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A preoperative planning method for long tubular bone osteosynthesis

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Abstract

Aim – the development of a preoperative planning method for long tubular bone osteosynthesis using the contralateral healthy bone.

Material and methods. To justify the usage of the opposite limb's intact segment model in order to reconstruct the damaged one, their matching in shape and size was analyzed. We built three-dimensional models of the right and left segments of the upper limbs of 20 people and compared them using the Hausdorff distance calculation algorithm. For treatment of a 24-year-old patient with a closed humerus fracture, an individual stereolithographic surgical template with fracture lines was created with the help of computed tomography data of the healthy humerus bone processed by AUTOPLAN EXPERT software. This template was used for pre-bending the plate for osteosynthesis. The plate positioning on the template defined the surgical approach, taking into account the anatomical structures located in the projection of the fracture line and the plate. The technique of "reverse bone reposition" on the prepared plate was applied.

Results. With the help of the created 3D models we revealed the size differences of the symmetrical segments of upper limbs. The greatest difference in the limits was registered in the area of the epiphyses (heads of the humeri) – up to 6.8 mm, and the smallest – throughout the entire diaphysis, less than 1.5 mm. Due to preoperative planning there were no intraoperative and postoperative complications, the installation of the plate and osteosynthesis was convenient. The fracture consolidation took place in 3 months.

Conclusion. The proposed method has a number of advantages. It is possible to make a stereolithographic template even for a seriously damaged bone with a copied fracture line. This allows the surgeon to plan the details of osteosynthesis, to model the plate according to the template, to determine the required length and shape of the surgical approach, thus reducing the surgical risks and injury for the patient.

Keywords: preoperative planning, plate osteosynthesis, 3D-model, Autoplan, template.

Conflict of interest: nothing to disclose.

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Способ предоперационного планирования накостного остеосинтеза длинных трубчатых костей

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Аннотация

Цель – разработать способ предоперационного планирования накостного остеосинтеза длинных трубчатых костей на основе контралатеральной здоровой кости.

Материал и методы. Для обоснования использования модели противоположного неповрежденного сегмента конечности в целях реконструкции поврежденного были проанализированы их соответствия по форме и размерам. Использовалось создание трехмерных моделей правых и левых сегментов верхних конечностей у 20 исследуемых с последующим сравнением по алгоритму дистанции Хаусдорфа. Далее пациенту 24 лет с закрытым переломом плечевой кости на основе данных компьютерной томографии плечевых костей в программе AUTOPLAN EXPERT был создан индивидуальный стереолитографический шаблон с нанесенными на него линиями перелома. По шаблону предоперационно отмоделирована пластина. С учетом расположения пластины на шаблоне и расположенных в проекции линии перелома и пластины анатомических образований был запланирован оперативный доступ. Использована техника обратной репозиции кости на подготовленной пластине.

Результаты. Выявлено несовпадение границ трехмерных моделей симметричных сегментов верхних конечностей: наибольшее (до 6,8 мм) – в зоне эпифизов (головок плечевых костей), наименьшее (не более 1,5 мм) – на протяжении всего диафизарного отдела. После проведенного предоперационного планирования интраоперационно и послеоперационно осложнения отсутствуют, сложностей с установкой пластины и остеосинтезом не было. Консолидация перелома через 3 месяца.

Выводы. Предложенный способ дает возможность изготавливать стереолитографический шаблон даже серьезно поврежденной кости с нанесенной на него линией перелома. Это позволяет определиться с возможными особенностями остеосинтеза, непосредственно отмоделировать пластину по шаблону, планировать длину и форму оптимального оперативного доступа, что снижает риски и травматичность операции.

Ключевые слова: предоперационное планирование, накостный остеосинтез, 3D-модель, Автоплан, шаблон.

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INTRODUCTION

Plate osteosynthesis is a type of external osteosynthesis that provides stable fixation without external immobilization and enables the implementation of early rehabilitation measures. The main stages in this technique include the repositioning of the fragments with their subsequent fixation with a metal fixator. Extra-cortical plates had been developed long ago; therefore, the surgeon's range of implant selection is wide enough [1].

Regarding the repositioning, the most important aim is to ensure the restoration of the length, rotation, and axis of the bone. To ensure a good reposition, correct selection, and modeling of the plate, preoperative planning of the surgery is required. This is not always implementable with conventional radiographs, especially for complex fractures. An attempt to select and model the plate intraoperatively after the reposition of fragments increases the surgery time [2].

In recent years, international literature has published studies on three-dimensional preoperative planning and intraoperative navigation systems in the treatment of fractures [3].

The most common technology is an attempt to perform a computerized reposition of three-dimensional models of fragments using the key points of the fracture line, followed by 3D printing of the repaired bone, which is then used to plan, assess, and select a plate [4]. However, many researchers report a number of disadvantages of this method [5]. Firstly, the method of selecting keypoints of reposition is not clear enough; points determined by eye are often used, until the surgeon is satisfied with the reposition obtained on the screen. This, in turn, increases the number of errors and inaccuracies in the reposition result. Secondly, manual reposition can take a long time and requires the direct involvement of the surgeon.

Lukun San et al. [6] conducted a retrospective study of the additive technology of minimally invasive bridge osteosynthesis in femoral fractures. The automatic simulation of the reposition of fragments in the femoral 3D model was applied using the Mimics Research 18.0 software. After selecting the plate model from the database and its positioning on the bone model in accordance with the selected screw position, "supporting columns" are created on a common platform on a 3D printer, which function as bushings for the placement of screws on the plate during surgery. According to the authors, the main disadvantage of this method is the inability of the program to perform three-dimensional reconstruction of complex multi-fragment fractures.

Another preoperative planning option is the printing of the external plates based on computed tomograms. Thus, Matev Tomadzhevich [7] conducted a study, when polyamide plates were created according to the shape of the bones of an artificial polymer pelvis. The anatomy of these plates was compared with several reconstructive plates curved in the shape of the pelvis. The disadvantage of this technology is the high cost and duration of printing (up to 5 days) of titanium alloy plates for use in surgical practice.

AIM

The study aimed to develop a method for the preoperative planning of plate osteosynthesis of long tubular bones based on the contralateral healthy bone.

MATERIAL AND METHODS

To substantiate the use of the model on the contralateral intact limb segment in order to reconstruct the damaged one, we analyzed their anatomical discrepancies in shape and size (since no such data have been found in the modern international and Russian literature). The analysis was performed based on the AUTOPLAN EXPERT software (an image processing system of the DICOM standard with advanced reconstruction capabilities, the construction of personalized 3D models for planning surgical interventions and

Figure 1. *Mated humeri left and right (in mirror copy). Color mapping indicates the distance between the identical locations on the bones. Red color marks a difference of no more than 0.1 mm, yellow – no more than 1.5 mm, green – from 1.5 to 5 mm, blue – more than 5 mm.*

Рисунок 1. *Совмещенные взаимно левая и зеркальная копия правой плечевые кости.*
Цветное картирование обозначает расстояние между одинаковыми локациями на костях. Красный цвет маркирует разницу не более 0,1 мм, желтый цвет – не более 1,5 мм, зеленый – от 1,5 до 5 мм, синий – более 5 мм.

Figure 2. *X-ray of the left humerus. Closed fracture of the left humerus at the border of the middle and lower thirds with displacement of fragments.*

Рисунок 2. *Рентгенограмма левой плечевой кости. Закрытый перелом левой плечевой кости на границе средней и нижней третей со смещением отломков.*

additional diagnostic imaging, with automated segmentation of bone structures, lungs, liver, and vessels).

Twenty healthy individuals were enrolled and computed tomography of the upper extremities was performed on them, and based on it, volumetric models of the humerus were formed. The specularly reflected copy of the right bone was projected onto the left one, after which the Hausdorff distance algorithm was used [8]. The algorithm calculates the distance between the same points of the bones projected onto each other. For better understanding, the result was visualized as a color-mapped model (**Figure 1**).

As a result, it was revealed that the discrepancy between the bones in the diaphyseal segment in all the cases studied did not exceed the thickness of the cortical layer. This discrepancy enables to consider the use of intact models, similarly named limb segments for the reconstruction of injured ones as justified.

The study was further performed using the method of preoperative planning of plate osteosynthesis of long tubular bones [9].

Computed tomography of a similar intact bone of the contralateral limb was performed. Using the AUTOPLAN EXPERT software, data were processed, and three-dimensional models of intact bone and damaged bone fragments were created. A specular model of intact bone was created using Meshlab software. It was consistently combined with the models of the damaged bone fragments, comparing them with each other, and drawing the contour of the fracture line on the specular model of the intact bone. Based on the resulting model, a full-size stereolithographic template corresponding to the damaged bone was made on a 3D printer, with fracture lines in the form of grooves applied to it.

Before the surgery, the plate was modeled according to the stereolithographic template and the surgical approach was planned taking into account the location of the fracture line.

Due to preliminary personalized modeling on a template, during open osteosynthesis, it is proposed to use a plate as a kind of matrix to perform reverse reduction of bone fragments, which are actually assembled on it, thereby ensuring the complete anatomical restoration of the bone integrity.

The proposed method for the preoperative planning of osteosynthesis of long tubular bones is illustrated by a clinical example.

CLINICAL CASE

Patient O., 24 years old, visited the trauma department with complaints of pain in the middle third of the left humerus after a fall in the street. On examination, the patient was diagnosed with a closed fracture of the left humerus at the border of the middle and lower thirds with displacement of fragments. The radiograph of the patient's humerus is presented in **Figure 2**. Preoperative planning was performed according to the above technique.

RESULTS

The discrepancy between the boundaries of the three-dimensional models of symmetrical segments of the upper extremities was revealed; the largest one (up to 6.8 mm) was in the area of the epiphyses (humeral

Figure 3. *Individual stereolithographic template of the patient's left humerus. The arrow indicates the fracture line of the left humerus copied to the template.*
Рисунок 3. *Индивидуальный стереолитографический шаблон левой плечевой кости пациента. Стрелкой указана нанесенная на шаблон линия перелома левой плечевой кости.*

Figure 4. *A bone plate modeled on the individual stereolithographic template.*
Рисунок 4. *Накостная пластина, отмоделированная по индивидуальному стереолитографическому шаблону.*

heads) and the smallest one (not more than 1.5 mm) was noted throughout the diaphyseal region.

Based on the method proposed, the processing of computed tomography data of the damaged and intact humerus was done, and an individual stereolithographic template was created (**Figure 3**) with a fracture line drawn in the form of a groove on it.

Taking into account the plate location on the template, a surgical approach of a certain shape and length was planned taking into account the anatomical structures located in the projection of the fracture line and the plate. Intraoperatively, there were no complications, injuries of the anatomical structures, or difficulties with plate installation and osteosynthesis of bone fragments. The bone integrity was restored, which was confirmed by the control X-ray of the humerus in the postoperative period (**Figure 4**). The follow-up examination of the patient was performed. Consolidation of the fracture was noted 3 months after the surgery.

Using this template, taking into account the course of the fracture line, the optimal position of the plate

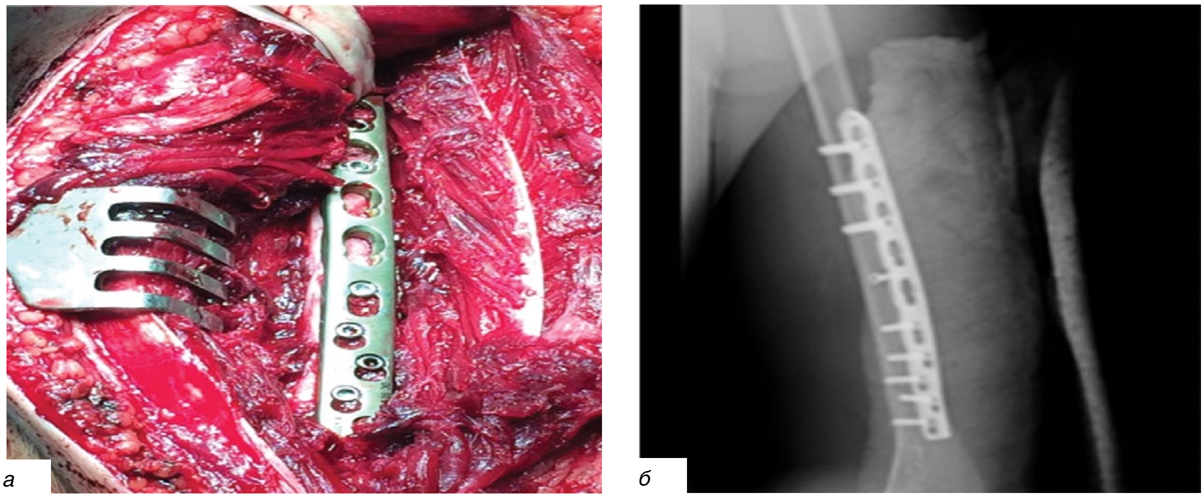

Figure 5. *a) Intraoperative view after osteosynthesis of the left humerus with a preoperatively modeled plate. b) Postoperative radiography of the left humerus.*
Рисунок 5. *а) Интраоперационный вид после остеосинтеза левой плечевой кости предоперационно моделированной пластиной. б) Послеоперационная рентгенография левой плечевой кости.*

was chosen. The latter was modeled using the template (**Figure 5**).

DISCUSSION

The method proposed has several advantages, as it provides the possibility of making a stereolithographic template even for a seriously damaged bone, with a fracture line applied to it. This helps to visually determine the nature of the fracture, possible characteristics of osteosynthesis, model directly the plate according to the template, while considering the aspects of its location, as well as the location of the screws. With the knowledge of the plate location on the template, it is possible to plan the length and shape of the optimal surgical access, which reduces the risks and trauma of the surgery.

In addition, the reverse reposition of fragments on the plate subjectively and greatly facilitates the process for the surgeon. In addition, the time of surgical intervention is reduced by an average of 20–25 minutes compared to conventional osteosynthesis of the humerus, while the tissues in the fracture zone are not damaged and the injury to the periosteum is reduced, which reduces the intensity of reparative osteogenesis.

CONCLUSIONS

The proposed method for the preoperative planning of osteosynthesis of long tubular bones provides precise personalized modeling of the metal fixator according to the template, as well as the planning of the surgical approach taking into account the fracture line and the location of the plate. This reduces the labor intensity, invasiveness, and time of surgery, while increasing its efficiency. The method can be widely used in trauma and orthopedic hospitals.

Conflict of interest. *The authors declare no conflict of interest.*

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