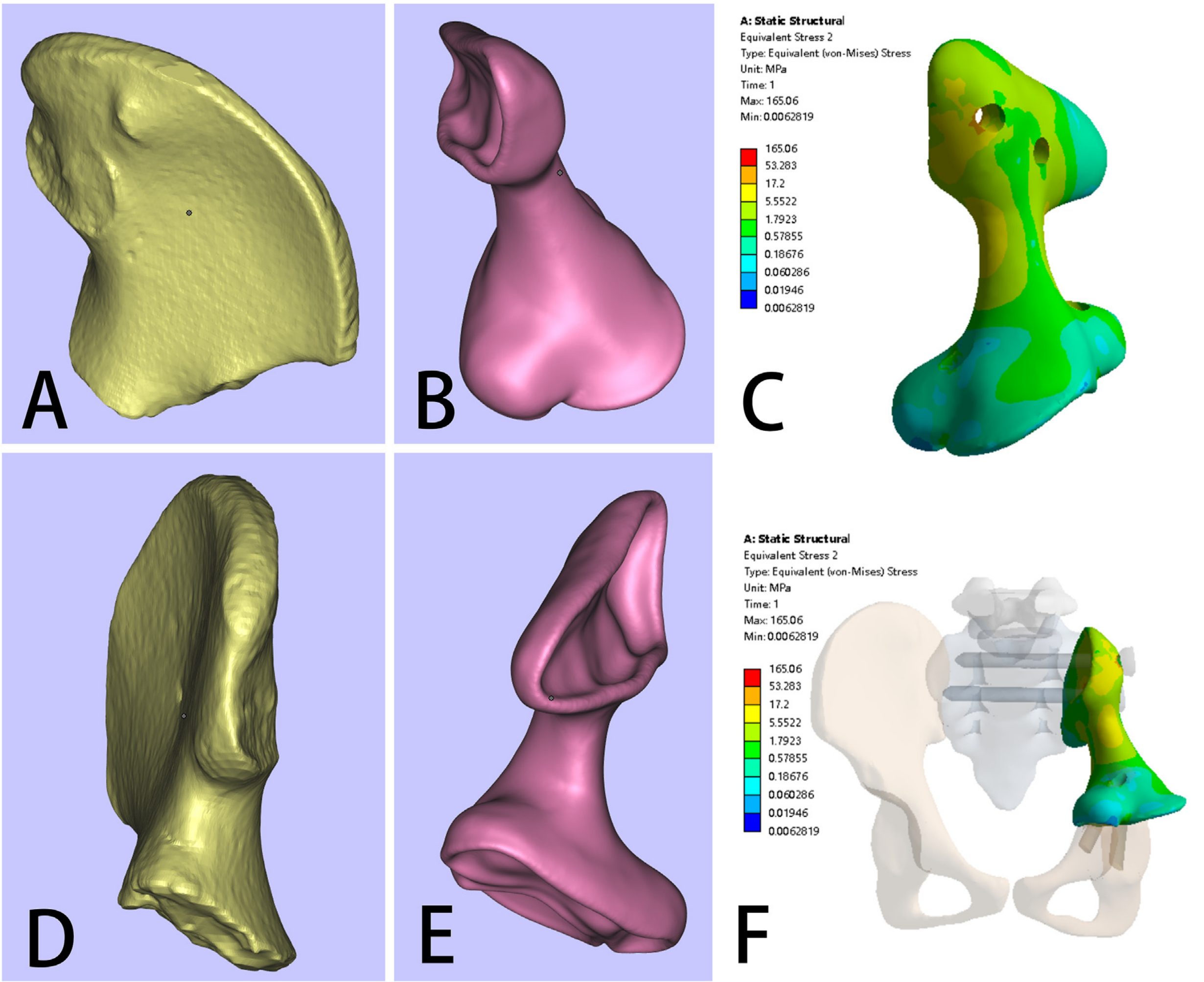

Fig. 8. (A, D) The A-P and lateral view of the prosthesis that was designed to mimic pelvic anatomical structure basing on CT data by Mimics software. (B, E) The A-P and lateral view of the prosthesis with reduced volume after topology optimization. (C) The prosthesis was examined in finite element (FE) model. (F) The prosthesis was simulated to install on pelvic model.

prosthesis was initially designed to a bigger size compared to native acetabular size for improving coverage of femoral head. Over-sized prosthesis usually required favorable soft-tissue coverage. However, the tumor resection needed sacrifice more soft tissue to achieve safe margin. Therefore, how to balance these two factors is still a question. In that case, flaps or artificial patch were used for closure of soft tissue defects. The migration of the femoral head might be attributed to the acetabular growth in children and imbalance of muscle force caused by tumor excision.

The second patient could ambulant without any aid. Before operation, finite element analysis indicated that the customized prosthesis was able to withstand the stress conditions of various activities [20]. At latest follow-up, the patient had no recurrence or metastasis, and the patient's hip function was well. Considering the possibility of dislocation due to acetabular growth, the customized 3D-printed prosthesis with changeable joint surface component maybe need further studied.

The short-term effects of metal prosthesis did not seem to have seriously influenced the development of degenerative changes of femoral head. Due to mechanical wear, the prosthesis theoretically released particles to increase articular inflammation and cartilage degeneration in long-term. Because there was no commercial hip prosthesis for young children, this customized 3D printing prosthesis was an expedience.

There were limitations in current study. Firstly, only two children with acetabular Ewing's sarcoma were included. Because of the small number of young children with acetabular sarcoma being surgically treated even in big tumor centers, multicenter collaborations are necessary to recruit an adequate number of patients in the future. Secondly, it was a short-medium follow up. Long-term follow-up is needed to further investigate the oncological and surgical outcome regarding this prosthesis.

In conclusion, the children with acetabular Ewing's sarcoma were successfully treated with our surgical strategy. Their tumor was removed by trans-acetabular osteotomy through triradiate cartilage. The defect was reconstructed with customized 3D-printed prostheses guided by navigation system. Up to the present follow-up, they were free of the disease and had satisfactory function. This study shows us the promising

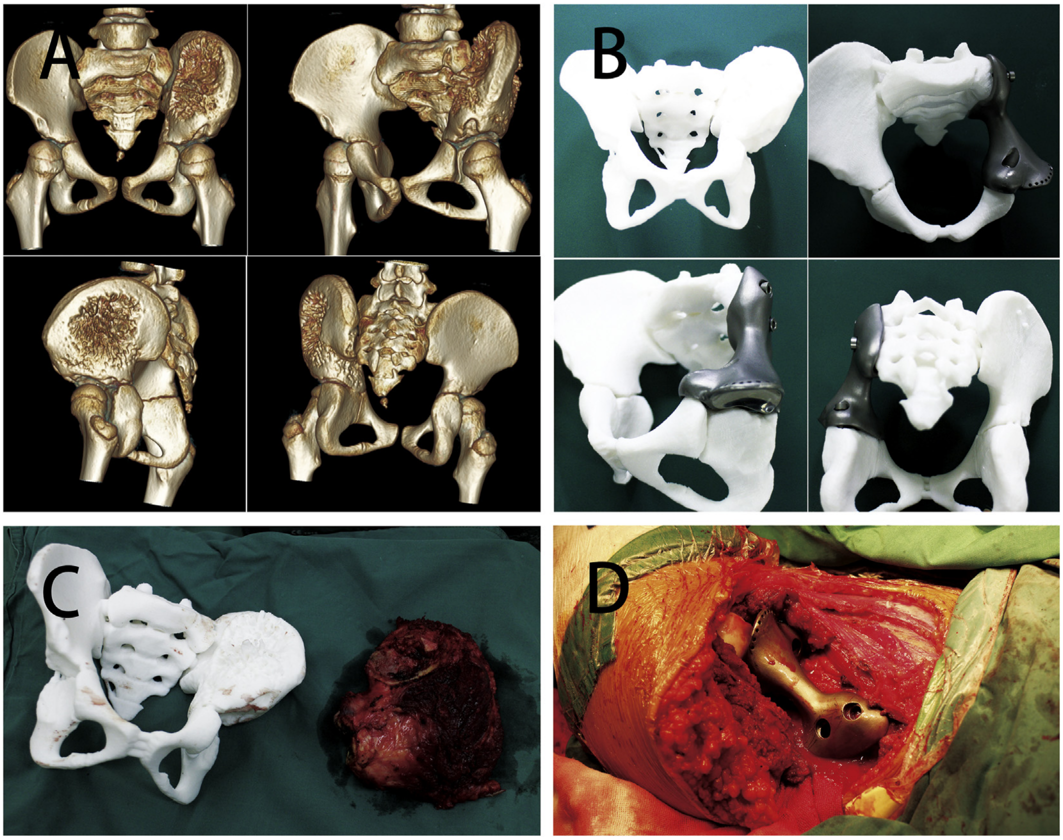

Fig. 9. **(A)** Pre-operative CT reconstruction showed the lesion located in left ilium and upper acetabular component; **(B)** The prosthesis was simulated to be implanted in pelvic model to verify the matching; **(C)** The comparison photograph of pelvic model and excised tumor; **(D)** The intra-operative image showed the prosthesis was implanted to fill the defect.

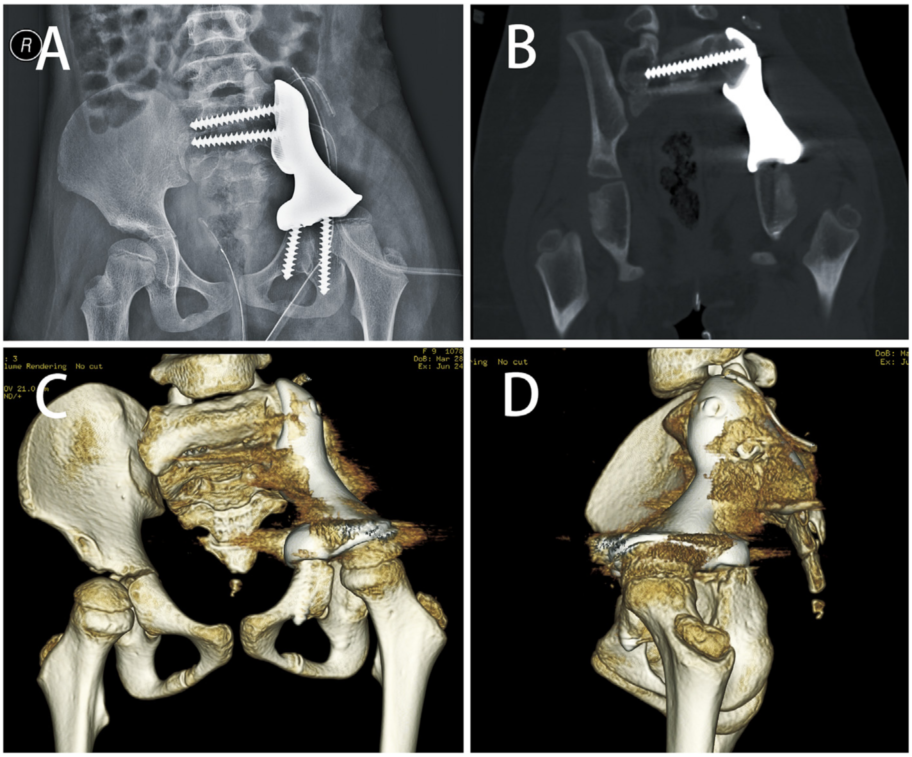

Fig. 10. **(A)** Pelvic radiograph immediately after operation; **(B)** CT scans at 24 months postoperatively; **(C, D)** 3D reconstruction of CT image showed the prosthesis was in appropriate position and femoral head had adequate coverage.

primary results of pelvic ES in children.

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Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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