

NEW TECHNOLOGIES IN TRAUMATOLOGY AND ORTHOPEDICS

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PLANNING CORRECTIVE OSTEOTOMY OF THE FEMORAL BONE USING THREE-DIMENSIONAL MODELING. PART II

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Introduction. Three-dimensional (3D) modeling and prototyping are increasingly being used in various branches of surgery for planning and performing surgical interventions. In orthopedics, this technology was first used in 1990 for performing knee-joint surgery. This was followed by the development of protocols for creating and applying individual patterns for navigation in the surgical interventions for various bones.

Aim. The study aimed to develop a new 3D method for planning and performing corrective osteotomy of the femoral bone using an individual pattern and to identify the advantages of the proposed method in comparison with the standard method of planning and performing surgical intervention.

Materials and methods. A new method for planning and performing corrective osteotomy of the femoral bone in children with various pathologies of the hip joint is presented. The outcomes of planning and performing corrective osteotomy of the femoral bone in 27 patients aged 5 to 18 years (32 hip joints) with congenital and acquired deformity of the femoral bone were analyzed.

Conclusion. The use of computer 3D modeling for planning and implementing corrective interventions on the femoral bone improves the treatment results owing to an almost perfect performance accuracy achieved by the minimization of possible human errors reduction in the surgery duration; and reduction in the radiation exposure for the patient.

Keywords: children, correcting osteotomy of the hip, 3D-modeling, individual pattern.

ПЛАНИРОВАНИЕ КОРРИГИРУЮЩЕЙ ОСТЕОТОМИИ БЕДРЕННОЙ КОСТИ С ИСПОЛЬЗОВАНИЕМ 3D-МОДЕЛИРОВАНИЯ. ЧАСТЬ II

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Введение. Все чаще в различных отраслях хирургии при планировании и выполнении оперативных вмешательств применяются 3D-моделирование и прототипирование. В ортопедии данная технология впервые появилась в 1990 г. при выполнении операции на коленном суставе. С тех пор началась разработка протоколов создания и применения индивидуальных шаблонов для навигации при хирургических вмешательствах на различных костях скелета.

Цель исследования — разработка нового трехмерного метода планирования и выполнения корригирующей остеотомии бедренной кости с использованием индивидуального шаблона, а также выявление преимуществ предложенного метода по сравнению со стандартной методикой планирования и выполнения оперативного вмешательства.

Материалы и методы. Представлен новый способ планирования и выполнения корригирующей остеотомии бедра у детей с различной патологией тазобедренного сустава. Проведен анализ результатов планирования

и выполнения корригирующей остеотомии бедра у 27 пациентов в возрасте от 5 до 18 лет (32 тазобедренных сустава) с врожденной и приобретенной деформацией бедренной кости.

Заключение. Использование компьютерного 3D-моделирования при планировании и выполнении корригирующих вмешательств на бедренной кости улучшает результаты лечения за счет практически идеальной точности выполнения; минимизации возможных субъективных ошибок; сокращения времени операции; уменьшения лучевой нагрузки на пациента.

Ключевые слова: дети, корригирующая остеотомия бедра, 3D-моделирование, индивидуальный шаблон.

Introduction

Today, three-dimensional (3D) technologies are actively being used in everyday medical practice. 3D modeling and prototyping are used in various branches of surgery for planning and performing surgical interventions. In the field of orthopedics, this technology was introduced in 1990 when a 3D-printed individual template with reference points for screw passing was used in knee replacement [1, 2, 3]. Thereafter, the use of individual templates for navigation in surgical interventions on various bones has been increasingly mentioned in international literature.

The first part of this article [4] shows how, using virtual simulation, precise calculations for the necessary correction of angular parameters are made to correct the deformity of the proximal femur. In the second part, the stages involved in prototyping an individual template and the technical aspects involved in performing corrective osteotomy of the femur using the prepared template are demonstrated using a clinical example.

Aim of the study

The study aimed to develop a new 3D method for planning and performing corrective osteotomy of the femur with the use of an individual template and to identify the advantages of the proposed method compared to that of the standard method of planning and performing surgical intervention.

Materials and methods

This study presents a new method for planning and performing corrective osteotomy of the femur in children with various hip joint pathologies (application for the invention “Method of correcting osteotomy of the femur,” filing certificate No. 2016105166 of 16.02.2016). The outcomes of planning and performing corrective osteotomy of the femur were

analyzed in 27 patients aged 5–18 years (32 hip joints) with congenital and acquired deformity of the femur. Parents (or guardians) of all children voluntarily signed an informed consent to participate in the study and perform a surgical intervention. For 3D modeling, we used computer tomograms of the femurs of the same patients and a complex of an adapted 3D-software. For prototyping, the 3D printer EnvisionTeC’s ULTRA 3SP (EnvisionTeC, Germany) was used.

As described, at the planning stage, 3D modeling was performed; the main angular parameters, such as the collum-diaphyseal angle, the anteversion angle, and the resected (if necessary) bone wedge size were calculated. Based on the data obtained, the corrective osteotomy of the femur was modeled stepwise [4]. To accurately “transfer” the results of preoperative 3D modeling to the surgical wound, we developed a protocol for creating an individual template. The information set in the template regarding the direction of the osteotomy lines, the angle of rotation, passing of the orienting spokes, and the fixing of screws enabled the projection of the computer image onto the femur to make the process of surgical intervention as predictable and minimally subjective as possible.

Clinical example

Patient K., 16 years old. Diagnosis: Slipped right capital femoral epiphysis of the third stage, of the first stage to the left. The clinical picture revealed lameness in the right lower extremity and relative shortening of the right lower extremity by 1.5 cm; the right lower extremity was in the external rotation position with a hip joint at an angle of 40°. Further, there was no internal rotation in the right hip joint, and the Dreman symptom was positive on the right (bending in the hip joint was possible only in the external rotation position). As per the X-ray examination conducted in the direct projection and

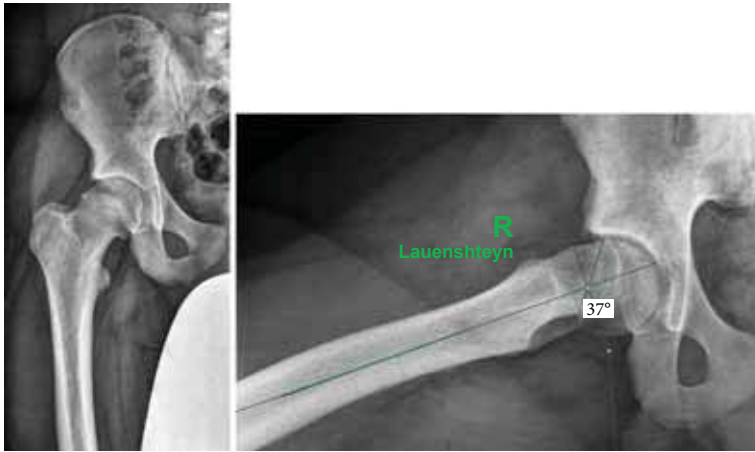


Fig. 1. Images obtained from the X-ray examination of patient K. (in a direct projection and according to Lauensteyn) prior to surgical treatment. Slipped right capital femoral epiphysis of the third stage

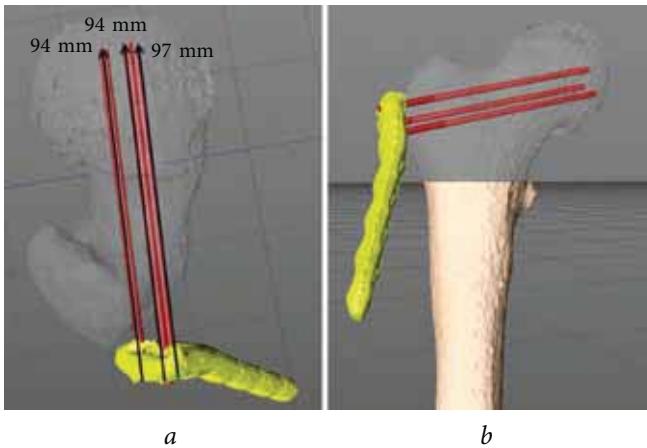


Fig. 2. Passing the guiding spokes: *a*, top view; *b*, front view

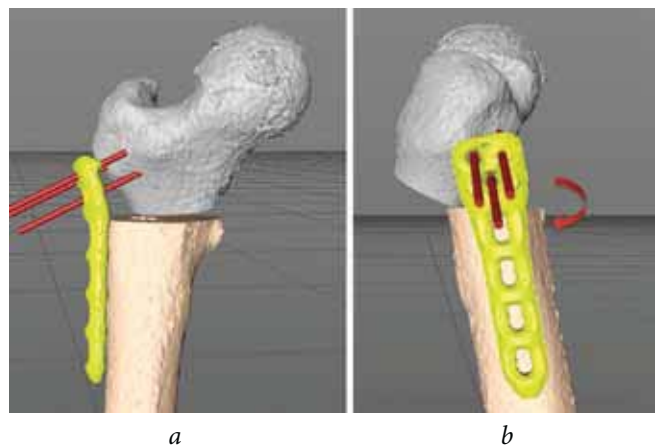


Fig. 3. Expected outcomes of corrective antero-rotational osteotomy: *a*, front view; *b*, lateral view

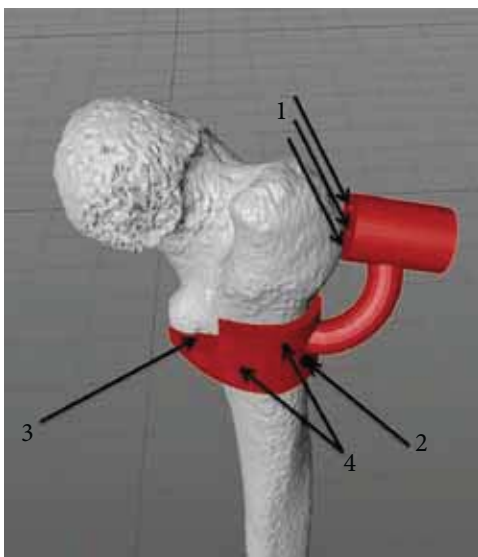


Fig. 4. Template for conducting correcting antero-rotational osteotomy of the femur: 1, guide bush; 2, a guide for the screw; 3, a guide for osteotomy; 4, holes for Kirschner wires

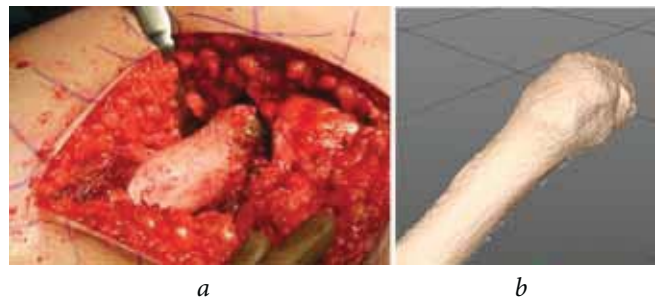


Fig. 5. Distinguishing the intertrochanteric region: *a*, surgical field; *b*, 3D model

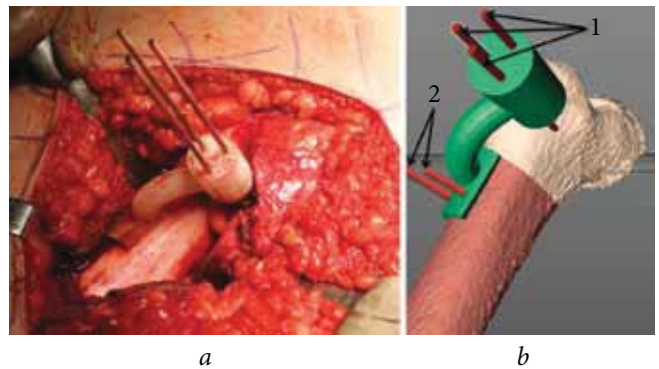


Fig. 6. Installation of the template and passing the orienting spokes: *a*, surgical field; *b*, 3D model (1, orienting spokes; 2, Kirschner wires)

according to Lauenshteyn, the displacement of the epiphysis of the head of the right femur backward was by 37° (Fig. 1).

This patient was chosen for conducting the case study for this pathology because of two main reasons:

1) In slipped capital femoral epiphysis, a complex multiplanar deformity always develops that requires a complex multiplanar correction;

2) The correction should be as high as possible; however, it should not exceed 50° ; otherwise, the risk of aseptic necrosis of the femoral head increases [2, 4, 5, 6].

Stages of creating and using an individual template for correction of multiplanar deformity of the proximal femur:

1. 3D modeling of corrective osteotomy of the femur was performed [4].

2. A virtual plate was fixed to the proximal part of the virtual femur with virtual guiding spokes. In this case, the spokes passing through the femoral neck were oriented to the epiphyseal center, and the longitudinal axis of the plate was located at an angle of the necessary correction to the longitudinal axis of the plate; in this case, the angle was 45° [7]. After the virtual osteotomy was performed, the proximal femur together with the plate was rotated until the plate jaw was aligned with the distal femur. The main advantage of 3D modeling is that it allows the location of the screws as centrally as possible in relation to the epiphysis and, if possible, without leaving the deformed femoral neck. Visual control in various projections (perspective, top, bottom, right, left, front, and back) was achieved by varying the “transparency” of the bone. After correction of the epidiaphyseal angle, the angle of anteversion was measured [4]. Next, the distal femur was rotated inwards to correct the angle of anteversion, by 10° in this case. The plate was fixed to the femur using virtual screws. The length of the neck screws was determined with pinpoint precision, preventing their penetration into the joint during the surgery, as well as by the length of the diaphyseal screws (Fig. 2, 3).

3. An individual template was modeled. The template had a guide bush with holes for passing the guiding spokes, a guide for osteotomy, as well as guides for screws that fix the plate and are used as orienting labels for correcting the angle of anteversion. The inner surface of the

template is an accurate “cast” of the outer surface of the corresponding femoral part. It is desirable that this site has a small trochanter wholly or partially because the more irregularities the surface has, the easier it is to position the template accurately during the surgery. At the base of the template, 2–3 holes for Kirschner wires were modeled for the temporary fixation on the bone (Fig. 4).

4. A template was made from a photopolymer on a 3D printer.

5. During surgical intervention, the intertrochanteric region was distinguished subperiosteally (Fig. 5). The template was installed on the bone. Considering that the inner surface of the template was a mirror image of the femoral bone, there were no challenges in its positioning. The template was fixed to the bone with 2–3 Kirschner wires (Fig. 6). Three orienting spokes were passed through the holes in the guide bush. A hole for the screw was drilled along the guide. The osteotomy of the femur was performed along the guide with the use of an oscillatory saw. The Kirschner wires and the template were removed from the wound. The surgical hardware was fixed to the proximal femur with the orienting spokes.

To eliminate the posteroinferior displacement of the epiphysis, the proximal femur with a plate fixed to it was rotated anteriorly around the axis of the femoral neck. To correct the angle of anteversion, the distal femur was rotated inward about its axis until the screw hole in the plate jaw was aligned with a similar hole in the femur. The plate was fixed to the diaphysis using screws (Fig. 7).

The wound was closed layerwise. Two images were obtained from X-ray examinations in a direct projection and according to Lauenshteyn (Fig. 8, 9).

Discussion

The results of 3D method for planning and performing corrective osteotomy of the femur with the use of an individual template were analyzed in 27 patients aged 5–18 years (32 hip joints) with congenital and acquired deformity of the femur. In the postoperative period, all patients underwent computed tomography examinations; the results were evaluated and compared. In addition, a 3D virtual model was created, and in the 3D-program adapted by us, the model of the planned surgery and

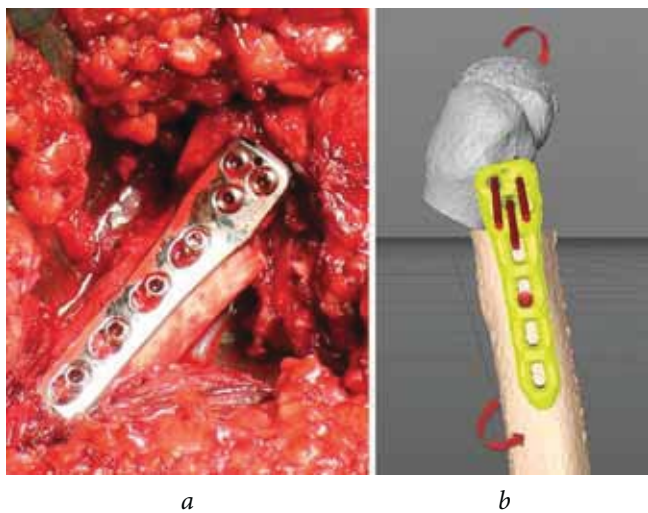


Fig. 7. Appearance after correction of the deformity: *a*, surgical field; *b*, 3D model

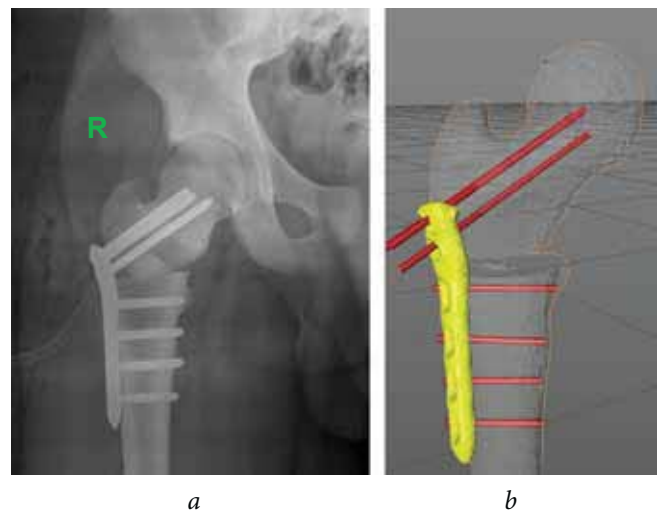


Fig. 8. Outcomes of the surgical treatment: *a*, Rg in a direct projection; *b*, 3D model, expected result

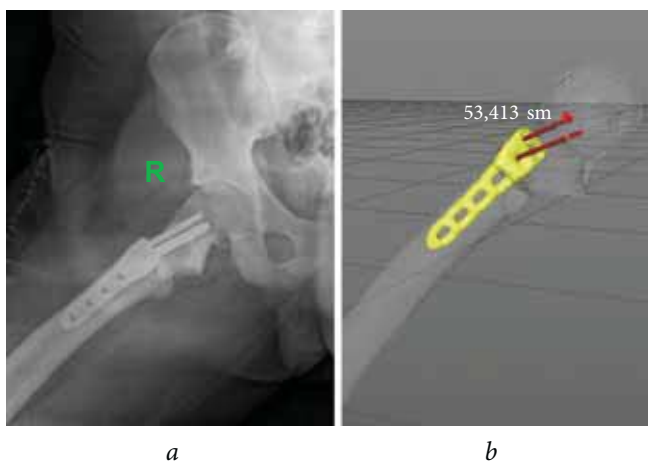


Fig. 9. Outcomes of the surgical treatment: *a*, Rg according to Lauenshteyn; *b*, 3D model, expected result

the model after surgical treatment were compared. The neck-shaft angle, the epidiaphyseal angle, and the angle of anteversion that were compared with the planned preoperative calculations were calculated again for the control on the 3D model after surgical treatment. In 30 cases (94%), the planned spatial position of the fragments of the femur and the fixing metal anchor corresponding to the preliminary calculations was obtained. In two cases (6%), the position of the fixing anchor and the femur fragments differed from the planned one. Both cases occurred at the initial stages of the study and attributed to a technical defect in the template that did not allow the correct positioning on the bone during the surgery. Deviations were within 6° and did not affect the clinical outcome. Further improvement of the template enabled the prevention of such errors.

For comparative analyses, the results of 32 cases involving planning and performing of corrective osteotomy of the femur were evaluated using standard X-ray dosimetry. The spatial position of the proximal femur fragment and the location of fixing the metal anchor on the postoperative X-ray examination images corresponded to preliminary calculations in 25 cases (78%).

A comparative analysis of the outcomes of planning and performing the corrective osteotomy using 3D-technologies and standard X-ray dosimetry was performed. It was revealed that the average difference in the measurement of angular indices amounted to $10^\circ \pm 2^\circ$ ($p < 0.05$); in linear terms, the difference was $5 \text{ mm} \pm 2 \text{ mm}$ ($p < 0.05$).

The time taken for performing interventions of the same type was compared. Using an individual template during corrective osteotomy of the femur reduced the operation time by an average of 11 min. In addition, using the template completely eliminated the necessity for intraoperative images and image intensifiers.

Conclusion

Using computer 3D modeling in planning and performing corrective interventions on the femur improves the treatment outcomes owing to the following reasons:

- Almost perfect performance accuracy
- Minimization of possible subjective errors
- Reduction in the operating time
- Reduction in the radiation load on the patient

Information on funding and conflict of interest

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