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Application of 3D-computed tomography angiography technology in large meningioma resection

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ABSTRACT

Objective: To discuss the role of 3D-computed tomography angiography (3D-CTA) technology in reducing injuries of large meningioma surgery. **Methods:** 3D-CTA preoperative examinations were done in 473 patients with large meningioma (simulated group). The images were analyzed by 3D post-processing workstation. By observing the major intracranial blood vessels, venous sinus, and the compression and invasion pattern in the nerve region, assessing risk level of the surgery, simulating the surgical procedures, the surgical removal plan, surgical routes and tumor blood-supplying artery embolisation plan were performed. Two hundred and fifty seven large meningioma patients who didn't underwent 3D-CTA preoperative examination served as control group. The incidence of postoperative complications, intraoperative blood transfusion and the operation time were compared between these two groups. **Results:** Compared with the control group, the Simpson's grade I and II resection rate was 80.3% (380/473), similar with that of the control (81.3%, 209/257). The incidence of postoperative complications in 3D-CTA simulated group was 37.0% which was significantly lower than that (48.2%) of the control (P<0.01). The intraoperative blood supply for simulated group and the control was (523.4±208.1) mL and (592.0±263.3) mL, respectively, with significant difference between two groups (P<0.01). And the operation time [(314.8±106.3)] min was significantly lower in simulated group than that in the control [(358.4±147.9) min] (P<0.01). **Conclusions:** Application of 3D-CTA imaging technology in risk level assessment before large-scaled meningioma resection could assist in the rational planning of tumor resectin, surgical routes, and is helpful in reducing injuries and complications and enhancing the prognosis of the patients.

1. Introduction

Due to massive blood supply requirement and long growth time, large meningioma often results in dislocation of surrounding blood vessels and reallocation of blood supply. It even invades and wraps up important blood vessels, and often affect major nerve regions. Hence, appropriate surgical plan is the key to avoid the lesion of this region. However, the surgery is usually performed on the basis of physicians' experience and habits, which could lead to the underestimation of various exceptional cases in the surgery. Therefore, the injury could only be limited at the lowest level by personalized surgical plan.

3D-computed tomography angiography (3D-CTA) technology has been widely recognized in diagnosing cerebral tumor and vascular disease[1,2]. It can visualize three-dimensional relationship of the tumor and the surrounding structures, simulate the operative procedures by repeatable post-processing, and help rational surgical plan performing. The present study was to explore the application value of 3D-CTA detection in reducing surgical injuries by recording the intraoperative blood supply, operation time and postoperative complications in 473 patients with large meningiomas after simulating the operative plan using 3D-CTA.

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2. Material and methods

2.1. Patients

During December 2004 to April 2012, 1 226 patients with meningioma were screened by CT and/or MIR. The inclusion standard of 3D-CTA simulated group were as follows: 1) The maximum diameter of tumor is ≥ 4.5 cm; 2) Received 3D-CTA detection preoperatively and three-dimensional stimulated surgery was planed; 3) The tracking information is completed intraoperatively and postoperatively. The total number of simulated group patients was 473 (male 232, female 241) with tumor diameter as (6.63±1.22) cm. The locations of the tumor were at skull base (185 cases), dorsolateral surface (194 cases), and beside the sinus (94 cases). A total of 257 patients who meet the 1, 3, 4 inclusion standards served as control group, including 133 male and 124 female with tumor diameter range of (6.14±1.13) cm. The locations of the tumors were at skull base (102 cases), dorsolateral surface (114 cases), and beside the sinus (41 cases).

2.2. Methods

2.2.1. Detection methods

Somatom sensation mutislice CT scanner (Siemens Ltd.) was employed. Plain scan was done to determine scanning area and then enhanced scan were performed. The scanning parameters were 120 kV, 200 mAs, layer thickness 2 mm, collimation 16×0.75 mm. Injection was performed via elbow vein by high-pressure syringe at a rate of 3 mL/s. The contrast media was 100 mL iopamidol (370 mg/mL) with 0.75 mm reconstructive layer thickness and 0.75 mm interval. Multiplanar reformations, maximum intensity projection (MIP) and volume rendering technique (VRT) were performed

2.2.2. Analysis of surgical plan in 3D-CTA simulated group

The obtained 3D-CTA information of 473 meningioma patients was analyzed in the post-processing workstation. Agreements from patients were obtained before image analysis and surgical stimulation.

The surgical plans were established in accordance with analyzing results. The operation routes and methods were evaluated by observing the three-dimension anatomic relation among tumor, blood-supplying arteries and other important surrounding blood vessels. The distance between tumor and bone window should be short, the number of impedimental blood vessels should be as few as possible, the space for the surgery should be enough and the important neuro-functional region and blood vessels in brain should be avoided efficiently. Surgical routes were optimized by balancing the four factors mentioned above. The operation methods including total resection, subtotal resection, partially resection, external neck artery embolisation and chemotherapy were selectively applied according to the predicted resection difficulty, risk level and residual level of tumor. Extended combined surgery or subtotal resection was performed if the surgical window or distal tumor could not be exposed completely in single surgical route.

For cases with important arteries wrapped up by tumors, subtotal resection and assisted chemotherapy were considered by assessing the peeling off difficulty degree of blood vessels through pre-simulating tumor resection process. For patients with surgical window obstructed by important encephalic blood vessels and region of nerves, the conventional surgical approaches were considered to be altered by pre-simulating tumor resection process. Subtotal resection was determined according to the risk level of the surgery for patients with important neurofunctional region invaded. Selective artery embolization was applied for tumors with predominant external carotid artery blood supply. Subtotal resection plan was also perfomed for patients with meningioma besides partially blocking venous sinus. Total resection along with ligation of venous sinus was performed if the venous sinus was totally blocked. The rationality of the surgery was assessed by comparing the expected situation with that met in the practical surgery.

2.2.3. Surgical plan for control group

The surgeries for control group were performed on the basis of CT and/or MR detection results.

2.3. Statistic analysis

Operation time, intraoperative blood supply and incidence of post-operative complications were recorded and compared.

Data were analyzed using SPSS 16.0 software. All the measurement data and enumeration data were expressed in mean ±SD and percentage, respectively, and tested by *Chi*-square test and *t*-test. $P<0.05$ was considered as significant difference.

3. Results

3.1. 3D-CTA simulated group

Expected surgery effects were achieved in all 473 patients through simulating the optimal surgical routes and methods by preoperative 3D-CTA detection. The intraoperation situation was highly consistent with operation simulated by 3D-CTA. Among them, 161 cases were found with obstruction of bone on skull base, exposure difficulty of distal tumor on which excessive operation will lead lesion of the surrounding tissue, or tumor of wide basement that could not be totally cut off because of the limitation of operative space. Plans with combined and expanded surgical routes were established at the early stage for the situations above (Figure 1).

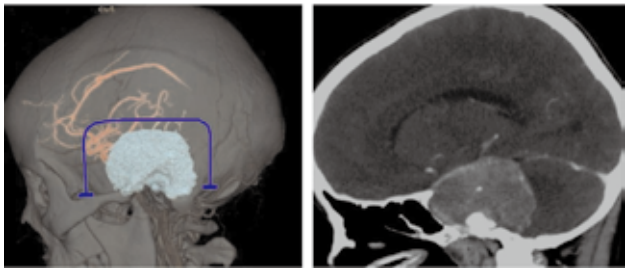

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Figure 1. Meningioma in petroclival area.
a) VRT image, b) MIP image.
The accurate location of the tumor was visualized by 3D-CTA, showing a difficulty of resection from the pterion. The blue curve line indicates the simulated resection region.

The size of the tumor and its growth area coincided with the simulated images which showed tumor with wide basement or growth towards the deep part in brain. After the implementation of combined, extended surgical approaches, tumors were exposed appropriately, the operation spaces were enlarged and the resection areas were optimized. The primary branches of cerebral arterial circles were compressed and dislocated at different degree. By simulating the conventional surgical routes using 3D-CTA, the primary arteries were predicted to be present in the surgical windows in 123 cases, among which these arteries could not be avoided or are difficult to be avoided, so the routes were altered for high risks (Figure 2). The blood vessels were avoided and separated in the operation, which confirmed the distribution of blood vessels visualized by 3D-CTA.

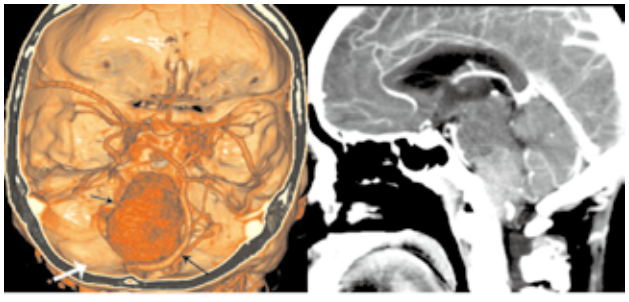

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Figure 2. Clivus meningiomas.
a) VRT image, b) MIP image.
The compression and dislocation situation of the surrounding base-skull arteries and the main branches of the posterior cerebral arteries visualised by 3D-CTA. (Black arrow: the arteries that need to be avoided; White arrow: The optimal surgical routes).

The meningiomas in all 473 patients had close relationship with important arteries and nerves functional regions in brain. Among them, tumors in 72 patients apparently invaded regions of optic nerves and brain stem (Figure 3). The main arteries of brain were deeply wrapped up by tumors in 51 cases in which anterior cerebral arteries were wrapped in 28, middle cerebral arteries wrapped in 13 cases, posterior cerebral arteries and vertibrobasilar arteries wrapped in 10 cases. By observing the invading degree in region of nerves and simulating the meningiomas resection process using 3D-CTA technology, it was predicated that the risks were very high. Hence sub-resection and chemotherapy were determined early before the surgery. The interspaces between the meningioma and arachnoid membrane disappeared, the optical nerves or brain stem were adhered with the meningiomas. The arteries were deeply wrapped up by the meningioma and were difficult to be peeled off, which confirmed with the result of 3D-CTA scan. Meningioma was found beside sinus in 94 patients. Among them venous sinus was totally blocked in 51 cases. Total resection of the meningioma and venous sinus were determined. The blocking of venous sinus was validated intraoperatively by digital subtraction angiography (Figure 4).

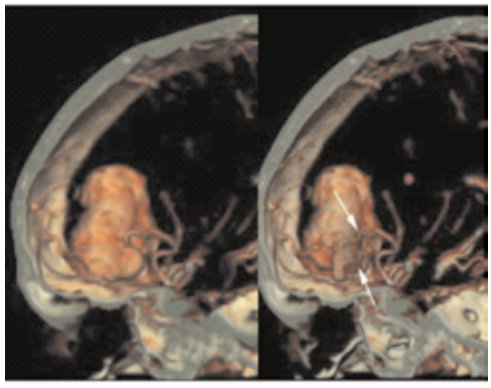

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Figure 3. Fossa cranii anterior and olfactory groove meningiomas.
a) before the simulated resection, b) after the simulated resection.
The anterior cerebral arteries were wrapped up by the tumor visualized by 3D-CTA. By simulating the situation ater the resection the blood for the tumor is predicted to be supplied by the wrapped blood vessels (white arrow), showing the peeling off difficulty of the vessels.

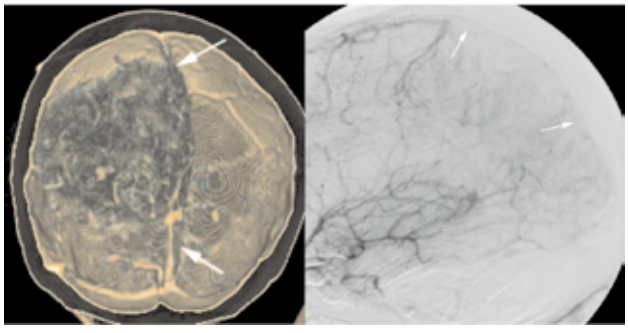

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Figure 4. Meningiomas beside the superior sagittal sinus.
a) 3D-CTA image, b) DSA image.
Bilateral wall of the veinus sinus were invaded visualized by 3D-CTA imaging. The sinus cavity was totally blocked, which was confirmed intraoperatively by DSA.

The meningioma and the venous sinus were clearly separated in 28 cases which were validated intraoperatively. Total resection was planed before the surgery, and the resection were successful without any serious complications. The tumor were rich in blood supply and some external carotid artery branches were in charge of blood supplying to the tumor using 3D-CTA scan (Figure 5, 6). External carotid artery embolisations were performed before the surgery, which helps in the softening of the tumor and the decrease in bleeding for easier resection. Meningiomas were totally cut off at Simpson I-II grade in 380 patients (80.3%).

Complications happened in 175 patients (37.0%). The average blood supply was (523.4±208.1) mL and average operation time was (314.8±106.3) min.

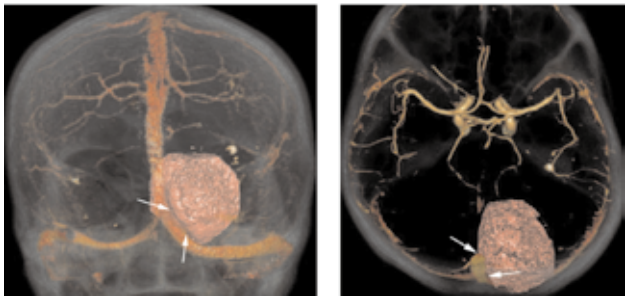

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Figure 5. Meningioma beside the confluence of sinus.
a) observation from the back of the brain, b) obsevation from the top of the brain.
The tumor closely connect with the veinus sinus, but the boundary is clear and the cavity of the sinus is full.

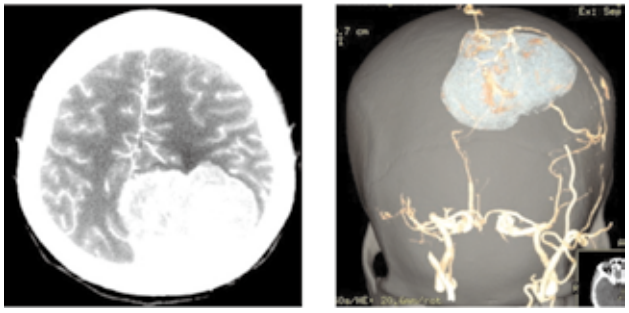

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Figure 6. Meningiama at the left top of the brain.
a) Enhanced back axial image, b) VRT image.
Tumor with abundant blood supply visualized by 3D-CTA imaging. The branches of middle meningeal arteries surrounding the tumor are in charge of the blood supply.

3.2. Control group

Seventy six patients were pre-treated with external carotid artery embolization in the control group. And total resection (Simpson grade I-II) was performed in 209 patients (81.3%). Complications happened in 124 patients (48.2%). The average blood supply was (592.0±263.3) mL and average operation time iwas (358.4±147.9) min.

3.3. Comparison of the curative effect

Compared with the control, The incidence of postoperative complications, blood supply and operation time in 3D-CTA simulated group were significantly lower (χ^2=8.72, P <0.005; t=3.87, P<0.01 and t=4.59, P<0.01).

4. Discussion

Meningiomas are mesodermal tumors originating in the arachnoid membrane. Usually, they grow outside the brain instead of infiltrated. The boundary is clear and there is a layer of arachnoid membrane between the tumor and the brain stem or blood vessels. Hence, the rate of total resection is high and the prognosis is favorable. As the growth of the tumor and the disappearance of arachnoid membrane, the cortex and piamater branches of the main arteries (anterior, middle cerebral and vertebral arteries) are involved in the support of the tumor[3]. Large meningiomas (diameter ⩾4.5 cm) are always difficult to be cut off in neurosurgery. Hence, rational selection of operation approaches and methods is the premise for the success of meningiomas resection[4]. A set of classical surgical approaches and methods has formed for tumors at different location[5-7], but, an ideal resection results usually can not be guaranteed by balancing the selections between classical minimally invasive or combined and extended surgical approaches, total resection or subresection, adjuvant treatments like pre-surgical external carotid artery embolisation or postoperative chemotherapy on the basis of the physicians' experience. Especially, accidents often happened because of the complicated anatomical variation in large meningiomas, which lead to the extended exposure time of the surgical window, increased blood supply and in turn increase in unnecessary surgical injuries and postoperative complications. Therefore, to fully understand the three-dimensional anatomical relation with the surrounding tissue and to simulate the optimal surgical plans are the key for reducing surgical injuries.

Reducing the exposure time of neurosurgery is important in enhancing the effects and prognosis[8]. Some important blood vessels are often dislocated from their normal anatomical position as a result of the compression from large meningiomas. The operation procedures are often affected for the occurrence of unexpected blood vessels in surgical window, increasing operative time. In the present study, the relation between the anatomical position of the tumor and nerves and vessel region was visualized using three-dimensional blood vessel imaging. The optimal surgical approaches were determined, the above mentioned structures were avoided or the conventional approaches were altered for the difficulty in avoiding, effectively decreasing the exploration time intraoperatively. For the cases of the large meningiomas with wide basis or interarea tumor, single conventional approaches could not estimate the important distal nerves and blood vessels. Extended combined surgery could increase the exposure areas of the tumor and the rate of total resection[9], while the operation time and injuries incidence will be increased. So the surgical plan should be determined by balancing the advantages and disadvantages of total resection and postoperative complications. In this study, the area of the basement of tumor was visualized in three-dimensional blood vessel imaging. If the distal important nerves or blood vessels could not be avoided, subresection in combination with chemotherapy was determined preoperatively on the basis of the clinical feature of the patients, which decreased the operation time (P<0.01 compared with the control). Also, the operations were conducted inside the tumors, decreasing the lesion for the surrounding vessels and nerves. While total resection were given up in most of the cases in the control because of above mentioned difficulties which increased unnecessary operation time, and the incidence of postoperative complications and injuries. The main blood vessels are usually invaded and wrapped up by meningiomas because of abundant blood supply[10], resulting in reallocation of the blood supply. And heaemorrhage often occur in the surgery. Serious consequence is always resulted from massive heaemorrhage in irrational total resections[11]. Also to peel off blood vessels that deeply wrapped up in the surgery will lead to failure of blood supply resulted from vasospasm. By visualizing the degree of invaded and wrapped blood vessel,

and simulating the peeling off difficulty, subtotal resection was determined early before the surgery in cases with deeply wrapped blood vessels, which significantly decreased the operation time and heaemorrhage incidence ($P<0.01$), and in turn reduced incidence of complications. While neurological dysfunctions (blind or paralysis) occurred a week later in 29 patients who were normal at early stage. It may be due to the blocking of peripheral blood vessel, which is attributed to delayed vasospasm because of excessive disturbance of arteries in the operation. The menginomas beside the venous sinus is always difficult in neurosurgery. Usually, total resection shouldn't be performed if the venous sinus is invaded but not completely blocked, or complications will be increased resulted from excessive operation towards the venous sinus[12]. Also, whether a ligature is needed should be judged according to the perfection degree of collateral circulation, or it will lead to encephaledema or even threaten the life because of the blocking of vein after operation[13]. Hence, to observe the invading degree is especially important before the resection. In the simulated group, MSCTA showed the superior sagittal sinuses in 51 patients were totally invaded. The cavity of the sinus is totally blocked. Ligation of venous sinus along with totally cut off were performed. The boundary between tumors and venous sinus was clear in 28 cases, for which separative resection were performed. The resection area was satisfied and no encephaledema or complications occurred. While for 32 cases of meningiomas beside the venous sinus in the control group, digital subtraction angiography (DSA) detection were performed to get to detect the unobstruction degree of the sinus cavity, but the invading degree could not be detected on the wall of sinus by DSA detection.

It is worthy of mentioning that when CTA is used as contrast agent in assessing the invading degree of meningiomas beside the sinus and when the threshold value of the sclerotin and CTA contrast agent is close, the accuracy will be affected. While in the simulated group of this study, the predicted situation is highly consistent with that in practical surgery and confirmed by DSA detection. Large meningiomas often grow to the offside of the venous sinus across the sinus wall, so the cavity of the sinus is often found to be filled with tumor tissue, leading to the blocking. The blocking degree of the cavity is highly consistent with DSA detection, but this does not mean the safety probability. We still think that DSA detection or ligation experiment of the sinus should be performed before total resection to ensure the safety. 3D-CTA image could supply highly reliable information for the plan of the operation. Besides, the blood supply for large meningiomas is often from two sources in which the blood from external carotid branched is always abundant, so when skull opening igation or embolisation of relative external carotid arteries will greatly decrease the haemorrhage and protect important arteries in brain[14]. By visualizing the blood supplying arteries using 3D-CTA, embolization was performed before the surgery in 102 cases with blood supply from external carotid arteries. The haemorrhage was efficiently controlled, and unnecessary DSA detection which can lead to injury is reduced.

In conclusion, 3D-CTA technology can be used to simulate and assess the expected injury rate of blood vessels and neurofuctional area within the surgical window against large meningioma, It can assess the risk degree of the operation and simulate multi-types of surgical plan, which helps the revision of surgical incision, the exposure of tumor-related blood vessels, control of haemorrhagia and protection of blood vessel and nerves region, It also can shorten the operation time, decrease haemorrhagia, avoid accidence by blinded operation, and decrease complication incidence. Therefore, 3D-CTA technology deserves to be promoted and applied in large meningioma resection.

Conflict of interest statement

We declare that we have no conflict of interest.

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