Anatomical and Imaging Studies of Endoscopic Optic Nerve Decompression

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ABSTRACT: Objective: To provide rationale for the clinical application of endoscopic optic nerve decompression based on anatomical and imaging studies. Methods: The anatomy of optic nerve canal and its adjacent structures of 20 facial sides of human cadaver heads were examined by multislice spiral CT scanning and imaging workstations. Anatomical and imaging measurements were compared. Results: The following types of optic nerve canal were found: canal, 5% (1 facial side); semicanal, 10% (2 facial sides); impression, 55% (11 facial sides); non-impression, 30% (6 facial sides). The relationships of the sinuses to the optic nerve canal and its adjacent structures are as follows: ethmoidal, 15% (3 facial sides), sphenoidal, 35% (7 facial sides), ethmoid-sphenoidal, 45% (9 facial sides); sella turcica, 5% (1 facial side). The ophthalmic artery is interior inferior to the optic nerve at the intracranial interior opening of the optic nerve canal (80%, 16 facial sides) and lateral inferior at the orbital aperture of the optic nerve canal (85%, 17 facial sides). 70% (14 facial sides) showed carotid canal protruding at the outer wall of the sphenoid sinus, while 95% (19 facial sides) resided with the optic nerve in the optic nerve canal recess. The length of the optic nerve canal interior wall measured (10.23 ± 1.31) mm. The distances and angles of the orbital aperture, intracranial interior opening, optic nerve, and internal carotid artery recess to the junction of the nasal columella and pinna were measure by anatomical and imaging methods. The differences in measurements between the methods were not statistically significant (p > 0.05). Conclusions: This study provides anatomical parameters for endoscopic optic nerve decompression. The use of a CT imaging workstation can facilitate accurate identification and measurements of anatomical landmarks of the optic nerve.

KEYWORDS: Endoscopic optic nerve decompression (EOND); Applied anatomy; multislice spiral CT (MSCT).

Endoscopic optic nerve decompression (EOND) is currently the treatment of choice for traumatic optic neuropathy (TON). Familiarity with anatomical landmarks and optic nerve decompression are important determinants of safe and effective surgeries [1,2]. Having a firm understanding of the anatomical structures of the optic nerve region and obtaining an anatomical image of the patient prior to the surgery could critically facilitate optic nerve decompression and reduce surgical risk [3]. This study examined the anatomy of optic nerve canal and its adjacent structures of 10 human cadaver heads (20 facial sides) through detailed dissection and anatomical measurements. Data were compared images taken via multislice spiral CT (MSCT) scanning and imaging workstation. We report here the important anatomical parameters obtained about the optic nerve and its adjacent structures and validate the accuracy of the measurements analyzed by the MSCT workstation. We lastly discuss safe and effective methods for EOND.

Materials and Methods

1.1 Materials

A total number of 10 whole adult cadaver head specimens (20 facial sides) were fixed by 4% paraformaldehyde. The structural integrity of the cadaver heads used in this study are well-kept with no pathological changes that would affect results of this study.

1.2 Instruments
Anatomical measurement instruments: One conventional anatomical and surgical instrument set was used. Measurements were made with a vernier caliper (accuracy to 0.02mm), compasses, ruler, pins, and wires. Imaging instrument: GE Light Speed the QX/I spiral CT 3D imaging workstation.

1.3 Imaging Acquisition and Anatomical Dissection

Axial scanning of specimen images were obtained with the GE Light Speed QX/I spiral CT imaging workstation. Post-processing of images were analyzed with the Advantage Windows 4.1 (AW4.1) software (Fig. 1). After MSCT imaging, specimens were sawed in half along the mid-sagittal line, dividing the skull into left and right sides. Each side contains a portion of the nasal columella. The nasal septum was removed. Along the surgical route of the EOND, via endoscopic and direct views, bilateral ethmoid sinuses and sphenoid sinuses were cut open. The optic nerve canal region was exposed upon peeling away the layers of tissue, revealing the confirmed structure of the nasal lateral wall. Anatomical dissection and measurements were done to the optic nerve canal and its adjacent structures, especially within the 180 degrees of the interior optic nerve canal wall that contains important anatomical landmarks (Fig. 2).

1.4 Imaging Measurements

Three-dimensional anatomical landmarks (midpoint of interior orbital aperture and of intracranial interior opening of the optic nerve canal) and the basal measurement points (junction of the nasal columella and pinnae, midpoint of Eustachian orifice) were determined by spatial processing and voxel coordinate reconstruction of the raw data obtained from the MSCT scans. Final coordinates (X, Y, Z) of the images were averages of triplicates. Spatial distances and angles of the anatomical landmarks were calculated by substituting the coordinates into trigonometry formulas.

1.5 Measurement Indices

The optic nerve canal and its relationship to adjacent structures of 20 facial sides of the specimens were observed. Using image workstations and conventional measuring instruments, the following parameters were measured: ① distance between midpoint of interior orbital aperture of optic nerve canal to the junction of nasal columella and pinnae and angle of orbital aperture-nasal columella-Eustachian orifice; ② distance between midpoint of intracranial interior opening of optic nerve canal and the junction of nasal columella and pinnae and angle of intracranial interior opening-nasal columella-Eustachian orifice. Using conventional measuring instruments, the following parameters were measured: ① distance from optic nerve canal and internal carotid artery recess to the junction of nasal columella and pinnae and angle of recess-nasal columella-Eustachian orifice; ② distance between posterior ethmoidal artery and the junction of nasal columella and pinnae and angle of posterior ethmoidal artery-nasal columella-Eustachian orifice (distance/
angle of posterior ethmoidal artery-nasal columella); ③ distance between the most prominent part of the internal carotid artery to the junction of nasal columella and pinnae and angle of internal carotid artery-nasal columella-Eustachian orifice (distance/angle of internal carotid artery-nasal columella). Using the vernier caliper, the following parameters were measured: ① average length of optic nerve canal interior wall; ② distance between posterior ethmoidal artery and orbital aperture (Fig. 3).

Results

2.1 Types of Optic Nerve Canal Protuberance

There are 4 types of optic nerve canal protuberance on the lateral sinus wall: ① canal (greater than 50% of optic nerve canal circumference protrudes out of the sinus); ② semicanal (less than 50% of optic nerve canal circumference protrudes out of the sinus); ③ impression (no clear protuberance is visualized on optic nerve canal, only the appearance of an impression); ④ non-impression (no impression is visualized on optic nerve canal).

2.2 Relationship between Optic Nerve Canal and Its Adjacent Nasal Sinus

The relationship between optic nerve canal and its adjacent nasal sinus can be categorized into 4 types: ① ethmoidal (the entire optic nerve canal is adjacent to the lateral wall of posterior ethmoid sinus); ② sphenoidal (the entire optic nerve canal is adjacent to the lateral wall of sphenoid sinus); ③ ethmoid-sphenoidal (optic nerve canal is partially adjacent to both the lateral walls of ethmoid and sphenoidal sinuses); ④ sella turcica (there is no development of sphenoidal sinus; optic nerve canal is adjacent to sphenoid bone and sella turcica). We report here that optic nerve canal is closely adjacent to the lateral wall of posterior ethmoid sinus, with a chance of the development of Onodi air cell up to 60% (12 facial sides).

2.3 Relationship between Ophthalmic Artery and Optic Nerve Canal

Anatomical studies found that ophthalmic artery originates from internal carotid artery, pierces through cavernous sinus, enters optic nerve canal via intracranial interior opening, and continues parallel with the optic nerve. Ophthalmic artery can continue inferior to optic nerve at the cranial opening (80%, 16 facial sides) or lateral inferior to optic nerve at the orbital aperture (85%, 17 facial sides) (Table 1).

2.4 Relationship between Optic Nerve Canal and Internal Carotid Artery

The internal carotid artery in all specimens used in this study was located at the lateral wall of sphenoid sinus, except in one instance where the sphenoid sinus was underdeveloped. Of these specimens, the internal carotid artery protruded at the lateral wall of sphenoid sinus and diverged away from optic nerve. Regardless of the type of optic nerve canal, 95% of specimens exhibited recesses of varying depths between optic nerve and internal carotid artery.

2.5 Comparison of Two Methods Used to Identify Anatomical Land-

Figure 3: Spatial relationship between optic nerve (ON), internal carotid artery (CA), and ophthalmic artery (OA)
scopic optic nerve decompression (EOND). Daniels et al. [4] reported that 40% of collected specimens exhibited this protuberance, where as Chun et al [5] have observed it to be 55%. In the horizontal plane, according to the extent of optical nerve protuberance into the sinus, Lee et al. [6] have categorized the protuberance into 3 types: canal, semicanal, and impression, while Chang et al. [7] added an additional type, non-impression. Shi et al. [8] observed that non-impression optic nerve canal are present 30% of all cases, which may complicate locating of the optic nerve during surgery. In this study, we report that of the 20 facial sides of human cadaver heads examined there were 5% (1 facial side) that were of the canal type, 10% (2 facial sides) semicanal, 55% (11 facial sides) impression, and 30% (6 facial sides) non-impression, supporting previously reported findings. Non-impression type is the main reason behind complications of locating optic nerve canal during surgery. Changes in the adjacent relationship between inner wall of optic nerve canal and outer wall of posterior ethmoid or sphenoid sinuses were greater. This study observed that of the adjacent relationships, 15% (3 facial sides) were ethmoidal, 35% (7 facial sides) were sphenoidal, 45% (9 facial sides) were ethmoido-sphenoidal, and 5% (1 facial side) were sella turcica. Of these, there was as high as 60% (12 facial sides) adjacent to the outer wall of posterior ethmoid sinus. This suggests that optic nerve canal is closely adjacent to the outer wall of posterior ethmoid sinus, with a high chance of developing Onodi air cell. Hence, identifying the anatomy of optic nerve canal protuberance based only on the outer wall of sphenoidal sinus during EOND is insufficient and may be misleading. The variable positioning between sphenoid sinus, posterior ethmoid sinus lateral wall, and optic nerve canal make the identification of the optic nerve canal during surgery more difficult and leads to increased complications. Furthermore, during routine sinus surgeries, the development of Onodi air cell is one of the main causes of iatrogenic damages to the optic nerve. Therefore, we need to understand the close anatomical

**Table 2: Comparison of data measured by anatomical dissection and imaging of structures adjacent to the optic nerve canal (Mean ± SD, n = 20)**

<table>
<thead>
<tr>
<th>Items</th>
<th>Anatomical measurements</th>
<th>Imaging measurements</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance of orbital aperture-nasal columella (mm)</td>
<td>77.85±3.61</td>
<td>77.34±3.23</td>
<td>0.132</td>
</tr>
<tr>
<td>Included angle of orbital aperture-nasal columella-eustachian orifice (°)</td>
<td>28.67±2.34</td>
<td>28.73±1.87</td>
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<td>Distance of intracranial interior opening-nasal columella (mm)</td>
<td>84.25±4.45</td>
<td>84.02±4.57</td>
<td>0.055</td>
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<tr>
<td>Included angle of intracranial interior opening-nasal columella- Eustachian (°)</td>
<td>26.53±2.36</td>
<td>26.95±2.12</td>
<td>0.075</td>
</tr>
<tr>
<td>Length of optic canal interior wall (mm)</td>
<td>10.22±1.33</td>
<td>10.01±1.23</td>
<td>0.481</td>
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</table>

<table>
<thead>
<tr>
<th>Items</th>
<th>Maximum value</th>
<th>Minimum value</th>
<th>x̄ ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance of recess - nasal columella (mm)</td>
<td>76.30</td>
<td>91.00</td>
<td>84.64±3.67</td>
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<tr>
<td>Included angle of recess-nasal columella-eustachian orifice (°)</td>
<td>21.50</td>
<td>29.00</td>
<td>25.39±2.40</td>
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<tr>
<td>Distance of internal carotid artery-nasal columella (mm)</td>
<td>70.00</td>
<td>79.00</td>
<td>75.21±2.69</td>
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<tr>
<td>Included angle of internal carotid artery-nasal columella-eustachian orifice (°)</td>
<td>29.00</td>
<td>35.00</td>
<td>31.21±1.94</td>
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<td>Distance of posterior ethmoidal artery-nasal columella (mm)</td>
<td>80.00</td>
<td>90.50</td>
<td>84.56±3.09</td>
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<tr>
<td>Included angle of posterior ethmoidal artery-nasal columella-eustachian orifice (°)</td>
<td>21.00</td>
<td>26.00</td>
<td>22.95±1.35</td>
</tr>
<tr>
<td>Distance of posterior ethmoidal artery-orbital aperture (mm)</td>
<td>3.50</td>
<td>7.50</td>
<td>5.39±1.16</td>
</tr>
</tbody>
</table>

**Table 3: Measurements of structures adjacent to the optic canal obtained via anatomical dissection (Mean ± SD, n = 20)**

marks Relevant to the Optic Nerve Canal Optic

Two methods, anatomical dissection and imaging workstation, were employed to determine the distance from orbital aperture or intracranial interior opening of optic nerve canal to the junction of nasal columella and pinnae and the angle formed between orbital aperture or intracranial interior opening, the junction of nasal columella and pinnae, and Eustachian orifice. The results were compared, and the difference between the two methods was not statistically significant (p > 0.05) (Table 2).

2.6 Results from Measurements of Important Anatomical Landmarks of the Optic Nerve Canal

To improve locating of optic nerve and protection of internal carotid artery during surgeries, we measured the following parameters via anatomical dissection: distance to and angle between the junction of nasal columella and pinnae to the most prominent point of internal carotid artery, orbital opening of posterior ethmoidal artery, and optic nerve-internal carotid artery recess; distance from orbital opening of posterior ethmoidal artery to orbital aperture of optic nerve (Table 3).

Discussions

3.1 Clinical value of understanding the anatomical structures of and relationship between optical nerve canal and its adjacent structures

The optic nerve canal protuberance formed by the impression of the optic nerve canal on either the medial sphenoid sinus or the posterior ethmoid sinus cavity is one of the most important anatomical landmark in locating the optic nerve during an endoscopic optic nerve decompression (EOND). Daniels et al. [4]...
relationship between optic nerve canal and posterior ethmoid sinus lateral wall, and conduct a preoperative analysis entailing detailed and comprehensive imaging of each patient to ensure safety of the surgery. Except in one instance where the sphenoid sinus was underdeveloped, the internal carotid artery in all specimens used in this study was located at the lateral wall of sphenoid sinus. Of these specimens, 70% (14 facial sides) of the internal carotid artery protruded at the lateral wall of sphenoid sinus and diverged away from optic nerve. Regardless of the type of optic nerve canal, recesses of varying depths between optic nerve and internal carotid artery were found. This recess can serve as a more constant anatomical landmark during surgery. The ophthalmic artery originates from internal carotid artery, pierces through cavernous sinus, enters optic nerve canal via intracranial interior opening, and continues parallel with the optic nerve. We report there that 80% (16 facial sides) of the time, the ophthalmic artery continues inferior to optic nerve at the cranial opening or lateral inferior to optic nerve at the orbital aperture 85% (17 facial sides) of the time. Thus, when cutting open the optic nerve sheath, especially near the cranial opening, extreme care should be taken to keep as close to the upper optic nerve to protect the ophthalmic artery.

3.2 Clinical value of anatomical measurements of optic nerve canal and related structural landmarks and imaging workstation

This study measured multiple crucial anatomical landmarks. Using measurements obtained via anatomical dissection as the standard, we measured the distance from orbital aperture (77.84 ± 3.60 mm) or intracranial opening of optic nerve canal (84.28 ±4.46 mm) to the junction of nasal columnella and pinnae and the angle formed between orbital aperture (28.69 ± 2.38°) or intracranial interior opening (26.52 ± 2.27°), the junction of nasal columnella and pinnae, and Eustachian orifice. The distance and angle between optic nerve-inner carotid artery recess to the same landmarks are 84.64 ± 3.67 mm and 25.39 ± 2.40°, respectively; distance and angle of the ethmoidal artery at the orbital aperture are 84.56 ± 3.09 mm and 22.95 ± 1.35°, respectively. Distance and angle of the most prominent portion of the internal carotid artery are 75.21 ± 2.69 mm and 31.21 ± 1.94°, respectively. Distance and angle measurements and calculations of the above anatomical landmarks to the junction of nasal columnella and pinnae, and Eustachian orifice can provide location of the optic nerve canal, posterior ethmoidal artery, and internal carotid artery to ensure safe and effective surgical procedures. Additionally, this study compared measurements obtained via anatomical dissection versus imaging workstation of the following parameters: the distance from orbital aperture or intracranial interior opening of optic nerve canal to the junction of nasal columnella and pinnae and the angle formed between orbital aperture or intracranial interior opening, the junction of nasal columnella and pinnae, and Eustachian orifice. The difference between the two methods was not statistically significant (p > 0.05), suggesting that measurements obtained by the image workstation are accurate and reliable. Based on findings of prior [9] and current studies, we conclude that imaging workstations can provide accurate clinical measurements that can then be directly used for clinical evaluation and guidance during surgery.

3.3 Relationship between preoperative measurement of optic nerve canal length and optic nerve decompression through the entire surgery

The effectiveness of optic nerve decompression is related to the degree of optic nerve damage and the range or decompression [10]. Decompression through the entire surgery is one of the main principles of EOND, and it critically ensures effective decompression of the optic nerve. It has been reported that changes within the optic nerve canal inner wall can be great, measuring between 7-23 mm. It is therefore imperative to measure the length of the optic nerve canal prior to surgery to determine the appropriate range of decompression and to guide adequate amount of decompression during surgery [1]. Therefore, accurate measurement of the length of optic nerve canal inner wall of every patient facilitates appropriate decompression from orbital aperture to cranial opening through the entire surgical procedure. This prevents the need to rely solely on the experience of the surgeon during the surgery. The length of optic nerve canal inner wall measured 10.23 ± 1.31 mm and 10.02 ± 1.24 mm by anatomical and imaging methods, respectively. There was no significant difference between the two measurements (p > 0.05), suggesting that imaging methods can easily and accurately measure the length of optic nerve canal inner wall. Thus, we suggest preoperative measurement of the length of optic nerve canal inner wall via imaging. During surgery, a sterile paper ruler can be used to verify range of decompression, which can help determine whether effective decompression of optic nerve canal through the entire surgery was achieved. This information obtained on a per patient basis was not available in past applications of imaging methods. Additionally, it has been reported that EOND can easily open optic nerve canal and anulus tendineus communis [11]. However, it generally cannot relieve the pressure generated from the falciiform fold at the cranial opening. This may be the main caveat of EOND. Therefore, there are still cases where transtorial approach for optic nerve decompression is necessary [12].

REFERENCES

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