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Construction of digital three-dimensional reconstruction model of rabbit vascular network

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ABSTRACT

In order to study the construction of digital three-dimensional model of rabbit vascular network and provide a powerful basis for the model construction and image processing of human vascular network, in this study, rabbit abdominal and pelvic vessels are perfused with latex-bismuth oxide contrast agent. After that, the internal fibrous structure of the abdominal and pelvic vascular network in rabbits is studied by micro-computed tomography (Micro-CT). Angiography and post-processing software are performed. Firstly, six female rabbits are selected as the study subjects and are anesthetized by intraperitoneal injection of 12% chloral hydrate. After complete anesthesia, laparotomy is performed on the rabbits. The abdominal wall of the rabbit is cut longitudinally to expose the pelvic and abdominal cavity completely. The posterior peritoneum is found and opened. The catheter is inserted into the abdominal aorta and renal artery to complete the abdominal aorta and arterial intubation. Latex, bismuth oxide and potassium hydroxide are mixed in a ratio of 1:1:1 to form latex-bismuth oxide mixed solution as a mixed contrast agent for blood vessel perfusion. After the rabbit is perfused with mixed contrast medium, four organs, including bladder, uterus, small intestine and kidney, are selected as the research organs to construct the three-dimensional model of vascular network in this study. Finally, the above organs are scanned in vitro by micro-CT technology, and the original images of each organ are processed. Then, Mimics 17.0 software is used to build a digital three-dimensional model of the abdominal and pelvic vascular network in rabbits, obtain the information parameters of each network, and analyze the classification and diameter of blood vessels. The results show that the classification of bladder vascular network can only be divided into two levels, uterine vascular network can be divided into three levels, and small intestine and kidney vascular network can be divided into four levels. Therefore, the combination of micro-CT scanning and contrast agent can successfully construct a digital three-dimensional model of rabbit vascular network, which provides a new idea and method for the study of human abdominal and pelvic organs and physiological characteristics.

1. Introduction

In recent years, Micro-CT technology has been developing continuously, and it has been widely recognized by the medical community in medical information extraction (Chen et al., 2014). However, contrast agents still limit the good development of micro-CT technology in the field of micro-system blood vessels. Traditional angiographic techniques have a good imaging effect for relatively thick and large vessels, while the results of microangiography cannot be in sharp contrast with the surrounding tissues (Wang et al., 2016). Therefore, micro-CT technology is widely used in orthopaedics, stomatology and other medical fields. The study of bone, teeth and periodontal tissue structure has absolute advantages (Roco et al., 2017). This is because all kinds of bone structures in orthopaedics can form a better contrast with the surrounding tissues and can also have a good imaging effect without the need for contrast agents (Zhang et al., 2017). Therefore, how to improve the imaging effect of microvascular system has become the research focus of researchers in the field of soft tissue (Park et al., 2015).

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The abdominal and pelvic vascular system is a complex system. Its arteries, veins and capillaries are connected with the adjacent digestive system, urinary system and reproductive system through various connections, forming a huge abdominal and pelvic vascular network (Russo et al., 2015). Various abdominal and pelvic diseases, such as abdominal aortic aneurysm, mesenteric thrombosis and pelvic tumors, are caused by changes in vascular structure and function, and changes in vascular anatomy also become the pathogenesis of abdominal and pelvic diseases (Zhang et al., 2018). Animal models are usually used to simulate and evaluate the efficacy of drug therapy or surgical treatment for related diseases. Rabbits have the advantages of easy reproduction, and similar physiological structure to human beings, and have become the most commonly used animal in human disease models. In order to study the structure of abdominal and pelvic vessels in rabbits, perfusion-casting technique is invented. These methods are cumbersome and have low resolution. The anatomical structure of the great vascular network can only be observed with the naked eye. Therefore, it is difficult to evaluate and study tissues and organs using microvascular networks (Cao et al., 2017). In this experiment, the vasculature network of abdominal and pelvic micro-organs is selected as the main research object in rabbits. In order to obtain better imaging effect, and to make the micro-vessels and the surrounding tissues have obvious contrast, the use of latex bismuth oxide mixture as a contrast agent is explored (Oberstar et al., 2017). The abdominal and pelvic vascular networks of rabbits are studied by micro-CT. Scanning imaging and post-processing software are used to successfully display three-dimensional reconstruction models of vascular tree in different organs of abdomen and pelvis of rabbits (Brinke et al., 2017).

The purpose of this study is to perform perfusion angiography of abdominal and pelvic vascular network in rabbits by using latex-bismuth oxide mixture. At the same time, micro-CT technology is used to scan the blood vessel network image, and digital processing method is used to reconstruct the three-dimensional model of rabbit blood vessel network in the later stage, which provides a new research idea and basis for the in-depth study of abdominal and pelvic micro-vascular network of small animals and even human beings.

2. Method

2.1. Research subjects

Six healthy female rabbits are selected as experimental subjects. In order to ensure the health of rabbits, six female rabbits are fed in a clean animal room equipped with air conditioning. The ambient temperature is 20 °C ± 3 °C, and the air humidity is 65% ± 5%. Rabbits can drink and eat freely. Before the operation, the rabbits need to fasting for 12 h, and the weight of all female rabbits is controlled between 2.0 and 3.0 kg.

2.2. Experimental procedure

The experimental steps of reconstruction of digital three-dimensional model of abdominal and pelvic vascular network in rabbits are as follows. First of all, it is necessary to prepare experimental animals, collocate latex-bismuth oxide mixed contrast agent, carry out laparotomy in rabbits, complete abdominal aorta and artery intubation, perfuse contrast agent, and obtain target organs. Finally, it is also necessary to deal with the experimental animals well and reconstruct the three-dimensional model by using micro-CT scanning technology. In this experiment, 6 female rabbits are successfully performed abdominal and pelvic vascular network perfusion angiography, and the target organs are obtained. The contrast agent in this experiment is a mixture of latex and bismuth oxide. The micro-CT model is SkyScan 1076, and the three-dimensional reconstruction software is Mimics Research.

2.3. Configuration of latex-bismuth oxide mixed contrast agent

Potassium hydroxide solid with a mass of 1 g is added to the sterilized water with a volume of 50 mL to dissolve it fully and to prepare into a solution of 2% potassium hydroxide. Then, 55 mL of white latex is added to the solution, which make the viscosity of the white latex decrease rapidly and enhance its fluidity. After the reaction of potassium hydroxide solution with white latex, bismuth trioxide powder with a mass of 50 g is added to the mixed solution to continue its full reaction. At this time, the prepared solution is a latex-bismuth oxide mixed contrast agent. The ratio of potassium hydroxide, latex and bismuth oxide in the mixed contrast agent is 1:1:1.

2.4. Surgical preparation of experimental animals before blood vessel perfusion

Female rabbits are anesthetized with 12% chloral hydrate by intraperitoneal injection. The dosage of chloral hydrate anesthesia is about 4.0–4.5 mL/kg. When the whole-body muscle tension of rabbits decreases and corneal reflex disappears, it indicates that the rabbits have been completely anesthetized. Then, the rabbits are fixed on the large anvil and exploratory laparotomy is performed. Before operation, abdominal skin preparation is performed, and the rabbit abdomen is completely deprived of pain and then abdomen is retreated. The abdominal skin and fascia are incised longitudinally with a scalpel. The incision ranges from the lower end of the xiphoid process to the bladder. After incision, abdominal and pelvic organs and double cervix and uterus are seen in rabbits. The intestinal tubes in the abdomen and pelvis are padded with clean wet gauze. Glass minute needles are used to open the posterior peritoneum to expose the aorta completely. The length of free abdominal aorta is about 2.5 cm. The proximal end of the abdominal aorta is ligated with 1–0 silk thread, and then two 1–0 silk threads are inserted at the distal end for reserve. A little saline is prepared in the syringe. The end of the syringe is connected to a rabbit artery cannula. The syringe is pushed gently to clear the air in the tube and then left for standby. The handle of the surgical knife is placed under the abdominal aorta, and the ophthalmic scissors are used to cut a hole in the wall of the blood vessel. Then, the tip of the cannula is placed into the abdominal aorta close to the vessel wall, and the depth of the cannula is about 1.5 cm. In addition, when releasing the tube, the movement should be gentle and not pierce the blood vessel. Finally, two spare threads through the distal end are used to ligate and fix the cannula. By this time, the abdominal aorta catheterization has been completed.

2.5. Micro-CT scanning imaging and three-dimensional model reconstruction of vascular perfusion specimens of target organs

In this study, the Micro-CT model used is SkyScan 1076. Firstly, on the Microsro-CT test platform, the research specimens are placed, and the parameters of the Micro-CT test platform are set. The performance parameters are shown in Table 1 below. The tube voltage is set to 75 V, the tube current is set to 150 μA, and the scanning mode is spiral scanning. The scanning time is 1 h–1.5 h. The above data parameters are used as the basis to obtain the original CT images of each organ. Finally, Mimics Research software is used to reconstruct the three-dimensional model of the original CT images of each organ. The distribution of blood vessels in the blad-

Table 1
Performance parameters of SkyScan 1076 Micro-CT.

Scope of application	Soft and hard tissues of small animals
Species of small animals	Rabbits and Rats
Resolution ratio	10 μm/19 μm/36 μm
Ball tube voltage	22–82 kV
Ball tube current	Maximum 250 μA
Ball tube power	30 w
Ball tube life	30,000 h
Scanning mode	Spiral scanning
Software operating platform	Windows platform

der, uterus, small intestine and kidney of rabbits is observed. Then, the grading of the vascular network and the average diameter of the vessel are measured. In this experiment, a new algorithm is used to reconstruct three-dimensional points. The parameters of CT imaging are shown in Table 2 below. LAO/RAO is the left and right angle of the angiography. CAUD/CEAN is the anterior and posterior angle of contrast. SID is the linear distance from the X-ray source to the image plane. L is the distance from X-ray to the center of rotation. FOV is the city view of the imaging system.

2.6. Statistical method

In this study, in vitro ligation of four target organs is used as a "starting point". The thickest vessel trunk formed at the "starting point" for the first time is defined as the primary vessel of the target organ. Then, the vessels formed by the first-order branches are defined as the second-order vessels. By analogy, vessel of bladder organ has only one or two levels, vessel of uterine organ has three levels, vessel of small intestine and kidney organ can be traced back to the fourth level.

3. Results

3.1. Primitive angiographic images of various organs

The vascular network of the target organs in the abdomen and pelvis of rabbits is perfused with a mixture of latex and bismuth oxide, and then the original image is obtained by micro-CT spiral scanning. Finally, the digitized model has clear picture and good effect. The arterial network of each target organ in rabbits is clearly displayed and the method of measuring data is simple. In this study, 6 female rabbits are successfully performed abdominal and pelvic vascular network perfusion angiography, and all target organs are scanned by micro-CT technology to obtain the original image with good display effect. As shown below, Fig. 1A is the original image of the bladder, Fig. 1B is the original image of the uterus, Fig. 1C is the original image of the small intestine, and Fig. 1D is the original image of the kidney. Finally, using Mimics Research 17.0 software, the original image is digitized, and the three-dimensional model is completed.

3.2. Classification of arterial vascular network and corresponding mean diameter

In this study, the classification and diameter of vascular network of target organs such as abdomen, pelvis, bladder, uterus, small intestine and kidney in rabbits are studied, and the digital three-dimensional reconstruction model of vascular network of target organs is successfully constructed. The results show that the bladder blood optical network is only divided into two stages. The average vessel diameter of the first stage is (0.76 ± 0.04), and that of the second stage is (0.39 ± 0.07). The uterine vascular network is divided into three grades. The average diameter of the first grade is (0.78 ± 0.04), the average diameter of the second grade is (0.61 ± 0.04), and the average diameter of the third grade is (0.41 ± 0.09). The diameter of the small intestinal vascular network is divided into four grades. The average diameter of the first grade is (1.45 ± 0.12), the second grade is (0.87 ± 0.03), the third grade is (0.56 ± 0.09), and the fourth grade is (0.25 ± 0.03). The diameter of renal vascular network is also divided into four grades. The average diameter of the first grade is (1.64 ± 0.17), the average diameter of the second grade is (0.79 ± 0.04), the average diameter of the third grade is (0.32 ± 0.01), and the average diameter of the fourth grade is (0.21 ± 0.02). As can be seen from the figure below, the vessel diameter of all target organs decreases with the increase of series (see Table 3 and Fig. 2).

4. Discussion

At home and abroad, the three-dimensional model of callus blood vessel is constructed by using rat long bone fracture model and Microfil as blood vessel contrast agent. The rule of the vascular

Table 2
Optimizing angiographic parameters before and after CT angiography.

Time	LAO/RAO (Degree)	CAUD/CEAN (Degree)	SID (mm)	L (mm)	FOV
Before optimization	−6.1	30.7	1092	712	0.218
After optimization	−21.8	52.8	730	531	0.26

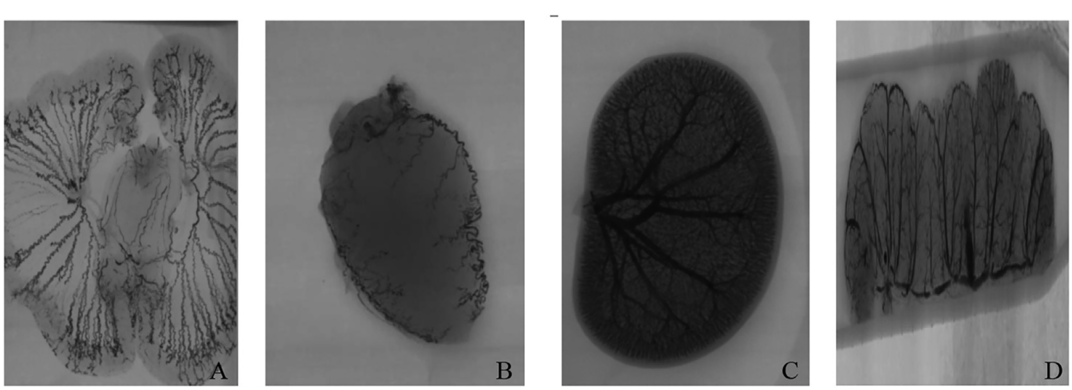

Fig. 1. The original image of the target organ blood vessel perfusion specimen obtained after CT scanning.

Table 3
Classification and mean diameter of arterial network in four kinds of target organs of abdomen and pelvis in rabbits (mm, $\bar{x} \pm s$).

Target organs	Primary vessel diameter	Secondary vessel diameter	Tertiary vessel diameter	Fourth grade vessel diameter
Bladder	0.76 ± 0.04	0.39 ± 0.07	N/A	N/A
Uterus	0.78 ± 0.04	0.61 ± 0.04	0.41 ± 0.09	N/A
Small intestine	1.45 ± 0.12	0.87 ± 0.03	0.56 ± 0.09	0.25 ± 0.03
Kidney	1.64 ± 0.17	0.79 ± 0.04	0.32 ± 0.01	0.21 ± 0.02

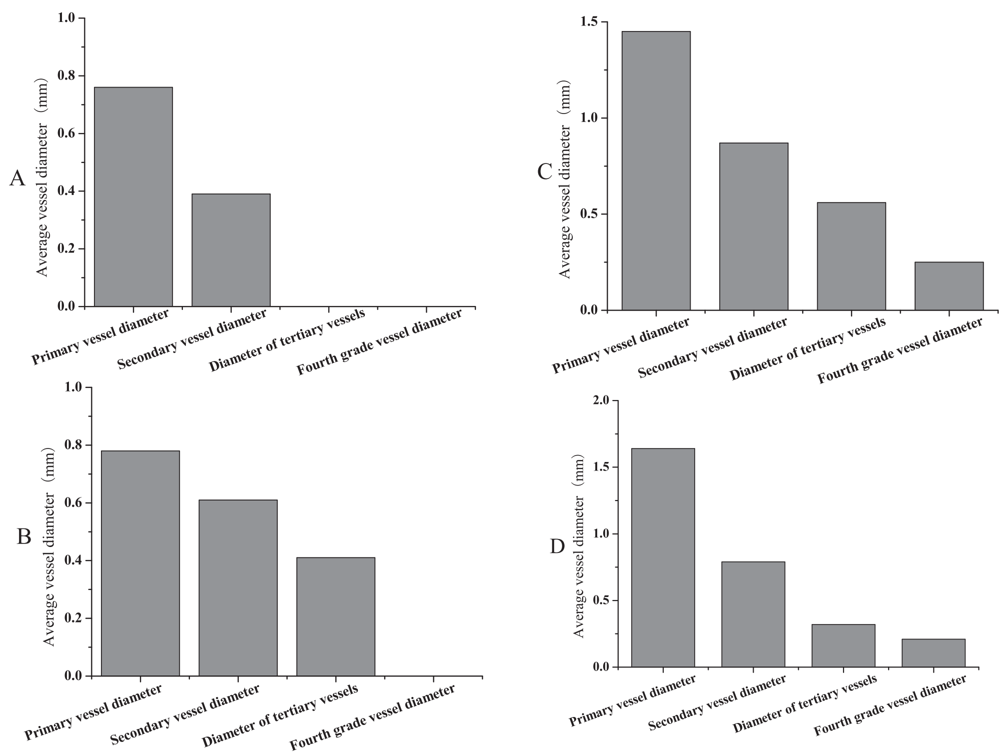

Fig. 2. Classification of arterial vascular network and corresponding mean diameter (A: the grading of vessel network of bladder and the corresponding mean vessel diameter; B: the grading of uterine vascular network and the corresponding average diameter of blood vessels; C: the grading of small intestinal vascular network and its corresponding mean diameter; D: the grading of kidney vascular network and its corresponding mean diameter).

growth during fracture healing is observed accurately through vascular reconstruction model. These scholars believe that microvascular contrast agent combined with micro-CT scanning-post-digital three-dimensional model reconstruction technology is of great significance for the study of small animal vascular anatomy, with the advantages of high resolution and intuition, which is similar to the idea of this study. In this study, by preparing latex-bismuth oxide mixture, the target organs such as abdomen, pelvis, bladder, uterus, small intestine and kidney of rabbits are perfused with perfusion angiography. Then, the digital three-dimensional model of rabbit vascular network was successfully constructed by micro-CT spiral scanning to the original image, combined with the later software, which is consistent with the previous research results of scholars. This experiment provides a simple, economical and more applicable modeling method for future medical images, and provides a new research idea and basis for the in-depth study of abdominal and pelvic micro-vascular network of small animals and even human beings.

The limitation of this study is that there are fewer types of target organs and samples. The collection of liver, spleen, pancreas and other organs can be increased in future research. Compared with the traditional contrast agents, the self-made latex-bismuth oxide mixed contrast agent has the advantages of high imaging clarity and low cost, but it cannot directly perform in vivo perfusion angiography in animals. Therefore, human and animal experiments still need to choose alternatives. In the future, it is necessary to gradually increase the study of target organ hemodynamics, further collect various parameters of blood vessel measurement, and improve the experimental scheme. Because of the low configuration of post-processing computer, this experiment cannot achieve the highest precision image processing effect. Therefore, although the three-dimensional reconstruction of the target organ vascular network is still in progress, the micro-CT scanning platform selects the maximum spacing resolution (32 μm) and the minimum image resolution (1000 * 1200). Although a clearer model image is obtained, the resolution of the model still has much room to improve.

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