Surgical Treatment of Patients with Benign Tumors and Tumor-Like Diseases of Tubular Bones Using 3D Modeling and Computer Navigation

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The aim of the investigation was to evaluate the possibilities of applying 3D modeling and computer navigation in treatment of benign tumors and tumor-like diseases of tubular bones.

Materials and Methods. The study involved 19 patients with benign tumors and tumor-like diseases of tubular bones of the skeleton, who were divided into two groups. The main group comprised 10 patients in whom three-dimensional models of affected bone segments were created in addition to radiography and computed tomography at the stage of preoperative planning. Surgical treatment was carried out using a navigation system. The control group included 9 patients who underwent only radiography and computed tomography of the affected segment at the stage of preoperative planning.

Results. The use of 3D modeling in diagnosis and computer navigation in surgical treatment of benign tumors and tumor-like diseases of tubular bones helped to reduce the time of surgery from 121.5±11.3 to 81.1±9.7 min, intraoperative blood loss from 718.7±43.2 to 364.2±28.4 ml, pain intensity by visual analogue scale from 7.6±1.9 to 5.3±1.2 scores. These results were achieved through the development of intuitively simple for the operator system of real-time spatial orientation in the operating field, more accurate and measured surgical procedures, precise calculation of the required transplant volume, which minimized trauma to the donor area and contributed to reducing postoperative pain.

Conclusion. The use of 3D modeling and computer navigation in treatment of patients with benign tumors and tumor-like diseases of tubular bones provides the possibility to improve immediate results of surgical treatment promoting fast social and functional adaptation of patients.

Key words: benign bone tumors; 3D modeling of intraosseous resection; computer navigation for surgical access; oncoorthopedics.

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Surgery is the main method of treating benign tumors and tumor-like diseases of tubular bones, with preference given to organ-preserving methods which provide different variants of intraosseous resections complying with the oncological principles of radicality. These methods should be based on accurate knowledge of personal anatomy of a particular patient with due regard for alterations caused by tumor lesion. Statistical data of recent years demonstrate steady intense growth of this nosology increasing the urgency of the problem. Children and young adults, i.e. the most socially significant and important segment of the population, are most likely to suffer [1, 2].

Preoperative planning, information and hardware support of surgery have major influence on surgical outcome in this group of patients [3–5].

Computed tomography is a kind of examination required at the stage of planning surgical intervention to clarify the location, extent and volume of tumor lesions [3, 6–8]. Assessment of patient individual anatomic and topographic characteristics and accurate calculation of the replaced material volume is difficult without creating a three-dimensional model of the zone of interest.

Intraoperative X-ray examination is considered to be the standard method to determine the zone of surgical intervention [1, 2, 4]. However, resolution of this method allows no accurate assessment of bone resection zone volume and extent, besides, the method is associated with additional radiation exposure [9–12].

Today, a promising trend in preoperative planning is the use of 3D modeling of tumor area [9, 13]. This method provides the possibility to ensure intraoperative support of surgical manipulation using navigation systems [3, 14, 15].

The aim of the investigation was to evaluate the possibilities of surgical treatment in patients with benign tumors and tumor-like diseases of tubular bones using 3D modeling and computer navigation.

Materials and Methods. The study involved 19 patients with benign tumors and tumor-like diseases of tubular bones of the skeleton. The main group comprised 10 patients in whom three-dimensional models of affected bone segments were created in addition to radiography and computed tomography at the stage of preoperative planning. Surgical treatment was carried out using computer-assisted navigation system Autoplan developed by the Center of Breakthrough Research of Samara State Medical University [9].

The main objective of the navigation system was correct positioning of surgical instruments inside the patient in real time.

Table 1

Distribution of patients according to lesion localization and the nosological form of tumor lesions (absolute number)

Characteristics	The main group (n=10)	The control group (n=9)
Localization		
Radial bone	1	1
Humerus	4	5
Femoral bone	3	2
Tibia	2	1
Nosological form		
Chondroma	5	5
Bone cyst	2	1
Giant cell tumor of typical structure	1	1
Fibrous dysplasia	2	2

The control group included 9 patients who underwent radiography and computed tomography of the affected bone segment at the stage of preoperative planning [1].

The mean age of the patients was 30.4±2.8 years in the main group and 32.1±3.2 years in the control group (p>0.05). In the main group there were 4 male patients and 6 female ones; in the control group they were 3 and 6, respectively (p>0.05).

Distribution of patients according to localization and nosological forms of tumor lesions is shown in Table 1.

In the main group, preoperative planning and surgical treatment were carried out according to the following algorithm. At the preoperative stage, there was performed X-ray examination using Precision 500 D apparatus (GE Healthcare, USA) and a series of contrast enhanced computer tomography using GE LightSpeed Ultra 16 Slice CT Scanner (USA), with images saved in DICOM format. The images with isotropic resolution

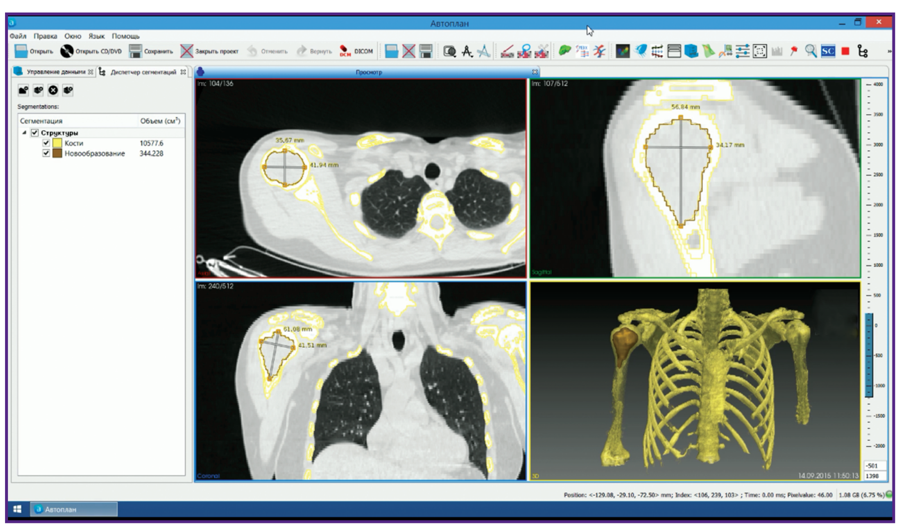

Figure 1. Preoperative planning using 3D modeling

of 0.8–1.0 mm were selected for analysis. These data were used to design a virtual three-dimensional model of the tumor nidus. The obtained 3D model corresponded completely to the form, volume and size of the existing pathological nidus, which allowed mapping out the boundaries of bone resection with regard to ablasticity principles and determining the required volume of plastic material [16] (Figure 1).

Spatial registration of surgical intervention area was done intraoperatively based on bone location in the navigation system using a special marker with reflective spheres (Figure 2).

Next, the virtual model of bone tumor was matched to the material basis on the operating table. In this way, the surgeon received information about the location and dimensions of intraosseous tumor process during the operation and had the opportunity to accurately control the manipulation (Figure 3).

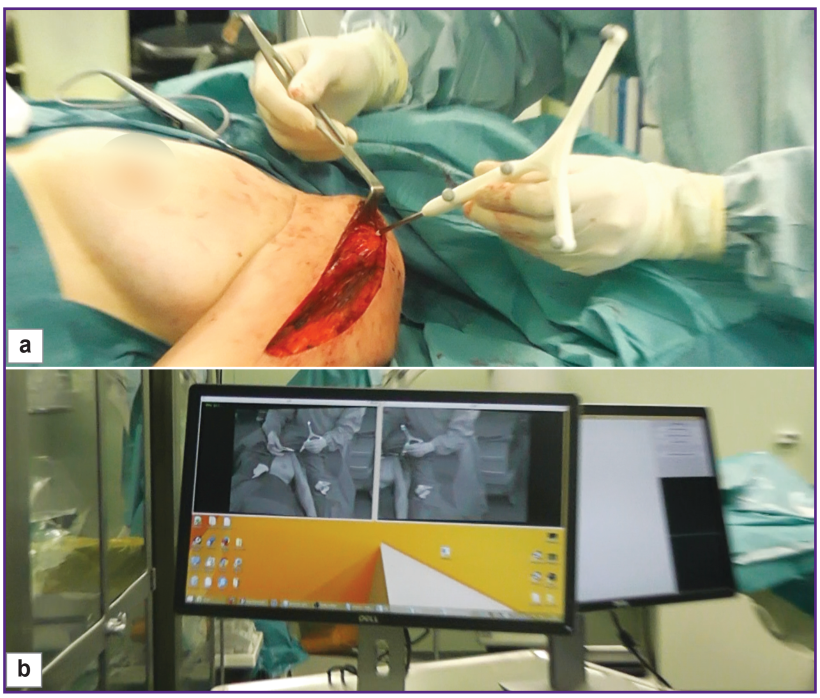

Figure 2. Navigation system Autoplan:
(a) bone marker registration; (b) images on the navigation system screen

As a result, intraosseous bone resection was carried out within the planned boundaries [17, 18] and the defect was replaced with the planned volume of transplant. Resection accuracy was 0.8±0.12 mm. Prior to defect replacement, the cavity formed after the removal of tumor mass was treated with a flow of low-temperature plasma to ensure additional ablasticity [19]. Osteosynthesis was performed after osteoplasty. The preparation was submitted for histological examination.

In the control group, preoperative planning was carried out using radiography and computed tomography of the affected bone segment. Resection boundaries were identified by the surgeon intraoperatively by means of fluoroscopy. In our opinion, a major disadvantage of this method is its subjectivity.

After that, the defect was replaced with the transplant whose model was created intraoperatively, material sampling being performed with osteotome in the donor area (the iliac wing) [1–3].

To estimate the immediate results, the following criteria were used: surgery duration, intraoperative blood loss, pain intensity in the early postoperative period according to visual analogue scale (VAS). On day 2–3 of the postoperative period, all patients underwent control X-ray examination of the operated limb in two projections, with resection volume, defect replacement adequacy and the state of metal osteosynthesis being assessed. When indicated, the donor area of bone graft was examined [19].

Statistical data processing was performed by means of Statistica 9.0 program. Arithmetic mean values were calculated for the studied parameters (M±σ, where M — arithmetic mean, σ — standard deviation). Statistical differences between the data of compared groups were determined using Student t-test. The value of significance level was considered critical at $p<0.05$.

Effectiveness of the proposed method was assessed according to the

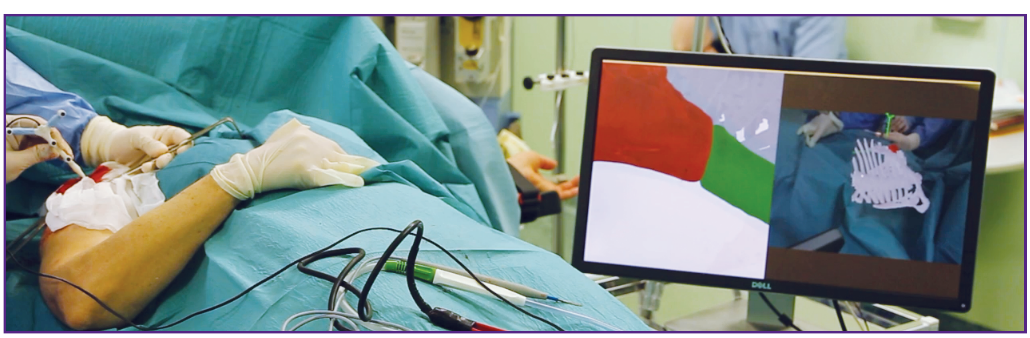
Figure 3. Determining the intended resection line

standards of evidence-based medicine. The study complies with the Declaration of Helsinki (the Declaration was passed in June 1964, Helsinki, Finland, and revised in October 2000, Edinburg, Scotland). All manipulations were made following approval by the Bioethics Committee of Samara State Medical University. Written informed consent was obtained from every patient.

Results and Discussion. The most frequent localization of the pathological process was the humerus and femur, chondroma being the most common histological form. No statistically significant differences were revealed between the groups (p>0.05).

T a b l e 2

The immediate results of surgical treatment in patients of compared groups (M±σ)

Parameters	The main group (n=10)	The control group (n=9)
Surgery duration (min)	81.1±9.7	121.5±11.3
Blood loss (ml)	364.2±28.4	718.7±43.2
Visual analogue scale (scores)	5.3±1.2	7.6±1.9

The immediate results of surgical treatment in patients of compared groups are shown in Table 2.

Application of the novel approach in surgical treatment of benign tumors and tumor-like diseases of tubular bones enabled reducing the surgery duration nearly 1.5 times, intraoperative blood loss nearly 2 times and pain intensity according to VAS by nearly 1.5 times (p<0.05). We managed to achieve these results due to intuitively simple for the operator system of real-time spatial orientation in the operating field, more accurate and measured surgical procedures, precise calculation of the required transplant volume minimizing trauma to the donor area.

Control X-ray examination performed on day 2–3 after surgery revealed shifting of resection boundaries by 0.90±0.14 mm in the main group, the shifting reached 4.20±0.93 mm from the planned line in control (p<0.05). Sharp soreness in the donor area was observed in a single control group patient during early postoperative period, which could be associated with inappropriately large volume of material taken for transplantation.

Thus, preoperative 3D modeling and intraoperative computer navigation may be recommended in management of these patients to simulate intraosseous tumor lesions based on individual patient-specific topographic-anatomical data, to improve the accuracy of intraosseous resection and volume of replacement transplant. They can be used both as a routine method and in difficult clinical cases improving the quality of specialized medical care. Besides, the use of navigation systems for intraoperative monitoring of surgical procedures allows reducing the radiation exposure of patients and medical personnel.

Conclusion. The use of 3D modeling and computer navigation in treatment of patients with benign tumors and tumor-like diseases of tubular bones provides the possibility to significantly improve the immediate results of surgical treatment and ensure fast social and functional adaptation of patients promoting the socio-economic effect of treatment.

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Conflicts of Interest. The authors have no conflicts of interest to disclose.

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