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Standard clinical computed tomography fails to precisely visualise presence, course and branching points of deep cerebral perforators

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ABSTRACT

Background: Standard computed tomography (CT) images have earned a well-established position in neuroimaging. Despite that, CT is somehow limited by its resolution, which does not enable to distinctively visualize structures smaller than 300 um in diameter. Perforating arteries, most of which measure 100-400 um in diameter, supply important subcortical structures (thalamus, basal ganglia, internal capsule). Consequently, pathologies affecting these vessels (e.g. lacunar strokes) can have a devastating clinical outcome. The aim of our study was to assess standard CT's ability to visualize perforators and compare it with microscopical and micro-CT pictures.

Materials and methods: We have obtained six brainstem and seventeen basal ganglia specimens. We infused them with barium sulphate contrast medium administered into either vertebral or internal cerebral artery. After that, the specimens were fixed in formalin and subsequently a series of CT, micro-CT and microscopical examinations were performed.

Results: The median number of visualized perforators in brainstem and basal ganglia specimens was 8 and 3, respectively for CT and 18 and 7 for micro–CT ($p < 0.05$). Standard CT failed to clearly visualize branching points and vessels smaller than 0.25-0.5 mm (1-2 voxels) in diameter. Parallel vessels, like lenticulostriate arteries could not be differentiated in standard CT due to their proximity being smaller that the resolution.

Conclusions: Basing on our results, we infer that CT is a poor modality for imaging of the perforators, presenting both quantitative and qualitative flaws in contrast with micro-CT.

Key words: perforating arteries, cerebral perforators, computed tomography, micro-computed tomography, cerebral circulation

INTRODUCTION

The clinical significance of the anatomy of cerebral perforating arteries is well known [14]: despite their relatively small diameter of below 1 mm [3, 5], their pathology results in development of serious diseases such as lacunar stroke, intracerebral haemorrhage, vascular dementia, as well as leads to severe ischemic complications after aneurysmal subarachnoid hemorrhage and neurovascular procedures [1, 2, 8, 9, 11]. Despite advances in neuroimaging techniques, assessment of presence and function of perforating arteries remains challenging.

The aim of the study was to assess suitability of standard contrast enhanced computed tomography (CT) for visualising deep cerebral perforators by comparing its results to microscopical and micro-computed tomography (micro-CT) studies of anatomical specimens.

MATERIALS AND METHODS

Preparation of the specimens

The specimens of basal ganglia and brainstem were prepared by obtaining an unfixed brain from the cadaver, filling the arteries with contrast medium (barium sulphate), and fixing in 10% buffered formalin solution, as precisely described previously [12]. In each case, the pontine branches of the basilar artery (from the vertebrobasilar junction to the superior cerebellar arteries) or the lenticulostriate arteries were counted and measured using a microsurgical microscope.

Scanning of the specimens and radiological analysis

Every specimen was scanned with both standard clinical CT scanner (Toshiba Asteion TSX-034A, voxel size 0.25 mm, 120kV, 150mA) and micro-CT scanner (Nikon Metris XT H 225 ST, voxel size 0.0034 mm, 225kV, 4 million pixels detector). Images were processed in CT Pro 3D software (Metris XT 2.2, Nikon Metrology, Belmont, CA) and Mimics Innovation Suite 24.0 (Materialise, Belgium). The pontine branches or the lenticulostriate arteries were counted in each case. The quality of visualisation of the branching sites and the course of the arteries were also determined. The numbers of arteries visualised in standard and micro-CT were compared with the Wilcoxon signed rank sum test.

RESULTS

Six specimens of brainstem and seventeen specimens of basal ganglia were prepared and scanned by both standard and micro-CT. The median (first—third quartile) number of the pontine branches of the basilar artery amounted to 8 (7-9) and 18 (17-21) in standard and micro-CT, respectively (P=.031). The median (first-third quartile) number of the lenticulostriate arteries amounted to 3 (3-4) and 7 (7-8) in standard and micro-CT, respectively ($P<.0001$). Numbers of arteries counted under microsurgical microscope and visualised in micro-CT were equal in all cases—every artery filled with contrast medium was visible in micro-CT. Diameters of the perforating arteries measured with the use of microsurgical microscope ranged from 0.11 to 0.76 mm and were equal to the diameters measured on micro-CT scans with an accuracy of arterial wall thickness. In standard CT vessels of diameter below 1-2 voxel sizes (0.25-0.5 mm) were either invisible or could not be measured reliably (Fig. 1). Moreover, perforating arteries tend to have parallel course (e.g. lenticulostriate arteries branching from M2 and distal M1 entering the hemisphere in the anterior perforated substance) and standard CT does not allow to differentiate them, because of distance between the arteries being smaller than the resolution. Therefore, counting and measuring perforating arteries in standard CT scans was significantly compromised. In contrast, micro-CT scans provided clear and precise geometry of branching points and course of studied arteries (Fig. 1 and Fig. 2).

DISCUSSION

The main purpose of the study was to investigate suitability of standard CT for visualising perforating arteries of cerebral circulation. Our work clearly shows that this method is ineffective and unreliable. There are several quantitative and qualitative differences between standard CT scans on the one hand and microscopical and micro-CT studies on the other.

Quantitative differences between standard and micro-CT scans

The number of visualised pontine and perforating arteries was significantly higher, when counted using microscopic or micro-CT images, which was mainly due to better visualization of smaller vessels. The resolution of standard CT significantly limited the ability to visualise the perforating arteries, because their diameters usually do not exceed 1-2 sizes of voxel.

Moreover, the number and the diameters of perforators in the micro-CT picture was the same as under the microsurgical microscope, suggesting that these techniques can be utilized interchangeably. This advantage is important especially when studying internal microvasculature as surrounding tissues can be left intact.

Qualitative differences between standard and micro-CT scans

As presented above, the standard CT could visualise only the presence of the biggest perforating arteries. What's more interesting, the resolution was not high enough to study geometry of branching points or courses of the arteries. The micro-CT has visualised branching points and the courses of the perforating arteries far better than the standard CT. Moreover, standard CT scans could not precisely determine the number and branching points of parallel lenticulostriate arteries or pontine branches, making determination of the parent segment impossible. These properties are crucial to plan intracranial procedures, create reliable three-dimensional models, analyse supply areas, dynamics of blood flow and forces acting on arterial walls. Micro-CT allows studying all of the aforementioned aspects.

Noteworthy, angio-CT of the head usually visualises veins to some extent, which further reduces the quality of image. It is especially important in the case of the lenticulostriate arteries because they are located parallel to the deep middle cerebral vein.

The resolution of digital subtraction angiography and magnetic resonance imaging (even 7T [4]) usually do not reach values below 0.25 mm [6, 7], therefore one can anticipate the same problems with visualising the perforators as in the case of computed tomography.

Clinical relevance of the study

Our study clearly shows that absence of a structure in imaging studies is not equivalent to non-existence in real life. This conclusion is critical, when studying cerebral vasculature, as the resolution is comparable to the diameters of some arteries (including variants of the circle of Willis with hypoplastic anterior cerebral artery or posterior communicating artery) [10]. Neurosurgeons and neuroradiologists should be aware of that fact when planning and performing intracranial interventions. Micro-computed tomography is an useful tool in preclinical studies [13, 15].

Limitations of the study

The study was specimen-based, however standard clinical CT scanner was used. Up to date, no micro-CT scanners are admitted to clinical use. It is only possible to study previously prepared anatomical specimens. The volume of the specimen is usually restricted due to technical features of scanners.

CONCLUSIONS

Computed tomography is inappropriate to study presence, course, and geometry of the perforating arteries of cerebral circulation. Micro-CT, in contrast, is a feasible and effective method that allows for precise determination of the number, branching points, and the course of the pontine and perforating arteries. These advantages may be used for several anatomical and hemodynamical studies, however clinical application is restricted by technical features of micro-CT scanners.

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Ethical approval

All procedures performed in the study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments. The study protocol was approved by The Ethics Committee of Medical University of Warsaw, Poland (Number 138/2020).

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Conflict of interest: None declared

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Figure 1. Comparison of micro-CT (upper row) and standard CT (lower row) images in the same plane of a representative middle cerebral artery. Resolution of the standard CT image does not allow to differentiate parallel lenticulostriate arteries and some perforators are invisible. In standard CT a group of perforators can easily be misinterpreted as one vessel. The diameters of the lenticulostriate arteries cannot be measured accurately, because of no clear border between contrast-enhanced vessel lumen and non-enhanced surrounding tissues. The branching points cannot be identified in the case of standard CT. Length of the ruler is 5 mm.

Figure 2. Comparison of micro-CT (top) and standard CT (middle) images in the same plane and microscopical images of a fixed brainstem specimen (bottom). The CT images on the left side are maximum intensity projection reconstructions (thickness 6.0 mm), and the CT images on the right side are midline sagittal slices. Some of the perforating arteries are invisible in standard CT. Similarly, branching points are not evident. Microscopical images show anterior and lateral view of the basilar artery and pontine branches. Length of the ruler is 5 mm.