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PECULIARITIES OF THE IDENTIFICATION OF DIFFERENT TYPES OF TISSUES DURING 3D-RECONSTRUCTION OF HUMAN MICROSCOPIC STRUCTURES

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Summary

3D reconstruction is an informative, objective method of morphological research that consists in transforming a series of successive sections (histological, macroscopic, anatomical sections, computed tomography (CT), etc.) into a virtual three-dimensional (digital) image that can be studied in different projections and measure volumes, areas, diameters, angles, save, copy, edit.

The aim of the study. *The aim of this work was to compare the effectiveness of 3D reconstruction methods of various tissues and microscopic anatomical structures of the human body in the prenatal period of development.*

Material and methods. *The research was carried out on 6 series of consecutive histological sections of human embryos at the age of 4 to 6 weeks of intrauterine development (IUD), 15 samples of organ complexes of the head, limbs and trunk of human fetuses at the age of 7 to 12 weeks of IUD, human fetuses aged 4-9 months of IUD by the method of making histological (5), as well as histotopographic sections (10) directly from the paraffin block and their digitization, and 14 CT of human fetuses aged 4 to 9 months of IUD.*

The studies were conducted in accordance with the most important regulations of the resolution of the First National Bioethics Congress «General Ethical Principles of Experiments on Animals» (2001), ICH GCP (1996), the European Union Convention on Human Rights and Biomedicine (April 4, 1997) and the European Convention for the Protection of Vertebrate Animals used in Experimental and Other Scientific Research (March 18, 1986). 1997) and the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (18.03.1986), the Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects (1964-2008), EU Directives № 609 (24.11.1986), Orders of the Ministry of Health of Ukraine № 690 dated 23.09.2009, № 944 dated 14.12.2009, № 616 dated 03.08.2012.

The work is carried out within the framework of the initiative research work of the Department of Histology, Cytology and Embryology of the Bukovinian State Medical University «Structural and functional peculiarities of tissues and organs in ontogenesis, regularities of variant, constitutional, gender, age and comparative human morphology». State registration number: 0121U110121. Terms of execution: 01.2021-12.2025.

Results. *3D reconstruction of series of consecutive histological sections is effective for the study of embryonic specimens, organ complexes of prefetuses and certain microscopic structures of human fetuses due to easy identification of histological structures, however, it is necessary to improve the methods of alignment of histological sections both in the correct sequence of the series and in the natural position. 3D reconstruction of histotopographic sections is recommended for the study of specimens of organ complexes of human prefetuses and fetuses. 3D reconstruction of CT sections is an effective and highly accurate tool for the study of X-ray contrast anatomical structures in the fetal period of IUD (bone tissue, contrasting blood vessels), allows using a certain research algorithm to detect and measure ossification centers and syntopy of blood vessels with bones.*

Conclusions. *For wide application in morphology, the method of 3D reconstruction requires technical improvement of the software-hardware complex for reconstruction, namely: automation of segmentation of sections, as well as improvement of methods of polychrome marking of anatomical structures for their clear differentiation.*

Key words: *3D Reconstruction; Bone Tissue Research; Human Prenatal Development; Human Fetuses.*

Introduction

Three-dimensional (3D) computer reconstruction of anatomical structures has become a classic method of morphological research in recent decades [1-3]. The method is used to reproduce and study the shape of rather small structures in cases where the specimen is ineffective or impossible due to the small size of the structures or their close syntopy [4]. Before the advent of computer technologies for image acquisition and processing, anatomists used graphic and three-dimensional (plastic or wax) reconstructions [5]. The first known reconstructions of microscopic anatomical structures were made by the scientist Born G. (1876, 1893) from serial histological sections. Further improvement of the reconstruction technique by Gaupp E. (1893); Turkevich M. G. (1967), Kuhn H.-J. (1971) included graphic reconstruction in the complex of morphological research methods [6, 7].

It is known that the first 3D computer reconstruction was performed in 1984 due to the development of computer technologies [8, 9]. Since then, anatomists, histologists, topographical anatomists, embryologists have included it in the complex of morphological research methods as a rather informative and objective method [10, 11]. In addition, this technology corresponds to the main principles of modern diagnostic medical imaging, therefore it contributes to the improvement of interpretation of non-invasive diagnostic methods [12].

Thus, 3D reconstruction is an informative, objective method of morphological research, which consists in transforming a series of successive sections (histological, macroscopic, anatomical sections, CT, etc.) into a virtual

three-dimensional (digital) image that can be studied in different projections and measure volume, area, diameter, angles, save, copy, edit [13]. Therefore, the reconstruction is the basis for creating educational visual materials, modeling anatomical variants, the course of the pathological process, age-related changes, organ movements, etc. [14, 15].

Modern medical diagnostic imaging techniques (CT, MRI, USD) are based on obtaining a 3D image from a series of successive «virtual» slices, which of course do not involve tissue destruction. Their interpretation requires exhaustive knowledge of the real anatomical structure, especially for objective monitoring of intrauterine development (IUD) [16, 17].

3D reconstruction of microscopic structures is a valuable method for morphological studies of the early period of human and animal ontogeny [18, 19, 20]. The microscopic size of fetal organs and structures compared to an adult organism provides the technical possibility to embed them in a single paraffin block and reconstruct them from serial sections in anatomical continuity for the study of form and syntopy. Such a research method is technically extremely difficult to carry out on an adult organism, since the same organ complex as that taken from a fetus, in which all variants of structure and topography of the structures have already been determined by the 4th month of development, has much larger dimensions, which makes the study of syntopy impossible.

The aim of the study. The aim of this paper was to compare the effectiveness of 3D reconstruction methods of various tissues and microscopic anatomical structures of the human body in the prenatal period of development.

Material and methods

The research was conducted on 6 series of consecutive histological sections of human embryos aged 4 to 6 weeks of IUD, 15 samples of organ complexes of the head, limbs and trunk of human prefetuses aged 7 to 12 weeks of IUD, human fetuses aged 4 to 9 months of IUD by the method of making histological (5), as well as histotopographic sections (10) directly from the paraffin block and their digitization, and 14 CT of human fetuses aged 4 to 9 months of IUD.

Histological specimens of human embryos were stained with hematoxylin and eosin, digitized using a photographic device consisting of a microscope MBR-1 with a lens Will Wetzlar 4/0.10, adapter M42-M4/3, digital camera Olympus PEN E-Pl 1. The surface of sections of paraffin blocks with embedded specimens of human prefetuses was photographed using the camera Canon G7, macro lens (Industar-100U 4/110), fixed on the feed mechanism of the microtome object holder. Digital photographs of histologic specimens, oriented in the natural position, were compared using a graphic editor. Long structures such as the rudiment of the spinal column, major blood vessels and the largest organs (stomach, liver, heart, etc.) were used as landmarks. Segmentation and rendering of virtual 3D reconstructions from both digital photomicrographs and DICOM CT files were performed using 3D-Doctor software (Able Software Corp.).

The studies were conducted in accordance with the most important regulations of the resolution of the First National Bioethics Congress «General Ethical Principles of Experiments on Animals» (2001), ICH GCP (1996), the European Union Convention on Human Rights and Biomedicine (April 4, 1997) and the European Convention for the Protection of Vertebrate Animals used in Experimental and Other Scientific Research (March 18, 1986). 1997) and the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (18.03.1986), the Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects (1964-2008), EU Directives № 609 (24.11.1986), Orders of the Ministry of Health of Ukraine № 690 dated 23.09.2009, № 944 dated 14.12.2009, № 616 dated 03.08.2012.

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Results and their discussion

According to the technology of obtaining and preparing digital images of a series of consecutive sections, which are loaded into the software for further stages of creating a 3D reconstruction, we divided the material into three groups: 1) microphotographs of a series of consecutive histological sections; 2) a series of microphotographs of the surface of the paraffin block; 3) DICOM CT files of fetuses.

The stages of 3D reconstruction from serial histological sections are as follows: 1) specimen preparation (injection of blood vessels, tubular and hollow organs, placement of landmarks); 2) obtaining a series of consecutive sections (microtomy); 3) digitization of sections (photography); 4) alignment of images of histological sections of a series in natural anatomical position; 5) selection of sections for reconstruction by area, number and step; 6) calibration of the morphometric block of the reconstruction software; 7) segmentation (manual delineation of the contours of the anatomical structures under study); 8) rendering (construction of a reconstruction model using information about the volume or contours of the object); 9) study, morphometry and animation of the reconstruction model for demonstration.

Creating of 3D-reconstruction from a series of consecutive histological sections. The undeniable advantage of using histological specimens for 3D reconstruction is their high level of information and detail, which allows easy identification of various tissues and organs according to their classical description and appearance given in histological, cytological and embryological atlases. For differentiation of blood vessels, injection of blood vessels and hollow organs with polychrome and X-ray contrast compositions was used (Fig. 1). This technique can be used for histological examination of organ complexes of human fetuses from the 4th month of gestation (Fig. 2).

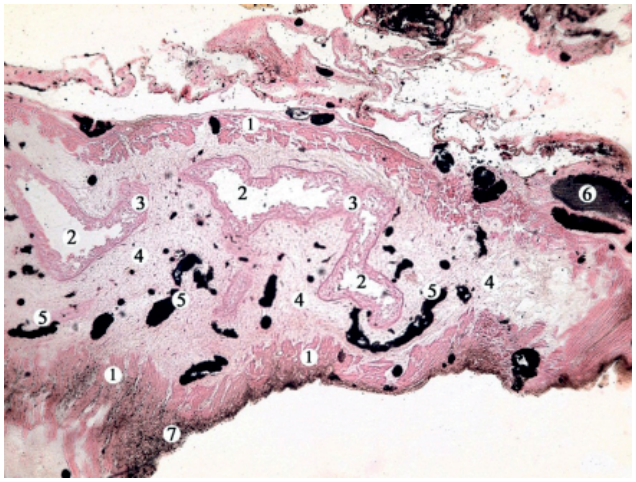

Fig. 1. Longitudinal section of the cystic duct of a 5-month-old human fetus (235,0 мм PCL). Injection of the venous system with a red lead. Hematoxylin-eosin. Photomicrograph. 40x: 1 – muscular membrane; 2 – lumen; 3 – mucous membrane; 4 – submucous membrane; 5 – venous plexus; 6 – branch of the gallbladder vein

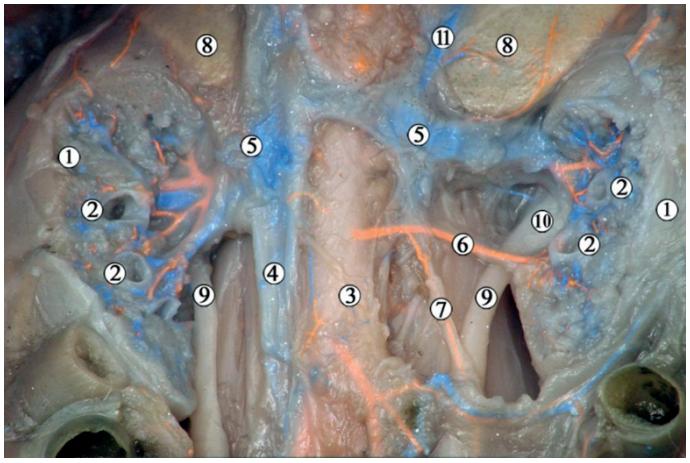

Fig. 2. Organs of the retroperitoneal space of a 6-month-old human fetus (180.0 mm PCL). Polychrome injection of blood vessels. Photo of macrospecimen. 2x: 1 – kidneys; 2 – major calices; 3 – abdominal aorta; 4 – inferior vena cava; 5 – renal veins; 6 – aberrant left inferior renal artery; 7 – left ovarian artery; 8 – adrenal glands; 9 – ureters; 10 – left renal pelvis; 11 – left adrenal vein

Among the anatomical structures of human embryos and fetuses, during their segmentation, epithelial layers, skeletal muscles and heart, cartilaginous tissues and ossification centers, glands, blood vessels, nervous tissues, hollow and parenchymal organs, mesenchymal layers are identified. This makes it possible to obtain detailed 3D reconstructions for studying the peculiarities of the microscopic structure of organ complexes during IUD (Fig. 3).

The quality of reconstructions from a series of histologic sections depends on a number of factors: 1) tissue changes during preservation, fixation, dehydration, clarification, and paraffin embedding; 2) tissue distortion due to microtomy (usually the histological section is shortened in the direction of movement of the microtome blade, which is partially or completely eliminated by straightening the sections in a water bath); 3) the accuracy of forming a series in the correct sequence of sections; 4) the accuracy of aligning (matching) the sections in their natural orientation; 5) the quality of surface generation, which depends on the accuracy of manual outlining of anatomical structures.

The histologic examination of preparations of human fetuses and organocomplexes has certain technological limitations that are characteristic of classical histotechnique: 1) the maximum size of a paraffin block with an embedded organocomplex should not exceed 15-20 mm in width or length due to difficulties with microtomy and obtaining low quality sections; 2) a longer flotation of sections in a water bath is required for their complete alignment and to avoid deformation that occurs during microtomy; 3) automation of staining of histological sections is necessary due to their large number, i.e. it is necessary to use a stainer or cassettes for 10-20 slides; 4) possible errors in marking or in the correct sequence of placing the sections on the slides, which leads to distortions of the 3D reconstruction model, distortions in the form of a step effect can also be caused by the displacement of the specimen holder during the restart of its feeding mechanism; 5) industrial microscopes with built-in digital cameras usually do not capture large areas

of histological sections, therefore in case of photographing sections larger than 5. 0x5.0 mm, a microscope with x2-x4 objectives and an adapter with a mirrorless digital camera installed at the attachment point of the tube was used with an eyepiece, while the image from the microlens was projected directly onto the photomatrix without any additional optical elements. It should be noted that the photomatrix of digital single lens reflex or mirrorless (single lens non-reflex) cameras, in which it is possible to detach the lens, has much larger physical dimensions than CCD cameras of microscopes, which allows to fit more structures or even the entire surface of the paraffin block into the photoframe window. This is important when studying organ complexes of human fetuses, body parts of prefetuses or whole embryos, where it is necessary to cover relatively large areas of the specimen with a microlens.

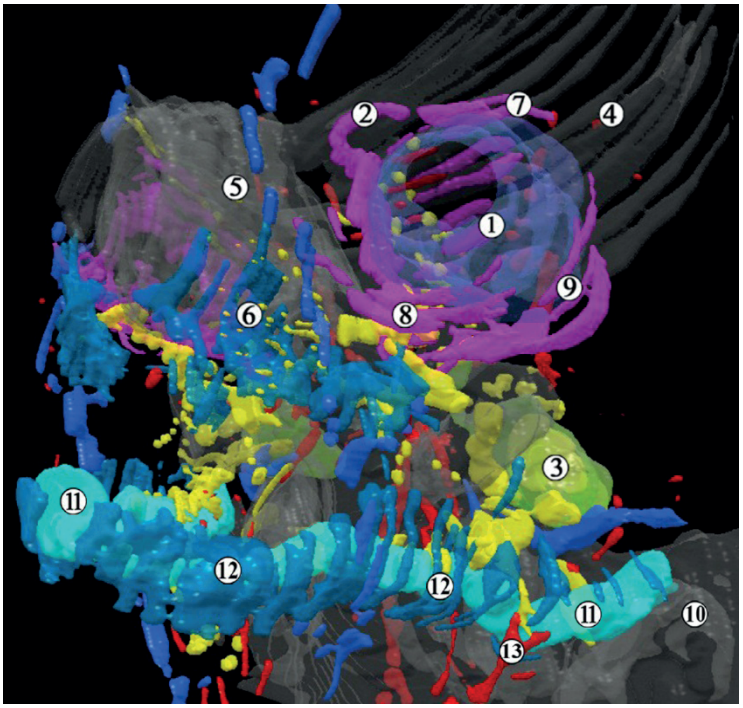

Fig. 3. 3D-reconstruction of the head of a 7-week-old human embryo (19.0 mm PCL). Left anterior-lateral projection. 25x: 1 – eyeball rudiment; 2 – superior oblique muscle; 3 – trigeminal ganglion; 4 – frontal bone rudiment; 5 – nasal capsule; 6 – centers of ossification of the maxilla; 7 – superior rectus muscle; 8 – inferior rectus muscle; 9 – lateral rectus muscle; 10 – otic capsule; 11 – Meckel's cartilage; 12 – centers of ossification of the mandible

Creation of 3D reconstructions from a series of consecutive images of the surface of a paraffin block. This technique involves the creation of 3D reconstructions of the organ complexes of human fetuses by photographing the surface of a paraffin block after each microtome section. Actually, histotopographic sections were digitized using special photographic equipment (Figs. 4, 5).

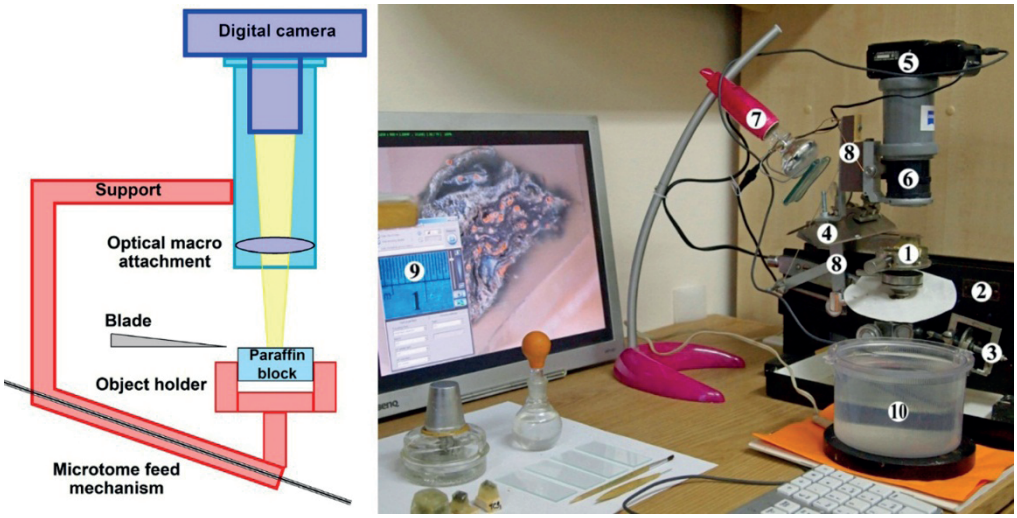

Fig. 4. Scheme (left) and software-hardware complex (right) for 3D-reconstruction of microscopic structures based on a series of microtome sections: 1 – paraffin block with specimen; 2 – microtome; 3 – feed mechanism; 4 – microtome blade; 5 – digital camera; 6 – macroscopic lens; 7 – lighting device with infrared filter

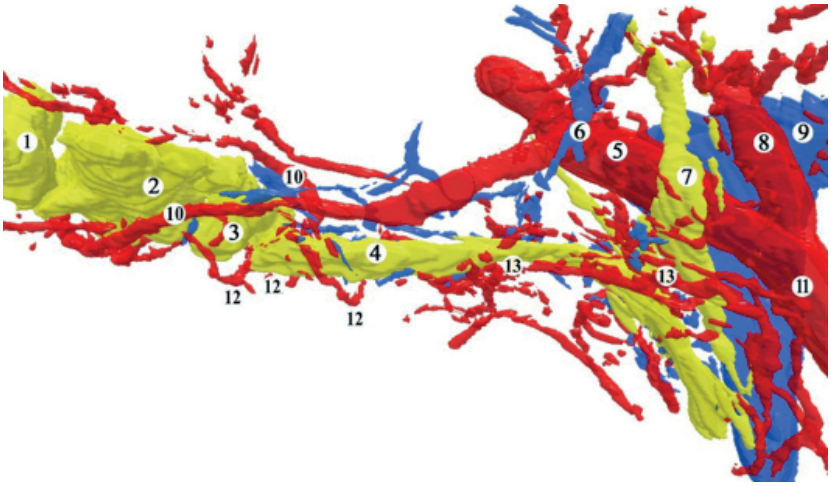

Fig. 5. 3D-reconstruction of serial frontal histotopographic sections of the human fetus (130.0 mm PCL). Anterior view. 30x: 1 – mucous membrane of the fundus of gallbladder; 2 – mucous membrane of the body of gallbladder; 3 – Hartmann's pouch and the neck of gallbladder; 4 – cystic duct; 5 – right branch of the hepatic artery proper; 6 – cystic artery and vein; 7 – common hepatic duct; 8 – left branch of the hepatic artery proper; 9 – portal vein; 10 – branch of the cystic artery; 11 –hepatic artery proper; 12 – spiral arteries of the cystic duct; 13 – anastomoses (arterial circle) of the cystic duct

This method of 3D reconstruction has certain advantages, but it is not without its disadvantages. The advantages include the following:

1. Since the photographic device is rigidly attached to the feed mechanism of the sliding microtome, it is impossible to shift the optical axis, thus ensuring the exact alignment of the sections, which is practically impossible to achieve when photographing histological specimens.

2. In parallel, histologic specimens are also prepared from microtome paraffin sections.

3. It is possible to use paraffin blocks with relatively large organ complexes – up to 40 mm in length and up to 25 mm in width (when using a conventional sled microtome).

4. Photographs are taken using a special tripod, a macro lens and a compact digital camera in semi-automatic mode with remote control using appropriate software and a personal computer.

The main disadvantage of the method of 3D reconstruction of histotopographic sections is the low clarity and detail of the obtained images, which makes the identification of histological structures difficult and requires professional knowledge of embryology, histology and anatomy. To improve the quality and clarity of the images, their batch processing is usually performed in a graphic editor. Despite its shortcomings, this technique makes it possible to identify microscopic anatomical structures (Fig. 5), study their shape and syntopy, and perform morphometry.

A significant advantage of the method is the possibility of automatic segmentation of blood vessels contrasted with dyes (Fig. 6), which is performed using 3D-Doctor and similar software. During manual segmentation, in addition to hollow and parenchymal organs, nerves, cartilage, bone tissue, muscles and glands are well identified. When studying the development of bones, it is possible to clearly determine the external contours of the cartilaginous rudiments of bones and centers of osteogenesis (Fig. 7, 8).

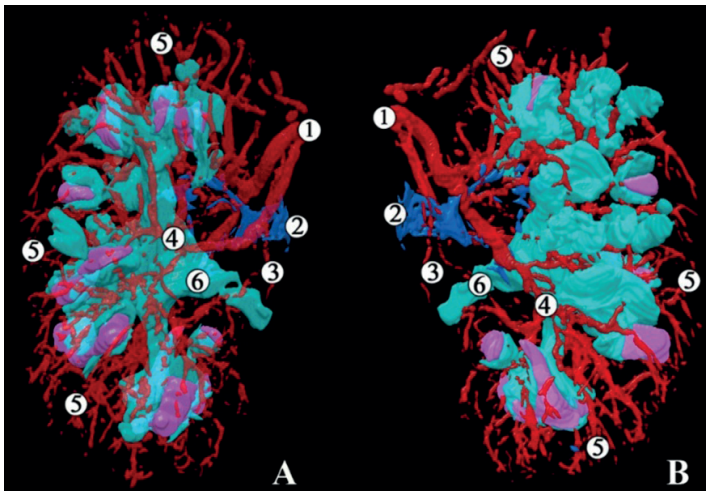

Fig. 6. 3D-reconstruction of the left kidney of a 7-month-old human fetus (260.0 mm PCL). Polychrome injection of arteries. A – posterior projection; B – anterior projection. The papillary parts of the renal pyramids are reproduced in pink. 7x: 1 – renal artery; 2 – renal vein; 3 – pelvic and ureteric branches; 4 – interlobular arteries; 5 – arcuate and interlobular arteries; 6 – renal pelvis

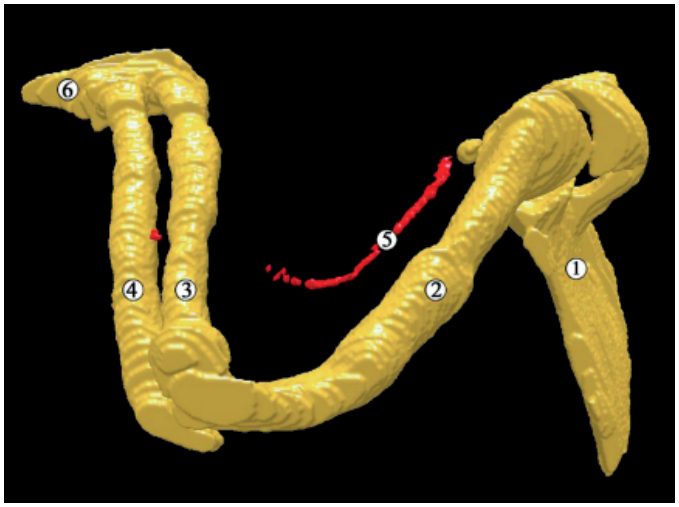

Fig. 7. 3D-reconstruction of the cartilage rudiments of the left upper limb of an 8-week-old human fetus (30.0 mm PCL). Left side projection. 30x: 1 – scapula; 2 – humerus; 3 – radius; 4 – ulna; 5 – brachial artery; 6 – rudiments of carpal bones

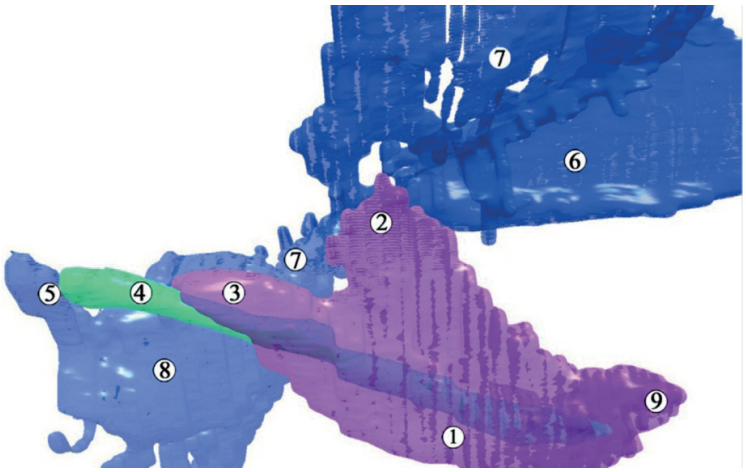

Fig. 8. 3D-reconstruction of the structures of the anterior part of the head of an 11-week-old human fetus (55.0 mm PCL). Right projection. 25x: 1 – body of mandible; 2 – coronoid process; 3 – condylar process; 4 – Meckel's cartilage; 5 –head of malleus; 6 – nasal septum; 7 – rudiments of the basicranium; 8 – otic capsule; 9 – Mental protuberance

Creation of 3D reconstruction from a series of DICOM CT files. During a CT scan, a series of DICOM PACS images are created that carry information about each virtual slice of the anatomical specimen. The resolution of modern CT allows the identification of structures with a resolution of up to 0.5 mm. Therefore, it is advisable to use this method on relatively large macro specimens of human fetuses when studying the shape, structure and syntopy of radiolucent organs and organ complexes. Not only bone tissue, but also blood vessels can be studied on CT scans of human fetuses contrasted with a composition based on red lead. In addition to specialized software for studying CT and automated creation of 3D reconstructions, such as RadiAnt Dicom Viewer (Medixant), we used 3D-Doctor, which has the ability to work with DICOM files. The interactive segmentation of fetal structures with different radiodensities allows the determination of contrasting structures (Fig. 9), the spatial shape of bone rudiments, and the location and shape of ossification centers (Fig. 10). The software automatically outlines the contours of bone rudiments according to the gradients of the Hounsfield scale, allowing visualization and morphometry of both the entire bone rudiment and ossification centers.

The advantages of the method of 3D reconstruction from a series of DICOM CT files include accuracy of matching, automatic calibration of slices, detailing of structures with high x-ray density, interactivity, and thus speed of rendering. Disadvantages include those characteristic of X-ray techniques.

The most difficult stage of 3D reconstruction is to outline the contours of the anatomical structures. This process requires time, professional knowledge and skills, a graphic manipulator pen or a special computer with a touch screen. This stage is the most difficult during 3D reconstruction of a series of successive images of the surface of the paraffin block. The final stage of creating a 3D reconstruction is rendering (application of a visualization algorithm). It is performed automatically by the software. The created reconstruction model is studied in different projections and its individual elements are measured. The next stage of work with 3D reconstruction can be its 3D printing [18].

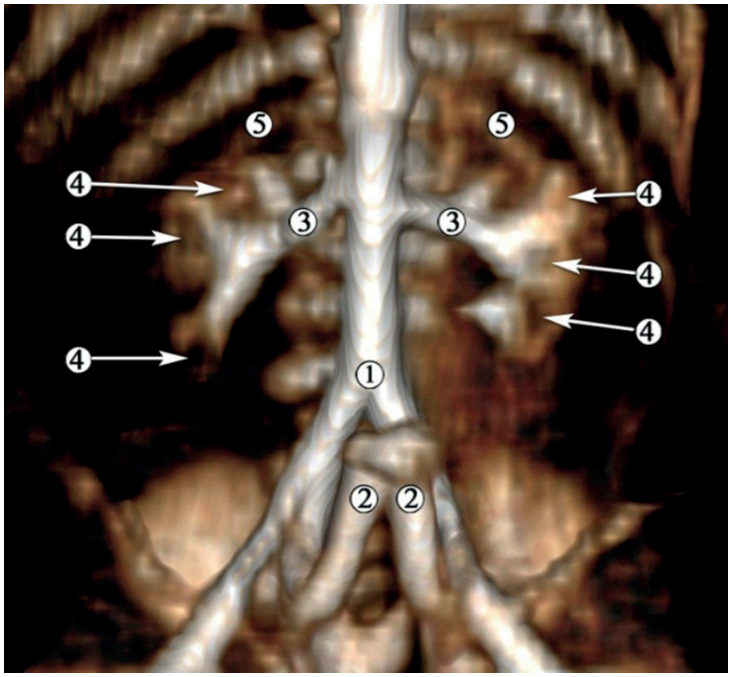

Fig. 9. CT of a 5-month-old human fetus (155.0 mm PCL). Injection of the arterial system with a composition of red lead. Anterior projection. 3x: 1 – bifurcation of the aorta; 2 – umbilical arteries; 3 – renal arteries; 4 – contours of the minor renal calices; 5 – XII rib.

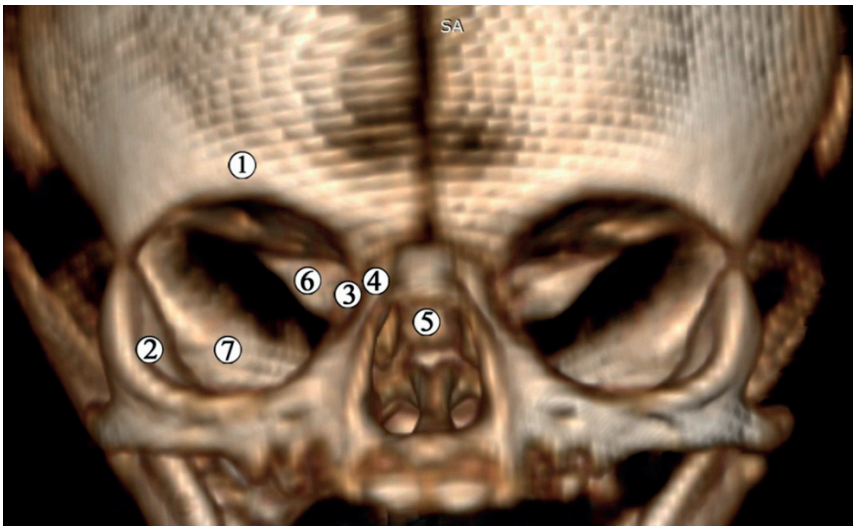

Fig. 10. CT of the head of a 6-month-old human fetus (200.0 mm PCL). Anterior projection. 3x: 1 – frontal bone; 2 – zygomatic bone; 3 – ethmoidal bone; 4 – frontal process of the maxilla; 5 – body of sphenoid bone; 6 – lesser wing of sphenoid bone; 7 – greater wing of sphenoid bone.

The prospects for improving 3D reconstruction methods, in our opinion, are as follows: 1) 3D reconstruction of a series of consecutive histological sections requires the use of effective landmarks for the correct alignment of the sections; 2) 3D reconstruction of a series of consecutive images of the surface of the paraffin block requires the use of total staining of the specimen before it is embedded in the paraffin block for a more contrasting image of organs and histological tissues; 3) 3D reconstruction of a series of DICOM CT files requires an increase in resolution (the thickness of the CT slices is less than 1.0 mm). Considering the fact that the tracing of anatomical structures remains the most difficult stage of 3D reconstruction, it is advisable to further develop software using elements of artificial intelligence, in particular to identify and automate the segmentation of sections of certain anatomical structures and tissues [21-26].

Taking into account all the advantages and disadvantages of the applied 3D reconstruction methods, they can be presented in the form of a table according to the degree of objectivity and automatic realization (Table).

Table

Comparative characteristics of 3D-reconstruction methods

Stages	Alignment of slices	Calibration of slices (determination of pixel and voxel sizes)	Recognition of microstructures	Segmentation (selection of contours of microstructures)	Detailing	Accuracy of morphometry
3D reconstruction of serial histological sections	–	–	+	–	+	+
3D reconstruction of serial images of the surface of the paraffin block	+	–	–	–	–	–
3D reconstruction of serial CT scans	+	+	–	+	–	+

Notes: (+) – objective factor, automatic execution; (–) – subjective factor, manual implementation.

Conclusions

1. 3D reconstruction of series of consecutive histological sections is effective for the study of embryo specimens, organ complexes of prefetuses and certain microscopic structures of human fetuses due to easy identification of histological structures, however, it is necessary to improve the methods of alignment of histological sections both in the correct sequence of the series and in the natural position in two-dimensional coordinate system.

2. 3D reconstruction of histotopographic sections (images of the surface of the paraffin block) is advisable to use in the study of samples of organ complexes of human fetuses and fetuses, allows identification of individual parenchymal and hollow organs and blood vessels, especially if their injection is performed before fixation of the sample.

3. 3D reconstruction of CT sections is an effective and highly accurate tool for the study of x-ray contrast anatomical structures in the fetal period of human development (bone tissue, contrast blood vessels). The method allows to detect and measure ossification centers and syntopy of blood vessels with bones using a certain research algorithm.

4. The choice of the technique of 3D reconstruction of microscopic structures in the prenatal period of human ontogenesis depends on the age period of the research material, which is caused by certain technological limitations of the specific technique: 3D reconstruction of a series of histological sections is recommended for the study of embryos and fetuses, as well as individual structures and organs of fetuses; 3D reconstruction of a series of histotopographic sections – for the study of organ complexes of human prefetuses and fetuses; 3D reconstruction of CT slices – for the study of individual structures of human fetuses.

Prospects for further research. Improving the technique of 3D reconstruction of organ complexes embedded in a paraffin block requires the development of methods for total staining of specimens, which will greatly facilitate both the preparation of serial histological sections and the delineation of the contours of anatomical structures on the images of histotopographic sections.

Conflict of interest: The Authors declare no conflict of interest.

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ОСОБЛИВОСТІ ІДЕНТИФІКАЦІЇ РІЗНИХ ТИПІВ ТКАНИН ПІД ЧАС 3D-РЕКОНСТРУКЦІЇ МІКРОСКОПІЧНИХ СТРУКТУР ЛЮДИНИ

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Резюме.

3D-реконструювання є інформативним, об'єктивним методом морфологічного дослідження, який полягає у перетворенні серії послідовних зрізів (гістологічних, макроскопічних, анатомічних розпилів, комп'ютерних томограм тощо) у віртуальне об'ємне (цифрове) зображення, яке можна вивчати в різних проекціях та вимірювати об'єм, площу, діаметри, кути, зберігати, копіювати, редагувати.

Мета дослідження – порівняти ефективність методик 3D-реконструювання різних тканин та мікроскопічних анатомічних структур організму в пренатальному періоді розвитку людини.

Матеріал і методи дослідження. Нами досліджено 6 серій послідовних гістологічних зрізів зародків людини віком від 4 до 6 тижнів внутрішньоутробного розвитку, 15 препаратів органокомплексів голови, кінцівок та тулуба передплодів людини віком від 7 до 12 тижнів внутрішньоутробного розвитку, плодів людини віком 4-9 місяців ВУР методом виготовлення гістологічних

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(5), а також гістотопографічних зрізів (10) безпосередньо з парафінового блоку та їх оцифровки, та 14 КТ плодів людини віком від 4 до 9 місяців ВУР.

Дослідження проводилося відповідно до основних положень Резолюції Першого національного конгресу з біоетики «Загальні етичні принципи експериментів на тваринах» (2001), ICH GCP (1996), Конвенції Європейського Союзу про права людини та біомедицину (1997), а також Гельсінської декларації про етичні принципи медичних досліджень із залученням людей (1964-2008), Директив ЄС № 609 (1986), Наказів МОЗ України № 690 від 23.09.2009, № 944 від 14.12.2009, № 616 від 03.08.2012.

Робота виконується в рамках ініціативної науково-дослідної роботи кафедри гістології, цитології та ембріології закладу вищої освіти «Буковинський державний медичний університет» «Структурно-функціональні особливості тканин і органів в онтогенезі, закономірності варіантної, конституційної, статево-вікової та порівняльної морфології людини». Державний реєстраційний номер: 0121U110121. Терміни виконання: 01.2021-12.2025.

Результати дослідження. 3D-реконструювання серій послідовних гістологічних зрізів ефективне для дослідження препаратів зародків, органокомплексів передплодів та певних мікроскопічних структур плодів людини завдяки легкій ідентифікації гістологічних структур, однак потребує удосконалення способів зіставлення гістологічних зрізів у природній позиції. 3D-реконструювання гістотопографічних зрізів доцільно застосовувати при дослідженні препаратів органокомплексів передплодів та плодів людини. 3D-реконструювання серійних КТ-зрізів – ефективний та високоточний інструмент дослідження рентгенконтрастних анатомічних структур у плодовому періоді ВУР (кісткової тканини, контрастованих кровоносних судин), дозволяє при використанні певного алгоритму дослідження виявляти та вимірювати осередки скостеніння та синтопію кровоносних судин з кістками.

Висновки. Для широкого застосування в морфології метод 3D-реконструювання вимагає технічного удосконалення програмно-апаратного комплексу для реконструювання, а саме: автоматизації етапів реконструкції, зокрема, сегментації зрізів, а також удосконалення методик поліхромного маркування структур анатомічного препарату для їхнього чіткого диференціювання.

Ключові слова: 3D-реконструювання; дослідження кісткової тканини; пренатальний розвиток людини; плоди людини.

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