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3D PRINTING APPLICATION IN BONE DEFECT AREA MEASUREMENT ON PATIENTS WITH DEVELOPMENTAL DYSPLASIA OF THE HIP

APLICAÇÃO DE IMPRESSÃO 3D NA MENSURAÇÃO DA ÁREA DE DEFEITOS ÓSSEOS EM PACIENTES COM DISPLASIA DO DESENVOLVIMENTO DO QUADRIL

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ABSTRACT

Objectives: Evaluate the application value of 3D printing technology in measuring acetabular bone defect area in adult patients diagnosed with developmental dysplasia of the hip (DDH). Methods: 23 cases of DDH requiring total hip replacement surgery were enrolled in this study. Preoperative examination confirmed the standard pelvic plain films Crowe, including 3 cases of Crowe I, 7 Crowe II, and 13 Crowe III. The 3D printing technology was used to print the hip model before the operation. Based on the pre-printed model, pre-operative planning and surgical procedures were established. The area of the acetabular bone defects was measured, the selected size prosthesis was recorded, and the surgery was performed (group A). The actual acetabular bone defect area and the prosthesis size were also recorded (group B). Results: The comparative results indicated that the actual acetabular defect area measured intraoperatively and the area measured using the 3D printing technology did not significantly differ for all participants (all P>0.05). Conclusion: Preoperative model can accurately measure the acetabular bone defect area for DDH. It is significant to develop individualized implants for DDH patients treated with the 3D printing technique. ***Level of Evidence IV: Case series.***

Keywords: Developmental Dysplasia of the Hip. 3 D Printing. Arthroplasty, Replacement, Hip.

RESUMO

Objetivos: Avaliar o potencial da aplicação da tecnologia de impressão 3D na medição da área de defeito ósseo acetabular em pacientes adultos diagnosticados com displasia do desenvolvimento do quadril (DDH). Métodos: 23 casos de DDH que requereram cirurgia de substituição total do quadril foram incluídos neste estudo. O exame pré-operatório confirmou os filmes pélvicos padrão Crowe, incluindo 3 casos de Crowe I, 7 Crowe II, e 13 Crowe III. A tecnologia de impressão 3D foi utilizada para imprimir o modelo de quadril antes da operação. Com base no modelo pré-impresso, o planejamento pré-operatório e os procedimentos cirúrgicos foram estabelecidos. A área dos defeitos ósseos acetabulares foi medida, a prótese de tamanho selecionado foi registrada, e a cirurgia foi realizada (grupo A). A área do defeito ósseo acetabular real e o tamanho da prótese também foram registrados (grupo B). Resultados: Os resultados comparativos indicaram que a área real do defeito acetabular medida intraoperatimente e a área medida usando a tecnologia de impressão 3D não diferiu significativamente para todos os participantes (todos P>0,05). Conclusão: O modelo pré-operatório pode medir com precisão a área de defeito ósseo acetabular para DDH. É relevante desenvolver implantes individualizados para pacientes com DDH tratados com a técnica de impressão 3D. ***Nível de Evidência IV: Série de casos.***

***Descritores**: Displasia do Desenvolvimento do Quadril. Impressão em 3D. Artroplastia de Quadril.*

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INTRODUCTION

The pathological changes underlying the developmental dysplasia of the hip (DDH) are mainly the reduction of femoral head acetabular coverage, which leads to unstable femoral head and anterolateral displacement and changes in the joint load status. Total hip arthroplasty (THA) is primarily performed for adults with DDH end-stage osteoarthritis and who will face three major challenges in acetabular reconstruction and soft tissue balance of the hip joint and femoral medullary cavity intraoperatively.[1] Given the considerable changes in the anatomy of the acetabulum, especially in adult DDH patients with Crowe Ⅲ, type IV patients have poorly developed mortar and are affected by the loss of

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femoral head. The outer wall often has defects. Coverage on the upper edge of the acetabulum is lacking when the prosthesis is placed on a mortar and is loose with insufficient support.[2] Preoperative condition of patients with acetabular bone defect area must be understood to guide the operation. Bone grafting method and prosthesis choice are of great significance when printing out the ipsilateral acetabulum of the patient using 3D printing technology. The acetabular bone defect area can be quantitatively measured through the print model. 3D printing technology is the use of metal or plastic powder and other special materials applied with laser beam or hot melt nozzle and other methods in the 2D X-Y plane bonded to a cross-sectional shape and in the Z coordinate layer overlay. In contrast to the traditional four "cut-and-remove" material approaches, 3D printing uses a "layer-by-layer" approach to making 3D solids.[3] In this investigation, whether or not 3D printing can accurately measure the area of acetabular bone defects in adults with DDH and contributes to guiding the surgery was investigated.

MATERIALS AND METHODS

Hard- and soft-ware

Hardwares and softwares mainly consisted of 3D Reconstruction Software Mimics 10.01 (Materialize, Belgium), 3D Printer, OS: Windows 7 Home Basic 64 bit, Photoshop CS6 (Adobe, USA) and SPSS19.0 Statistical Software (SPSS Inc., Chicago, U.S.).

Inclusion criteria

Those suffering from pain severely affecting daily life; workers aged 40–75 years; those untreated after conservative therapy; those requiring total hip arthroplasty of all types of adult DDH end-stage osteoarthritis; those with no medical history of hip orthopedic surgery; those with no medical history of hip injuries; those able to tolerate surgery and with some knowledge of the procedures. All surgical procedures were performed by the same highly-qualified surgeon using the same surgical approach.

Exclusion criteria

Those complicated with alternative severe diseases; those fail to tolerate the surgery; those who are allergic to the implant; those suffering from mild pain whichdoes not affect their normal quality of life; those refused the surgery and the pregnant or lactating female patients.

Preoperative examination

All patients underwent preoperative physical examinations, routine blood test, coagulation, immunity and other laboratory tests. Shooting pelvic plain film, full-length double-leg films, and hip CT scan + 3D reconstruction were also conducted. Scanned data were obtained as output in a recordable DVD disc to preclude the risk of surgical contraindications. (Figure 1)

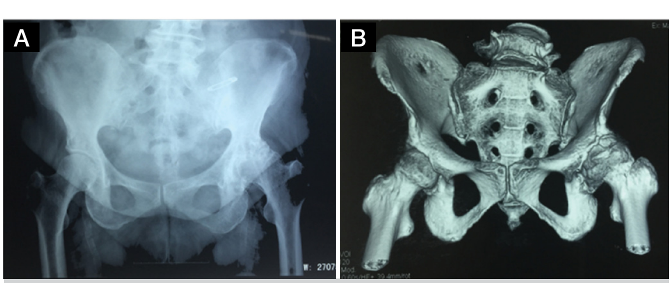

Figure 1. Preoperative pelvic X-ray (A); preoperative CT scan+3D reconstruction (B).

3D print modeling

Twenty-three patients underwent acetabular CT scan in DICOM format. The data were imported into Mimics 10.01 for 3D reconstruction. A series of initial settings, threshold adjustment, noise removal, segmentation and region growth, and slice data integration was completed. 3D reconstruction of mortar was conducted in a STL format output file, which was coded into the main program of the 3D printer computer. Plastic powder was used in the Z coordinate layer overlay to obtain the required acetabular model. Based on the related imaging data, the operation on the acetabular model was simulated. Acetabular grinding with a suitable depth was used to determine the acetabular center of rotation. The suitable acetabular mortar was placed in the acetabulum, which was covered with cement in the defect area. Once the cement is fixed, it is removed, and the cement model of the desired acetabular bone defect was obtained. (Figure 2) This study was approved by the ethic committee of First Affiliated Hospital of Bengbu Medical College, written consent was obtained from the patients.

Acquisition of intraoperative acetabular bone defect area

After successfully implementing anesthesia in patients in lateral position, conventional disinfection, shop towels, and surgery in the lateral approach were performed. Assuming the greater trochanter site as the center, the skin layer was cut until the subcutaneous fascia. Shun gluteus maximus muscle fibers were exposed, and the flap was cut before and after surgery. The left lower limb flexion adduction was revealed, and the outer swollen muscle group was cut off. Most of the joint capsule was excised to reveal the femoral head and neck. Pendulum saw perpendicular to the trochanter was cut off the femoral neck, and the diseased femoral stump was removed to reveal the acetabulum. The hyperplastic tissue above the osteophyte was removed, acetabular anterior tilt 15°, 40° outreach direction step by step to expand the soft tissue and cartilage surface. The appropriate acetabular mold placed in the acetabulum was selected with bone wax covering the defect area. After fixation, the bone wax was removed and the bone wax model of the actual acetabular bone defects was obtained. (Figure 3)

Data measurement

In group A, a cement model in which acetabular defects were obtained from a 3D printed model. Bone wax model of the actual acetabular defects was intraoperatively located in group B. The bone

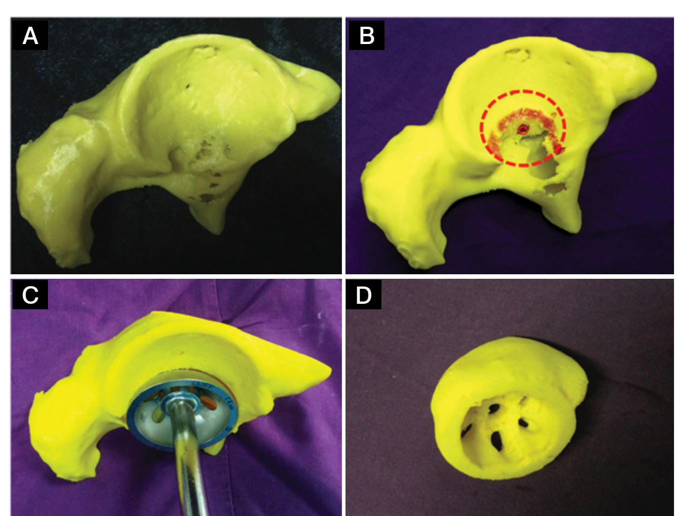

Figure 2. 3D printed acetabular model (A); acetabular cup polished in the acetabular model (B); appropriate acetabular abrasive (C); Covering the area of the defects (in red color) with cement (D).

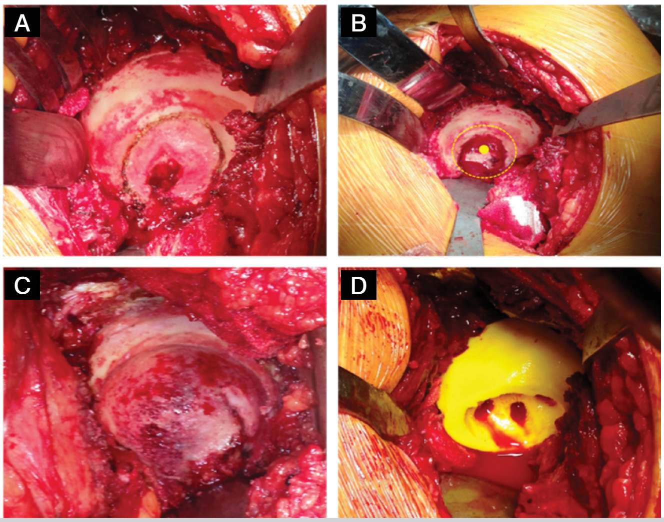

Figure 3. Surgery on the affected hip acetabulum (A); Surgery revealed the polished acetabulum (B); Selecting the appropriate mold placed in the acetabulum department (C); Removing the acetabular bone surgery at the wax model (D).

cement model was obtained by 3D printing, whereas the actual bone model was obtained during the operation. The acetabular defect area was an irregular 3D smooth surface. The 3D surface was first transformed into a figure on a 2D plane for convenient calculation. Steel rulers perpendicular to each other were used as a reference for vertical shooting to keep the steel ruler and the calculated area in the same plane. The shots were imported into Photoshop software, and the pixels in the blue selected area were divided by the pixels in the steel ruler area (5545/263283). The actual area of the area enclosed by the steel straightedge was multiplied to obtain the required acetabular bone defect area.

Statistical analysis

All experimental data were statistically analyzed by using SPSS19.0 statistical software (SPSS Inc., Chicago, U.S.). The obtained were statistically compared between two groups by using the paired t-test. A P value of less than 0.05 was considered as statistical significance.

RESULTS

Twenty-three adult patients diagnosed with DDH in the First Affiliated Hospital of Bengbu Medical College were enrolled in this study. Among them, 6 cases were male and 17 female. Prior to surgery, all patients were subject to Crowe classification including type I in 3 cases, type II in 7 cases and type III in 13 cases. All enrolled patients were aged 41–72 years with an average age of 59.2 years. Patients possessed limited activity and experienced preoperative hip pain, which seriously affected their quality of life. Physical examination and imaging analysis prompted the surgical indications. For each of the 23 patients, the actual acetabular defect area and the area measured based upon the 3D printing model were measured and statistically compared. The comparative results indicated that the actual acetabular defect area measured intraoperatively and the area measured using the 3D printing technology did not significantly differ for all participants (all $P>0.05$). The detailed data were illustrated in Table 1.

DISCUSSION

3D printing technology has been widely applied in multiple fields of orthopedics. For DDH patients, 3D printing technology can aid in preoperative planning, improve the success rate of operation and reduce the intraoperative blood loss and postoperative complications by preoperatively measuring the size and direction of the implants. Zhang et al.[4] demonstrated that the operation time was 118.6 min and the bleeding loss was 410.9 mL in the control group (140.2 minutes, 480.6 mL, controllable abduction angle, and anteversion tilt angle of $(1.2\pm0.9)°$ and $(2.1\pm1.2)°$ were significantly better than those in the conventional surgery group $(5.4\pm3.2)°$ and $(4.1\pm2.8)°$. In addition, Chinese scholars have also proposed that 3D printing technology play a vital role in adult patients with DDH and total hip arthroplasty. Guan et al.[5] performed total hip arthroplasty in eight patients with dysplasia of the hip. Preoperative 3D printing model and surgical planning were adopted to identify the acetabular defects and sclerosis and the size of the defect site. Intraoperative acetabular prosthesis polished range, intraoperative acetabular center position, and 3D printing prosthesis model were exactly the same. The operation time and bleeding volume were significantly reduced over the traditional surgery. Preoperative selection of the size of the prosthesis is consistent with that used in surgery, for the postoperative functional improvement of joint function.

Given the proximal femoral deformity of patients with DDH, narrow marrow cavity, soft tissue contracture, and the common femoral stem prosthesis often do not match the femoral canal and thus complicate the surgery. With the development of 3D printing technology, the optimal matching of the femoral canal cavity can be designed, and the stress can be transmitted uniformly, thus greatly reducing the operation difficulty. Sixty patients with individualized prosthesis were followed up by Martini et al.[6] who found that bone mineral density around the prosthesis were significantly increased compared with those in patients with other types of prosthesis, and the prosthesis and medullary cavity were well fitted.

DDH is a common disease that causes secondary osteoarthritis of the hip.[7] Patients with the development of end-stage osteoarthritis often require total hip arthroplasty. Intraoperative acetabular reconstruction is one of the most difficult parts. The principle of acetabular reconstruction is to reconstruct the rotational center of the acetabulum, provide adequate osseous coverage for the acetabulum, and maintain the integrity of the acetabulum. We can establish a 3D printing model of the patient's affected acetabulum preoperatively. Accurately calculating the area of acetabular defects through the printed model is important to provide adequate osseous

Table 1. Comparison of acetabular bone defect area between group A and group B.

Case No.	Area in group A (cm^2)	Area in group B (cm^2)
1	7.29	7.13
2	3.16	3.25
3	5.14	5.21
4	6.81	6.71
5	4.40	4.62
6	6.69	6.56
7	3.97	3.77
8	4.94	4.82
9	5.36	5.31
10	4.47	4.42
11	3.62	3.51
12	4.52	4.46
13	3.17	3.25
14	7.12	7.11
15	3.56	3.44
16	5.35	5.56
17	6.42	6.52
18	4.72	4.62

coverage. 3D printing is more intuitive than previous imaging data and simulates surgical procedures on the model. The depth of grinding, bone graft method, and bone mass must be determined. Contradictions exist between standardized acetabular components and differentiated individuals. The 3D printing technology can be used according to each patient's different designs of different mortar to improve its mechanical properties. Perticarini et al.[8] used a 3D printed titanium cup for 134 total hip arthroplasty. Postoperative 60–86 months of follow-up showed no surgical complications, and 99.3% of acetabular components were radiographically stable. No osteolysis occurred around the acetabular component. Qu et al.[9] used large-scale acetabular bone defects in 26 patients (26 hips) to design individualized cages using 3D printing technology. After an average follow-up of 67 months, the Harris score improved from 36 to 82 on average, and no imaging artifact shift was found. The accuracy of the acetabular defect area may be affected by the location and orientation of the acetabular mold implants and the depth of acetabular abrading. Therefore, the location of the need for acetabular implantation should be maintained at the lower edge of the tear level and the upper edge of the closed hole. To date, the techniques of orientation of acetabular components mainly include the following four methods: manual method, anatomical marker positioning method, instrument orientation method and computer-assisted orientation method. All acetabular bone defect area models in this study were obtained by "unarmed" methods. The direction of implantation was based on Lewinnek et al.,[10] who reported that the abduction angle (40 ± 10) ° and anteversion angle (15 ± 10)° are the "safe areas" for the acetabular component implantation. On the contrary, the depth of acetabular grinding affects the size of acetabular bone defects. This experiment was based on the study of Zhou Jiansheng et al.,[11] who restored the Harris nest to determine the depth of acetabular grinding. The rotation center can be reconstructed accurately, and the coverage of the acetabular component and the clamping of the prosthesis by the acetabular anterior and posterior wall can be maximized. In addition, Minoda et al.[12] suggested the posterior lateral approach. Considering the intraoperative pelvic 14 ° forward tilt, the posterior superior iliac spine must be touched to determine the pelvic tilt angle. The operating table must be adjusted simultaneously to ensure that the pelvis and the ground are completely vertical. The acetabular model was then placed, and all the surgeries in this study were performed by the same senior physician to control the different levels of operation of doctors on the experimental results. The 2D bone defect model of bone wax was photographed to ensure that the ruler and the calculated area were perpendicular in a plane. The image of the calculated area must be at the center of the field of view. Given the different shooting angles, the area calculated into Photoshop is different; hence, the shooting angle and the calculated area of the image must be vertical.

CONCLUSION

3D printing has advantages over other conventional imaging examination. It can capture a virtual image preprocessed by a series of image processing softwares and then print a 3:1 solid model with a 3D printer. Based upon this model, we can intuitively observe the patient's hip joint situation, simulate the operation of the model and foresee the difficulties encountered in actual surgery. Based on a series of data, 3D printing technology can accurately calculate the acetabular bone defect area to help understand the patient's hip defect before surgery. 3D printing plays a unique role in guiding the intraoperative bone graft, the way of using the bone graft, the difficulty in reducing the operation and the reduction of complications.

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