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3D modeling and 3D printing technology for personalized models of pelvic bones and proximal femur malignant tumors for surgery planning and rehearsal

N.K. Ternovoy[1], O.V. Drobotun[1], N.N. Kolotilov[2], V.F. Konovalenko[1], I.M. Voyeykova[1], S.I. Vasilieva[1]

R.E. Kavetsky Institute of Experimental Pathology, Oncology and Radiobiology of NAS of Ukraine[1], Kyiv
SI "Institute of Nuclear Medicine and Diagnostic Radiology of NAMS of Ukraine[2]", Kyiv

The adequate planning of onco-orthopedic operations is one of the most important conditions for its successful conduction, excellent and good immediate and remote functional results, the patient's quality of life [1, 2]. Operations can vary considerably in volume, duration, concomitant blood loss, that largely depends on the tumor location, its size, surgeon's manual skills and ability to rebuild the surgery without loss of quality in accordance with the patient's anatomy personalized in detail on the diagnostic images [2-7]. The full implementation of these conditions is associated with the mastering of 3D modeling and 3D printing technologies of the personalized solid-state models of bone tumors [5-7, 9].

The purpose of the article is to present the experience of 3D modeling of pelvic and proximal femur malignant tumors application for surgery planning, rehearsal and manual skills improvement.

Material and investigation methods

In the department of tumor process monitoring and therapy design, diagnosis, treatment (tumor resection, endoprosthesis, bone grafting) were performed in 8 patients with benign and malignant bone tumors (Table 1). The control group was based on the analysis of archival case histories of 16 patients with similar diagnoses and treatment without modeling.

Patients were examined on Light Speed® VCT multi-detector tomograph (General Electric, USA).

The following 5-stage technology for creation 3D-model was developed and applied.

1 – MDCT with X-ray contrast of the patient's volume of interest (Fig. 1) with the compliance of the following requirements: slice thickness 0.5-1 mm, minimum collimation, minimum distance between slices (ultrathin slices), maximum slice overlap (up to 50 %). Rules for files' writing to disk: only in DICOM format in axial projection and bone mode of the window; exclusion of multiplanar reconstructions; raw RAW files.

Table 1.
The distribution of patients with bone tumors by nosological forms.

Nosological form	абс	%
Benign tumors	5	62,5
Giant cell bone tumor	2	25,0
Aneurismic bone cyst	1	12,5
Osteoblastoma	2	25,0
Malignant tumors	3	37,5
Osteogenic sarcoma	1	12,5
Periosteal osteosarcoma	1	12,5
Malignant giant cell tumor	1	12,5
Total	8	100,0

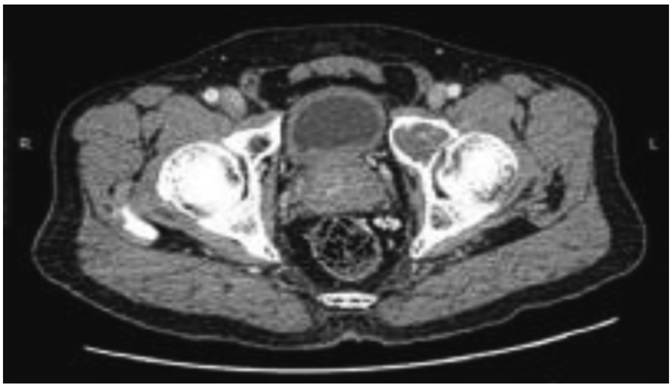

Fig. 1. *Diagnostic CT image.*

2 – processing of 2D images in DICOM format to improve their quality: enhanced contrast, clarity, noise filtration, artifacts' elimination.

3 – registration of the processed 2D images, reduction to a single coordinate system (Fig. 2), segmen-

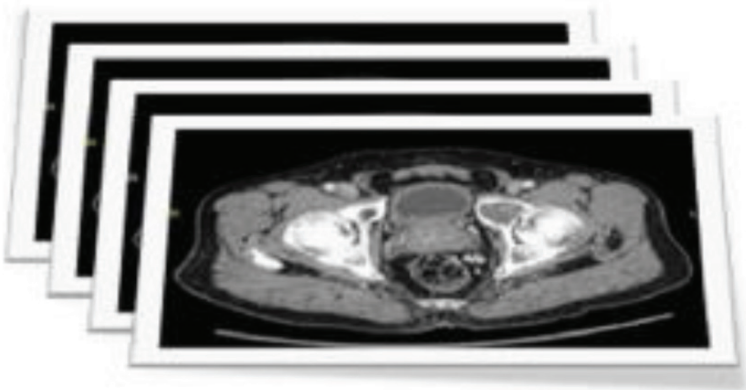

Fig. 2. *The set of diagnostic CT-images.*

tation to form an accurate anatomical computer 3D-model, DICOM files' convertion to STL format (STereoLithography) – file format for storage of 3D-models of the objects for additive technologies. Information about the object is stored as the list of triangular faces (which describe its surface) and their normals.

4 – 3D-model editing by the oncologist-orthopedist (together with radiologist and medical physicist) for detailed examination of the area of interest, for its geometric dimensions' analysis, syntopia, identification of anomalies and deviations in the structure, diagnosis formation. The MIMICS software package (Materialize's Interactive Medical Image Control System) is applied as a software interface and image postprocessing system for transferring images from medical visualization equipment to the systems of analysis, design, synthesis, simulation, and reproduction.

5 – model importation into the automated 3D printer system for the designing of the perfectly personalized 3D-model of the organ.

6 – 3D-model printing (Fig. 3).

3D Creatbot D600 printer (China) was used for printing. Printing was performed by the method of fused deposition modeling (FDM). FDM technology creates 3D objects by applying successive layers of material that follow the contours of the digital model. Material for printing: thermoplastics in the form of spools of threads or rods. At the stage of 3D print mastering, polylactide (PLA) was used – biodegradable, biocompatible (raw materials for production: corn and sugar cane), thermoplastic, aliphatic polyester, the monomer of which is lactic acid.

Statistical processing of quantitative indicators was carried out with methods of variation statistics in the framework of the tabular processor "Microsoft Excel" version 5.0 (USA) on the personal computer.

Patients' examinations were conducted with their informed consent in accordance with the provisions of the Helsinki Declaration of the World Medical Association on Medical Ethics.

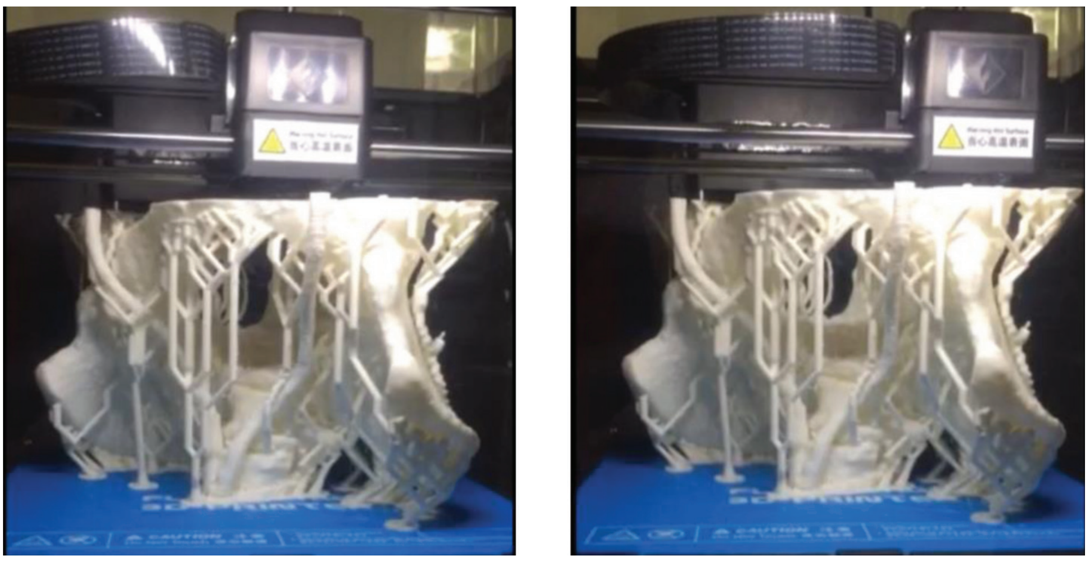

Fig. 3. *Printing process with layer-by-layer polylactide melting method.*

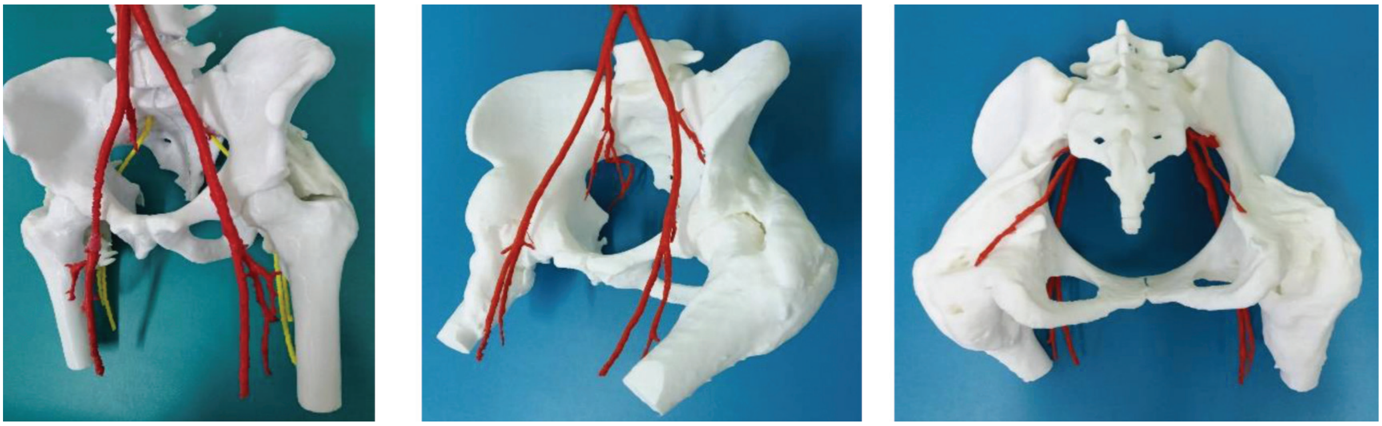

Рис. 4. *3D-model of pelvic bones' tumor lesions with main arteries.*

Results and their discussion

In accordance with the developed technology, 8 patients with bone tumors were investigated with MDCT. Based on the results of the survey, the personalized solid-state 3D-models were created and printed in relation to the prototype 1: 1 (Fig. 4).

Preoperative surgery planning and surgical training on the personalized 3D-model of the surgical area. On the personified 3D-models of bones tumor lesions the following procedures were carried out: the choice of the optimal surgical access to the neoplasia focus accounting the volume and topographic-anatomical location of the tumor and the convenience of intraoperative tasks performing (tumor removal, bone grafting or endoprosthetics); planning of the lines for the proposed bone resection in compliance with the oncological principles of radicality and ablasticity; calculation of the optimal amount of the required plastic material (biomin [8]); training of the surgery main basic techniques with the ability to obtain tactile feedback; patient-oriented repetitions of surgical intervention.

Regular implementation of the main basic surgical techniques on personified 3D-models allows to automatize the psychomotor component, which enables to concentrate more productively on the cognitive support of the operation, enhance situational awareness, that is, sensory perception of the situation elements, their importance and prediction the near future.

Surgical interventions based on planning and training were performed in 8 patients.

Intraoperative verification of 3D-models of bones with benign and malignant tumors demonstrated their almost full identity to the prototypes in all important for surgery dimensions (tumor radiological dimensions, arterial segments length, blood vessels walls caliber and thickness), an exact match to the organs' structure of the particular patient, in view of inherent only to him structural features and syntopy of the adjacent organs.

Comparison of the effect of planning and training variants in the main and control groups on the arthroplasty quality indicator (minimum set of obvious indicators was analyzed) in 2 groups of patients is presented in Table 2.

Table 2.
Comparison of treatment quality indicators.

Criteria	Groups	
	Control (n= 16)	Main (n= 8)
Surgical incision length (cm)	18,5±1,9	13,4±1,3
Blood loss (l)	1,0-1,3	0,3-0,4
Full restoration of limb functions	8-9 weeks	4-5 weeks
Surgery duration*	3,0-3.5 h	2,0-2,5 h

*Note: * - hip arthroplasty.*

It can be seen that planning and training in all 8 observations reliably reduced the duration of surgical intervention and, accordingly, intraoperative blood loss and the risk of postoperative complications.

At the same time, it is necessary to study the possibility of reproducing on the 3D-model the exact true contour/surface of the tumor by the superposition of CT/ MR images.

Conclusion

The technology for 3D-model creation of bones affected by benign and malignant tumors was developed.

3D-models of pelvis with bone tumor have anatomical conformaties with the real prototype in all quantitative indicators (arterial segment length, vessel wall caliber and thickness), they are identical to the organs' structure of the particular patient, with only him inherent features of the structure and syntopy of the adjacent organs.

Training of the surgical approaches and techniques allows to reduce the anesthesia and surgery duration, tissue trauma and blood loss.

Operations planning and constantly implemented on personalized 3D-models manual skills training contribute to the stable maintenance of high surgical skills realization.

The theme of the article is the fragment of the research work of R.E. Kavetsky Institute of Experimental Pathology, Oncology and Radiobiology, NAS of Ukraine "Development of technology for 3D modeling and 3D printing of personalized bone models affected by malignant neoplasms for surgery planning and intraoperative navigation."

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3D MODELING AND 3D PRINTING TECHNOLOGY FOR PERSONALIZED MODELS OF PELVIC BONES AND PROXIMAL FEMUR MALIGNANT TUMORS FOR SURGERY PLANNING AND REHEARSAL

N.K. Ternovoy, O.V. Drobotun, N.N. Kolotilov, V.F. Konovalenko, I.M. Voyeykova, S.I. Vasilieva

The purpose of the article is to present the experience of 3D modeling of pelvic and proximal femur malignant tumors application for surgery planning, rehearsal and manual skills improvement.

Material and methods. Diagnosis, treatment (tumor resection, endoprosthesis, bone grafting) were performed in 8 patients with benign and malignant bone tumors. Control group: archival histories of 16 patients with similar diagnoses and treatment without modeling. Patients were examined on a Light Speed® VCT tomograph. For printing by layer-by-layer welding, Creatbot D600 3D printer was applied. Material for printing: thermoplastic polylactide.

Results. The following procedures were performed on the 3D models: the choice of the optimal surgical access to the neoplasia focus accounting the volume and topographic-anatomical location of the tumor and the convenience of intraoperative tasks performing (tumor removal, bone grafting or endoprosthetics); planning of the lines for the proposed bone resection in compliance with the oncological principles of radicality and ablasticity; calculation of the optimal amount of the required plastic material (biomin); training of the surgery main basic techniques with the ability to obtain tactile feedback; patient-oriented repetitions of surgical intervention.

Results. The technology for creating personalized solid-state 3D models of bones affected by benign and malignant tumors, in relation to the 1: 1 prototype was developed.

ТЕХНОЛОГІЯ 3D МОДЕЛЮВАННЯ ТА 3D ДРУКУ ПЕРСОНІФІКОВАНИХ МОДЕЛЕЙ ЗЛОЯКІСНИХ ПУХЛИН КІСТОК ТАЗУ І ПРОКСИМАЛЬНОГО ВІДДІЛУ СТЕГНОВОЇ КІСТКИ ДЛЯ ПЛАНУВАННЯ ТА РЕПЕТИЦІЙ ОПЕРАЦІЙ

Н.К. Терновий, О.В. Дроботун, М.М. Колотілов, В.Ф. Коноваленко, І.М. Воєйкова, С.І. Васильєва

Мета статті – виклад досвіду використання 3D-моделювання злоякісних пухлин кісток тазу і проксимального відділу стегнової кістки для планування операції, репетиції та вдосконалення мануальних навичок.

Матеріал і методи. Діагностику, лікування (резекція пухлини, ендопротезування, кісткова пластика) проведено у 8 хворих з доброякісними і злоякісними пухлинами кісток. Контрольна група: архівні історії хвороби 16 пацієнтів з аналогічними діагнозами і лікуванням без моделювання. Обстеження хворих виконано на томографі Light Speed® VCT. Для друку методом пошарового наплавлення використовувався 3D принтер Creatbot D600. Матеріал для друку: термопластик полілактид.

Результати. На 3D-моделях здійснювали: вибір оптимального хірургічного доступу до вогнища неоплазії з урахуванням обсягу і топографо-анатомічного розташування новоутворення і зручності виконання інтраопераційних завдань (видалення пухлини, кісткової пластики або ендопротезування); планування лінії передбачуваної резекції кістки з максимальним збереженням інтактної кісткової тканини з дотриманням онкологічних принципів радикальності і абластичності; розрахунок оптимальної кількості необхідного пластичного матеріалу (біомін); тренування основних базових прийомів хірургічної техніки з можливістю отримання тактильного зворотного зв’язку; пацієнт-орієнтовані репетиції операційного втручання.

Висновки. Розроблено технологію створення персоніфікованих твердотільних 3D-моделей кісток, уражених доброякісними і злоякісними пухлинами, в співвідношенні до прототипу 1: 1.

ТЕХНОЛОГИЯ 3D МОДЕЛИРОВАНИЯ И 3D ПЕЧАТИ ПЕРСОНИФИЦИРОВАННЫХ МОДЕЛЕЙ ЗЛОКАЧЕСТВЕННЫХ ОПУХОЛЕЙ КОСТЕЙ ТАЗА И ПРОКСИМАЛЬНОГО ОТДЕЛА БЕДРЕННОЙ КОСТИ ДЛЯ ПЛАНИРОВАНИЯ И РЕПЕТИЦИЙ ОПЕРАЦИЙ

Н.К. Терновой, О.В. Дроботун, Н.Н. Колотилов, В.Ф. Коноваленко, И.М. Воейкова, С.И. Васильева

Цель статьи – изложение опыта использования 3D-моделирования злокачественных опухолей костей таза и проксимального отдела бедренной кости для планирования операции, репетиции и совершенствования мануальных навыков.

Материал и методы. Диагностику, лечение (резекция опухоли, эндопротезирование, костная пластика) проведено у 8 больных с доброкачественными и злокачественными опухолями костей. Контрольная группа: архивные истории болезни 16 пациентов с аналогичными диагнозами и лечением без моделирования. Обследование больных выполнено на томографе Light Speed® VCT. Для печати методом послойного наплавления использовался 3D принтер Creatbot D600. Материал для печати: термопластик полилактид.

Результаты. На 3D моделях осуществляли: выбор оптимального хирургического доступа к очагу неоплазии с учетом объема и топографо-анатомического расположения новообразования и удобства выполнения интраоперационных задач (удаления опухоли, костной пластики или эндопротезирования); планирование линии предполагаемой резекции кости с максимальным сохранением интактной костной ткани с соблюдением онкологических принципов радикальности и абластичности; расчет оптимального количества необходимого пластического материала (биомин); тренировку основных базовых приёмов хирургической техники с возможностью получения тактильной обратной связи; пациент-ориентированные репетиции операционного вмешательства.

Выводы. Разработана технология создания персонифицированных твёрдотельных 3D-моделей костей, пораженных доброкачественными и злокачественными опухолями, в соотношении к прототипу 1 : 1.