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FULL PAPER

High-pitch spiral CT with 3D reformation: an alternative choice for imaging vascular anomalies with affluent blood flow in the head and neck of infants and children

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Objective: To evaluate the feasibility of high-pitch spiral CT in imaging vascular anomalies (VAs) with affluent blood flow in the head and neck of infants and children.

Methods: For patients with suspected VAs and affluent blood flow pre-detected by ultrasound, CT was performed with high-pitch mode, individualized low-dose scan protocol and three-dimensional (3D) reformation. A five-point scale was used for image quality evaluation. Diagnostic accuracy was calculated with clinical diagnosis with/without pathological results as the reference standard. Radiation exposure and single-phase scan time were recorded. Treatment strategies were formulated based on CT images and results and were monitored through follow-up results.

Results: 20 lesions were identified in 15 patients (median age of 11 months). The mean score of image quality was 4.13 ± 0.74 . 7 patients (7/15, 46.67%) were diagnosed with

haemangiomas, 6 patients (6/15, 40%) were diagnosed with venous malformations and 2 patients (2/15, 13.33%) were diagnosed with arteriovenous malformations. The average effective radiation doses of a single phase and of the total procedure were 0.27 ± 0.08 and 0.86 ± 0.21 mSv. The average scanning time of a single phase was 0.46 ± 0.09 s. After treatment, 13 patients (13/15, 86.67%) achieved excellent results, and 2 patients (2/15, 13.33%) showed good results in follow-up visits.

Conclusion: High-pitch spiral CT with an individualized low-dose scan protocol and 3D reformation is an effective modality for imaging VAs with affluent blood flow in the head and neck of infants and children when vascular details are needed and ultrasound and MRI could not provide the complete information.

Advances in knowledge: This study proposes an alternative modality for imaging VAs with affluent blood flow.

Vascular anomalies (VAs) are a group of diseases associated with the vascular system, varying from skin colour changes to cosmetic deficits, malfunctions and even life-threatening disorders. There has been great progress in VA management in the past decade.^{1,2} Advanced therapeutic methods, such as sclerotherapy for venous malformation (VM),^{3,4} propranolol/bleomycin treatment for infantile haemangioma,^{5,6} as well as the importance of eliminating the “nidus” in arteriovenous malformation (AVM),⁷ obviously improve the cure rate of VAs.

As an important component of vascular medicine, imaging studies are necessary to determine the full anatomical extent of the anomaly, follow up the treatment response, confirm the diagnosis, provide the correct classification in challenging cases⁸ and, most importantly, guide the specific

therapy suitable for each patient. Both ultrasound and MRI have generally been considered the imaging modalities of choice for VAs, particularly for those located in the body. CT, with radiation exposure, is not an appropriate primary imaging technique, particularly for patients with small VAs. However, for complex cases such as deep or extensive lesions involving the brain and/or orbit, CT imaging may be an appropriate alternative choice. The second generation of dual-source CT systems allows the examination to be performed at high-pitch mode, with pitch values up to 3.2–3.4. A gantry rotation time of 0.28 s enables a temporal resolution of 75 ms. Scans in high-pitch mode can be completed in <1 s, which reduces the need for sedation. In addition, three-dimensional (3D) reformation images can provide sufficient information for appropriate VA management. Feeding and draining vessels as well as the details,

such as tiny vessels, calcifications and relationships with the skull, brain or orbit, can be clearly depicted on axial and 3D reformation images.

Few articles^{9–12} have discussed the applications of CT in imaging VAs. To the best of our knowledge, the efficacy of high-pitch spiral CT for the diagnosis of VAs has not been evaluated in previous studies.

The purpose of this study was to evaluate the feasibility of high-pitch spiral CT, using individualized low-dose scan protocols and 3D reformation, as an alternative imaging modality for diagnosing and treating VAs with affluent blood flow in the head and neck of infants and children.

METHODS AND MATERIALS

Patients

This study was approved by the local ethics board. Adverse effects of contrast medium (CM) injection and risk of radiation exposure were explained to the legal guardians of all patients and written informed consent was obtained. Patients suspected with VAs in the head and neck were selected. The inclusion criteria were as follows: (1) lesions present at birth or at a few days/weeks/months of age, with a growth rate equal to or faster than that of physical development; (2) the presence or absence of a change in skin colour (red, blue, purple or mixed); (3) change in shape or colour in response to different pressure/positions or warmth to the touch; (4) affluent blood flow (arterial/venous/mixed) confirmed by Doppler ultrasound examination; (5) lesions with complex anatomic structure involved/lesions with suspected bony involvement/patients could not complete MRI examination, MRI/ultrasound was unable to provide sufficient information for clinical management. Lymphatic malformations receive no blood flow, and capillary malformations are relatively superficial. Therefore, there is little need for 3D CT imaging of patients with these particular VAs. They were identified based on clinical history and ultrasound results and were subsequently excluded from this study. From August 2011 to December 2012, 15 patients (5 males, 10 females) participated in the study. The median patient age at the time of CT was 11 months (range from 2 months to 7 years). For patients too young to co-operate, CT examinations were performed as soon as the patients fell asleep naturally.

CT protocol

CT examinations were performed using a high-pitch spiral CT scanner (SOMATOM® Definition Flash; Siemens Healthcare, Forchheim, Germany) within 3 days after ultrasound. Scanning parameters were set as follows: configuration 0.6×128 slices, flash mode with a pitch of 3.2, rotation time of 0.28 s and tube voltage of 80 kV; the tube current (mAs per rotation) was set depending on the body weight of each patient (<5 kg, 60 mAs; 5–10 kg, 61–80 mAs; >10 kg, 80–120 mAs). The reconstruction slice thickness was 0.75 mm with a slice interval of 0.4 mm.

Non-contrast images were obtained for the purpose of phlebolith detection, bone surveillance and lesion location. Using a dual-head power injector (Stellant®; Medrad®, Indianola, PA),

a total of 1.5 ml kg^{-1} of CM (iohexol, 350 mgI ml^{-1}) pre-heated to a temperature of 37°C was injected, followed by 1.0 ml kg^{-1} of normal saline, through peripheral veins in the elbow or the back of the hand. The total injection time was fixed as 25 s. Bolus tracking was used to synchronize CM injection and scanning. The trigger vessel was the common carotid artery, and the arterial phase was started 4 s after the trigger threshold (120 HU) was attained. Venous phase with a scan delay of 30–40 s was acquired only if the lesions showed no obvious enhancement during the arterial phase.

CT images post-processing and analysis

Reconstruction images were transferred to a multimodality workplace (Siemens Healthcare). 3D reformation techniques including multiplanar reformation (MPR), maximum intensity projection and volume rendering were used for image interpretation and anomaly evaluation. The location, boundary and vessel structures of the VAs were interpreted by two radiologists with 5 years' experience blinded to the clinical diagnosis and ultrasound result. Then a final CT diagnosis was performed. In the case of disagreement between the two observers, a consensus was reached. The overall image quality was evaluated using a five-point scoring system: 5 for excellent anatomical clarity, excellent image quality; 4 for good anatomical clarity, all structures are clearly interpretable; 3 for fair anatomical clarity, the anatomical relationships required clinically could be defined with confidence; 2 for poor image quality or anatomical detail, incomplete demonstration of anatomical structures; 1 for no useful information obtained. Images of Score 3 or higher were considered sufficient for diagnostic purposes.¹³

The diagnostic criteria of VAs were as follows.^{6,8,14–16} (1) For lesions with predominantly straight arterial feeders, a soft-tissue component and serpiginous veins, haemangiomas were the first diagnosis considered. (2) Lesions with dilated and tortuous feeding arteries, early enhancing draining veins during the arterial phase and a tangle of vessels with no prominent soft-tissue component were initially considered to be AVMs. (3) For lesions demonstrating no arterial feeders or normal-looking arteries that existed during the arterial phase (artery in the normal position and of normal size, similar to the contralateral artery), channel-like or heterogeneous enhancement and enlarged draining veins during the venous phase, and lesions with phleboliths, VMs were the first diagnosis considered.

The radiation dose parameters were obtained from the scan protocol generated by the CT system after scan. The parameters included the CT data acquisition time of a single phase, and the dose-length product (DLP) of a single phase and the entire procedure. The DLP provided in the scan report was specified to the 32-cm phantom; the paediatric enhancement factor of 2.3 was used to adapt the DLP to the 16-cm phantom. The effective dose (ED) delivered by the CT examination was calculated according to an age-dependent conversion factor ($\text{ED} = 2.3 \times k \times \text{DLP}$, $k = 0.013$ for patients aged 0–12 months, $k = 0.0085$ for patients aged 1–5 years, $k = 0.0057$ for patients aged 5–10 years¹⁷). Because the total scan time, including the preparation time before CM injection, varies under different conditions, only the scan time of a single phase was recorded in this study.

Figure 1. A 2-month-old girl with haemangioma on her left tempus. The effective radiation doses of a single phase and the total of all phases were 0.09 and 0.29 mSv, respectively, with a single-phase scan time of 0.49 s. (a, c) Multiplanar reformation images. (d, e) Maximum intensity projection images. (b, f, g) Volume rendering images. (a, b) Lesion invasion into the middle cranial fossa through the orbit and communicating with the left cavernous sinus (arrows). (c) Invasion of the mucous membrane of the nasopharynx (arrow). (d, e) The feeding arteries (arrows and annotations), including the left ophthalmic artery and the left external carotid artery, both of which were non-tortuous. (f, g) Enlarged draining veins (arrows).

Clinical treatment and follow-up visit

Treatment strategies were formulated according to CT images and subsequent diagnosis. Guidance for treatment was as follows.^{1,2,4,5,7,18,19}

Haemangiomas with intraorbital and/or intracranial intrusion would receive medical treatment. For haemangiomas non-responsive to propranolol or located on the eyelid, or that had complications, surgical resection or sclerotherapy combined with surgical resection would be performed. Focal haemangiomas of the face were also potential candidates for surgical approaches. For localized or limited VAs that could be removed surgically, large focal ones would receive sclerotherapy combined with surgical resection. Spongiform cavity-type VMs would receive sclerotherapy. AVMs would receive surgical resection. For highly vascularized lesions, pre-operative sclerotherapy is needed to improve the safety and efficacy of subsequent surgical resection. Surgery should be performed after the angioneurosis.

A follow-up period of at least 6 months was recorded based on follow-up CT scan. Complete resolution, near complete resolution, or >50% reduction in VA size was considered an “excellent” result. A moderate decrease in VA size was considered a “good” result. No additional growth in the lesion size was considered a “fair” result. Continuous lesion growth or discontinuation of medication owing to side effects was considered a “poor” result.²⁰

Statistics

Clinical diagnosis and pathological results were taken as the reference standard. Results were expressed as means $\pm$ standard

deviations for quantitative variables and as frequencies or percentages for categorical variables. Interobserver agreement for grading image quality was assessed by using kappa statistics ($\kappa > 0.81$, excellent agreement; $\kappa = 0.61$ –0.80, good agreement).

RESULTS

All 15 patients successfully completed the high-pitch spiral CT scans. No adverse effects were recorded.

CT image quality assessment

Diagnostic CT images were obtained in all patients. The mean image quality score was 4.13 ± 0.74 , distributed as Score 3 (3/15 patients, 20%), Score 4 (7/15 patients, 46.67%) and Score 5 (5/15 patients, 33.33%). The agreement on the overall image quality scoring between the two observers was excellent ($\kappa = 0.84$).

CT image diagnosis

A total of 20 lesions were detected in 15 patients. 7 lesions (7/20, 35%) were located on the face (including 1 on the underlip), 3 (3/20, 15%) on the periorbital region, 3 (3/20, 15%) on the tempus, 3 (3/20, 15%) on the neck, 2 (2/20, 10%) on the vertex, 1 (1/20, 5%) on the forehead and 1 (1/20, 5%) was widely distributed on the face and neck. 3 patients (3/15, 20%) exhibited more than one lesion.

7 patients (7/15, 46.67%) with 7 lesions were diagnosed with haemangiomas. Brightly enhancing lesions were shown on axial

images. Four lesions showed clear boundaries, the remaining lesions had connection to adjacent tissue. One lesion had invaded the middle cranial fossa through the orbit and was connected to the cavernous sinus (Figure 1). 3D reformation images showed straight feeding arteries or arterioles and enlarged but non-tortuous or slightly tortuous draining veins (Figure 2). Of seven patients, five patients (71.43%) were confirmed by clinical diagnosis and two patients (28.57%) were confirmed pathologically.

6 patients (6/15, 40%) with 10 lesions were diagnosed with VMs. The lesions had ill-defined boundaries. Four lesions had invaded the muscular layer. Heterogeneous enhancement showed non-specific enhancement characteristics, with the exception of two lesions that demonstrated serpiginous-channel-like enhancement. Two lesions showed phleboliths on MPR images. 3D reformation images showed enlarged and tortuous draining veins (Figure 3). No feeding arteries were observed during the arterial phase. Of six patients, five patients (83.33%) were confirmed by clinical diagnosis and one patient (16.67%) was confirmed pathologically.

2 patients (2/15, 13.33%) with 3 lesions were diagnosed with AVMs. One lesion had a clear boundary (Figure 4), whereas others had blurry demarcations between neighbouring structures. The 3D

reformation images showed dilated and tortuous feeding arterials and draining veins. Some of the draining veins were early enhancing. Both patients (2/2 100%) were confirmed by pathological diagnosis (Table 1).

Clinical treatment and follow-up visit

Based on CT images and subsequent diagnoses, treatment strategies were formulated. After a follow-up period of 6 months, 13 patients (13/15, 86.67%) achieved excellent results and 2 patients (2/15, 13.33%) showed good results (Table 2).

Of the seven patients with haemangiomas, three patients (42.86%) received medical treatment (propranolol therapy), two patients (28.57%) underwent sclerotherapy, one patient (14.29%) underwent sclerotherapy combined with surgery (performed after angioneurosis had shrunk the lesions) and one patient (14.29%) underwent surgical resection. All seven patients (100%) achieved excellent results in follow-up visits (Figure 5).

Of the six patients with VMs, five patients (83.33%) underwent sclerotherapy, although two did not finish the entire treatment for personal reasons. Of these six patients, one patient (16.67%) underwent sclerotherapy combined with surgery (performed after angioneurosis). Four patients (66.67%) achieved excellent results in follow-up visits; and the two patients (33.33%) who

Figure 2. A 16-month-old girl with haemangioma on her left tempus. The effective radiation doses of a single phase and the total of all phases were 0.09 and 0.28 mSv, respectively, with a single-phase scan time of 0.46 s. (a, b, c) Maximum intensity projection images. (d, e, f) Volume rendering images. (a, d) The enlarged but straight feeding artery (arrow). (b–f) Enlarged [arrow on (b, e)] or small, tortuous [arrows on (c, f)] draining veins.

Figure 3. A 3-year-old girl with venous malformations on her right face and neck. The effective radiation doses of a single phase and the total of all phases were 0.09 and 0.29 mSv, respectively, with a single-phase scan time of 0.44 s. (a) A multiplanar reformation image shows a phlebolith (arrow). (b, c) Volume-rendering images. (b) Serpiginous-channel-like enhancement as well as an enlarged draining vein (arrows). (c) Isolated lesion on the right face containing the phlebolith (arrow). (d) A photograph of the lesions.

did not finish their therapy had good results. None had fair or poor results.

Of the two patients with AVMs, one patient (50%) with enlarged vessels underwent sclerotherapy combined with surgery (performed after angioneurosis had shrunk the lesions) and one patient (50%) with a superficial and limited lesion underwent surgical resection. Both (2/2, 100%) achieved excellent results in follow-up visits.

Radiation dose and scan time estimation

The mean DLP of a single phase was 10.07 ± 3.07 mGy cm (range, 3–15 mGy cm), resulting in an estimated mean ED of 0.27 ± 0.08 mSv (range, 0.10–0.41 mSv). The mean DLP of the entire procedure was 32.13 ± 9.52 mGy cm (range, 11–49 mGy cm), resulting in an estimated mean ED of 0.86 ± 0.21 mSv (range, 0.37–1.25 mSv). The mean scanning duration of a single phase was 0.46 ± 0.09 s (range, 0.29–0.63 s) (Table 3).

DISCUSSION

The classification of VAs on the basis of cellular kinetics and clinical behaviour was adopted by the Internal Society for the Study of Vascular Anomalies to standardize the diagnosis of VAs and improve targeted treatment.^{6,18,21} Some VAs do not require treatment, such as the majority of infantile haemangiomas. Most others can be treated with conservative management and medical

treatment. Under certain severe conditions, however, sclerotherapy, laser treatment, embolization, interventional radiologic therapy and surgery might be necessary. All of these treatment methods have advantages and disadvantages. As the most common location of VAs,²² the head and neck contain many important structures (e.g. vessels and nerves) that may complicate treatment. A full understanding of a lesion's characteristics is necessary for appropriate treatment. It makes clear images particularly important in developing a treatment plan.

Image modalities for diagnosing vascular anomalies
Ultrasound and MRI are considered to be the first-line advanced diagnostic modalities for patients with VAs. High-resolution greyscale and Doppler ultrasound remain the primary imaging modalities for the initial assessment and subsequent follow-up and provide excellent visualization of most superficial lesions. However, limited by the restricted field of view and acoustic window, ultrasound is often unable to visualize the true extent of the lesion and the relationship to intracranial vessels. Also, the repeatability of ultrasound is low because of operator dependence. MRI yields more details, including flow characteristics, soft-tissue involvement and the relationship to normal anatomy, but MRI is time consuming.^{7,8,23} Recent studies reported that time-resolved MRI or contrast-enhanced magnetic resonance angiography (MRA) could generate images in a short time.^{23,24} However, the time resolution of MRI (3–8 s) is still

Figure 4. A 5-month-old girl with arteriovenous malformation on her vertex. The effective radiation doses of a single phase and the total of all phases were 0.14 and 0.48 mSv, respectively, with a single-phase scan time of 0.51 s. (a, b) Multiplanar reformation images show a clear boundary (arrow) and no intracranial connection *via* either feeding arteries or draining veins. (c, d) Volume rendering images show feeding arteries (bold black arrow) and enlarged early enhancing draining veins (thin black arrows).

much longer than that of high-pitch spiral CT (75 ms). In addition to the noise, sedation or general anaesthesia is necessary when the recommended dosage of oral chloral hydrate dose not

sufficiently sedate infants to complete MRI acquisition. Furthermore, because of the low spatial resolution ($1.5 \times 1.5 \times 2 \text{ mm}^3$ for MR *vs* $0.6 \times 0.6 \times 0.6 \text{ mm}^3$ for CT) and

Table 1. Diagnostic summary of 15 patients

Patient no.	Doppler ultrasound findings (before CT examination)	CT diagnosis	Clinical diagnosis	Pathological results
1	Abundant blood flow, mainly arterial blood flow signal	Haemangioma	Haemangioma	–
2	Abundant blood flow	Haemangioma	Haemangioma	Haemangioma
3	Abundant blood flow, mainly arterial blood flow signal	Haemangioma	Haemangioma	–
4	Arterial blood flow signal	AVM	AVM	AVM
5	Abundant blood flow	Haemangioma	Haemangioma	Haemangioma
6	Abundant blood flow, mainly arterial blood flow signal	Haemangioma	Haemangioma	–
7	Venous blood flow signal	VM	VM	–
8	Blood flow signal	VM	VM	–
9	Venous blood flow signal	VM	VM	–
10	Abundant blood flow signal	AVM	AVM	AVM
11	Venous blood flow signal	VM	VM	VM
12	Abundant blood flow signal, mainly arterial blood flow	Haemangioma	Haemangioma	–
13	Affluent blood flow signal	VM	VM	–
14	Affluent blood flow, venous blood flow signal	VM	VM	–
15	Abundant blood flow signal	Haemangioma	Haemangioma	–

AVM, arteriovenous malformation; VM, venous malformation.

Table 2. Follow-up visit of 15 patients

Vascular anomalies	Excellent	Good	Fair	Poor
Haemangioma	7	0	0	0
Venous malformation	4	2	0	0
Arteriovenous malformation	2	0	0	0
Total	13	2	0	0

bone imaging, MRA may miss some vascular details, such as small feeding arteries,²⁵ which would be important for the choice of therapy in a surgical or interventional pathway, and the choice of sclerotic agent.⁷ Digital subtraction angiography plays a significant role in the diagnosis and treatment of vascular malformations, but it is not suitable for all VAs. Besides, its invasive nature makes it more widely used for treatment.²²

Reasons why CT was chosen

High-pitch spiral CT with 3D reformation images provides abundant information on the soft-tissue and surrounding structures, especially for lesions with suspected osseous involvement. In this study, three lesions with partially small feeding arterials (diameter <1.5 mm) and two lesions with trans-skull vessels (Figure 6) were depicted clearly by CT images. Different from the treatments for simple lesions, pre-operative sclerotherapy should be adopted for lesions with trans-skull vessels, also ethanol may very well be contraindicated as a sclerotic agent for lesions with trans-skull vessels. 3D reformation CT images provide an excellent view of vessel structures such as feeding arteries, draining veins and their sources. This is especially important for VA treatment.¹¹

Radiation exposure is the major obstacle in CT scanning in infants and children. Ait-Ali et al²⁶ found that exposing children to a significant cumulative dose might lead to radiation-induced chromosomal DNA damage, and the median life time cumulative ED in the study of Ait-Ali et al was 7.7 mSv per patient (range, 4.6–41.2 mSv). Following the as low as reasonably achievable principle, low-dose techniques are needed for CT examination. The

most important two factors that affect radiation dose are tube voltage and tube current. Patient-specific adaptation of tube current and tube voltage is considered to be the most important method for minimizing dosage during CT scans. Low tube voltage has been reported²⁷ as an effective strategy for radiation dose reduction. The downside of tube voltage has an additional advantage of higher attenuation for iodinated contrast agent.²⁸ Lesions with affluent blood flow were pre-selected on ultrasound and the vascular structure was the most important information needed, so it was totally feasible to perform low tube voltage (80 kV) CT angiography in this study. Additionally, the tube current was set according to the patients' weight to ensure this study utilized the minimum possible dosage without influencing diagnostic confidence. Therefore, we achieved a mean ED of 0.86 ± 0.21 mSv (Table 3). It should be noticed that, although the ED was low in this study, radiation exposure is unavoidable during CT examination. To compare with MRI, radiologists should balance the radiation risk against the vascular details plus sedation risk.

Lell et al²⁹ and Hardie et al³⁰ have reported that using the high-pitch mode can significantly reduce the dosage in CT scans. However, another group³¹ stated that using the high-pitch mode ($1.6 \leq \text{pitch} \leq 3.2$) for CT scans has only a minor impact on radiation dose. Further studies are needed to determine the effect of pitch on radiation dose. However, a short acquisition time is doubtless a benefit of high-pitch scanning with a temporal resolution of 75 ms. One single scan phase can be performed in less than 1 s (the average scanning time in our study was 0.46 s). This reduced scanning time renders sedation less important for infants,²⁹ and slight movements do not influence high-pitch CT image quality. One patient in the present study could not keep stationary during the CT scanning, but, by using the high-pitch mode, feeding arteries, draining veins and the extent of the lesion were clearly identified, and image quality was adequate for diagnosis and therapy planning (Figure 1).

CT results and treatment strategy

AVM is a true fast-flow malformation with little to no parenchymal component. The lack of capillary beds exposes the venous system to high-pressure arterial blood through the nidus, which is responsible for the special flow dynamics of AVMs.¹⁶ Arterial-phase CT brightly displayed the circuitous enlargement of the feeding artery, the enhanced nidus, and the early enhancing

Figure 5. A 2-month-old girl (a) with haemangioma on her tempus. Before (a) and after (b) medical treatment.

Table 3. Radiation exposure and scanning time estimate for each patient

Patient no.	Age (months)	DLP-SP (mGy × cm)	ED-SP (mSv)	DLP-TP (mGy × cm)	ED-TP (mSv)	Scanning time (s)
1	7	10	0.39	26	0.88	0.52
2	24	12	0.27	38	0.84	0.6
3	2	6	0.20	26	0.88	0.36
4	5	11	0.37	37	1.25	0.51
5	11	8	0.27	26	0.88	0.29
6	16	10	0.22	33	0.73	0.46
7	27	10	0.22	32	0.75	0.42
8	28	13	0.29	42	0.93	0.44
9	7	11	0.37	34	1.15	0.43
10	84	13	0.19	44	0.65	0.63
11	8	12	0.41	28	0.94	0.55
12	2	3	0.10	11	0.37	0.33
13	36	15	0.333	49	1.08	0.44
14	36	10	0.22	34	0.75	0.44
15	2	7	0.24	22	0.74	0.49

DLP, dose-length product; ED, effective radiation dose; SP, one single phase; TP, total procedure.

and enlarged draining veins in this study. According to the literature,^{7,12} simple embolization or ligation of feeding arteries leaving the nidus intact is not the correct approach.¹² Both the procedure planning and the appropriate selection of embolic-sclerotic agents⁷ require a precise description of the morphologic and topographic anatomy of an AVM. In this study, therapeutic plans were guided by 3D CT images. One patient with simple AVM underwent surgical resection, and one patient with trans-skull vessels underwent sclerotherapy combined with surgical resection.

VMs are pathologically composed of variably sized dysplastic post-capillary and thin-walled venous channels.⁸ On CT images, VMs were characterized by serpiginous-channel-like enhancement in this study. Phleboliths are clearly visible on non-contrast CT images. Treatment of small and superficial VMs is relatively simple and effective; however, treatment of deep and extensive lesions involving multiple anatomical sites remains a challenge. Sclerotherapy, laser therapy and surgery are the most common methods for VM treatment, and sclerotherapy has become the current mainstream treatment. It can be used alone or combined with surgery. Localized or limited lesions can be removed surgically.¹⁹ One patient with a large but localized VM in our study underwent sclerotherapy combined with surgery (performed after the angioneurosis) and achieved excellent results in follow-up visits.

The most common vascular tumours are haemangiomas, and the diagnosis of haemangioma depends primarily on the medical history and physical examination.¹⁵ Imaging is usually requested to assess the extent and depth of the lesion, to assess the vessel structure and to determine any relationship with adjacent structures, particularly the skull, orbit and brain. Haemangiomas

appeared on CT images as brightly enhancing, mostly well-defined lesions. The involvement of adjacent structures was clearly shown by heterogeneous enhancement of the lesions and normal structures in this study. The high spatial resolution of CT illuminates the tiny details in small feeding arteries and veins. With 3D reformation, the configuration of a haemangioma can be visible. In this study, 3D reformation images demonstrated non-tortuous feeding vessels and occasionally revealed serpiginous veins (Figure 2). Treatment of haemangioma has significantly evolved during recent decades.¹ Medical treatment, particularly beta-blockers—propranolol therapy, has now become the first-line treatment of haemangiomas with intraorbital and/or intracranial intrusion. But focal haemangiomas of the face or periorbital region are still potential candidates for a conventional surgical approach. For small-/medium-sized lesions with permeated and enveloped vital structures, sclerotherapy could also be an effective treatment modality.³² Thus, anatomical details, such as intraorbital or intracranial involvement, trans-skull vessels, bony changes and muscle invasion, are important for management planning or surgical planning (e.g. to prevent excessive blood loss) of haemangiomas in the head and neck and should be clearly sought out.

Limitations

There are some limitations to our study. First, most VMs and haemangiomas require sclerotherapy and chemical treatment. Biopsy and resection was not clinically justified in these cases. Second, ultrasound and MRI should still be considered the gold standard in the majority of VAs. CT was presented as an alternative choice, and we did not subclassify haemangiomas by type owing to small sample size. Further research is required using a larger sample size. Third, there are some iterative reconstruction techniques such as iterative reconstruction in space, adaptive

Figure 6. A 7-year-old girl with arteriovenous malformation on her forehead. The effective radiation doses of a single phase and the total of all phases were 0.07 and 0.25 mSv, respectively, with a single-phase scan time of 0.63 s. (a, b) Multiplanar reformation images show the skull opening for trans-skull vessels (arrows). (c, d) Volume rendering images show the opening of the skull located just behind the centre of the lesion (arrows).

statistical iterative reconstruction and sinogram-affirmed iterative reconstruction, which have the potential to reduce the radiation dosage, that were not evaluated in this study.

CONCLUSION

High-pitch spiral CT with an individualized low-dose scan protocol and 3D reformation images, which provide precisely

described details and a global overview of lesions, and reduce radiation dose and exposure time, can be useful for diagnosing and treating VAs with affluent blood flow in the head and neck of infants and children. Given its radiation nature, CT scan could raise the radiation risk. We suggest that it should be used when vascular details are needed and ultrasound and MRI could not provide the complete information.

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