Morphology of the atlas pedicle revisited: a morphometric CT-based study on 120 patients

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Abstract

Purpose To quantify the dimensions of the atlas pedicles and to analyze the relationship between extra medullary height (EMH) with intra medullary height (IMH) of the atlas pedicle.

Methods The images of the patients who had CT scanning and three-dimensional (3D) reconstruction involving atlantoaxial complex between June 2011 and April 2012 and meet our inclusion criteria were studied retrospectively. After reformatting the original images, the EMH and IMH of the atlas pedicles were measured.

Results Extra medullary height and IMH were, respectively, 4.83 ± 1.13 and 1.29 ± 1.10 mm for males and 3.75 ± 0.93 and 0.60 ± 0.83 mm for females, with statistical difference ($P < 0.05$). EMH and IMH had some correlation (correlation coefficient $r = 0.804$) but showed a large variability. Of 240 pedicles of 120 cases, 47.92 % (115 pedicles) were ≥ 1 mm; 12.08 % (29 pedicles) were between 0 and 1 mm; and 40 % (96 pedicles) were 0.

Conclusion The EMH and the IMH of the atlas pedicles were measured by using CT images of the atlas, providing anatomic parameters for surgery. They showed a certain

correlation but with a high variability. C1 pedicle screw fixation was well performed when the medullary canal was ≥ 1 mm, but the surgical procedure should be careful when it was between 0 and 1 mm, and avoided when there was no medullary canal in the atlas pedicle! So 3D CT reconstruction should be conducted to obtain data and establish individualized fixation strategy preoperatively.

Keywords Atlas pedicle · Medullary canal · Screw fixation · Anatomy

Introduction

Atlas pedicle screw fixation technique has been gaining an increasing popularity since it was proposed by Resnick and Benzel [1]. Multiple studies have been conducted to determine the optimal trajectory for the atlas pedicle screws [2, 3], and its clinical application has been reported in the published literatures [4–6]. Although several screw trajectories have been established for the atlas pedicle placement, all the screw path has to pass through the posterior arch of the atlas at the position of the vertebral artery groove, which is defined as the pedicle of the atlas and is the lowest height among all anatomic structures through the screw path. It is obvious that the atlas pedicle is the limiting structure for the feasibility of pedicle screw placement and selection of the screw size. In our clinical practice, we noticed that not all the cases could achieve successful placement of pedicle screws, although preoperative images measurements of the pedicles indicate that the bony structure is adequate to accommodate the screw, which may be relate to the size of the medullary canal. We conducted this study to investigate the size of the medullary canal with computed tomography (CT) scans and three-dimensional (3D) reconstruction technology. Also, the relationship between extra

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medullary height (EMH) with intra medullary height (IMH) of the atlas pedicle was analyzed.

Materials and methods

All protocols were approved by our institutional review board. The patients who had CT scanning with 1.2 mm interval and 3D reconstruction involving atlantoaxial complex between June 2011 and April 2012 in our hospital were included for analysis. Cases who were younger than 18 years old or suffered from these disorders, which were known to effect the bone morphology of the atlas such as fracture, tumor, infection, rheumatoid disease, and malformation were precluded from our study.

The atlas pedicle was defined as the posterior arch at the position of the vertebral artery groove, and the cancellous bone contained in the pedicle was defined as the medullary canal of the atlas pedicle, which was grey in the image with a CT value of 200–500 Hu. The coronary images of the atlas pedicles were obtained. Measurements of the EMH and IMH were made Fig. 1.

To insure consistency of data, all parameters were measured by the same investigator using the bone window setting. The mean and standard deviation were calculated for EMH and IMH. The differences between the left and right side were determined by the Student *t* test. The differences between men and women were determined also. The data were then evaluated to determine the percentage of cases whose IMH was ≥ 1 mm, between 0 and 1 mm, and equal to 0. Correlation between EMH and IMH was investigated too. The level of significance was set at $P < 0.05$ for all statistical analyses.

Results

A total of 120 consecutive patients fulfilling the selection criteria were included in this study, giving a total of 240

atlas pedicles. There were 68 males with an average age of 45.5 years (range 18–74 years) and 52 females with an average age of 45.2 years (range 18–79 years). No significant difference was found in data obtained between the left and right pedicles and consequently, the data obtained from the left and right pedicles were merged. Overall, EMH and IMH were 4.43 ± 1.18 and 1.03 ± 1.06 , respectively. 23.3 % of the atlas pedicles have bone thicknesses < 4 mm. The average thickness in women (3.75 mm) was found to be substantially less than that of men (4.83 mm) (Table 1). EMH and IMH had some correlation (the correlation coefficient $r = 0.804$) but showed a large variability. The scatterplot was shown in Fig. 2. Of 240 pedicles of 120 cases, 47.92 % (115 pedicles) of the IMH of the atlas pedicles was ≥ 1 mm; 12.08 % (29 pedicles) was between 0 and 1 mm and 40 % (96 pedicles) was 0.

Discussion

C1 lateral mass screw fixation was first described by Goel and Laheri [7], and later modified by Harms and Melcher [8]. The starting point for these screws is at the posterior aspect of the lateral mass, just below the posterior-lateral arch of the atlas. Several anatomic studies have confirmed that the lateral mass is large enough so that all the population can be safely instrumented using that starting point. However, the entrance point of C1 lateral mass screw is covered by a large venous plexus, bleeding from these vessels can obscure visualization, and stopping bleeding is rather a time-consuming, difficult, and frustrating task. In order to over this drawback, Resnick and Benzel described a case in which they inserted a C1 lateral mass screw through the pedicle into the lateral mass by starting on the posterior arch of C1, which was called C1 pedicle screw fixation, though it places the vertebral artery at high risk and has the potential risk of C1 posterior arch fracture. Since then, a lot of studies have been conducted to investigate the anatomy and the feasibility of C1 pedicle screw

Fig. 1 **a** The axial image of the atlas; **b** the coronary image of the atlas pedicle. 1.7 mm is the intra medullary height (IMH) of the right side of the atlas pedicle. **c** 4.4 mm is the extra medullary height (EMH) of the right side of the atlas pedicle

Table 1 EMH and IMH of 120 patients measured by 3D reconstruction (the mean $\pm$ SD, mm)

Items	Male	Female	All
EMH	4.83 $\pm$ 1.13* (2.4–6.8)	3.75 $\pm$ 0.93 (2.4–6.0)	4.43 $\pm$ 1.18 (2.4–6.8)
IMH	1.29 $\pm$ 1.10* (0–3.8)	0.60 $\pm$ 0.83 (0–3.2)	1.03 $\pm$ 1.06 (0–3.8)

EMH extra medullary height, IMH intra medullary height

* $P < 0.05$, versus females

Fig. 2 The scatterplot of EMH and IMH

placement. All these studies indicated that the rostrocaudal height of the atlas pedicle is the limiting factor in determining whether it is suitable for C1 pedicle screw fixation [2, 3]. In our clinical practice, we noticed that the size of pedicle medullary canal plays a substantial role in the successful placement of atlas pedicle screws. A variety of studies have demonstrated that the width of the atlas pedicle is greater than the height of the atlas pedicle, so we only evaluated the height of atlas pedicle and its medullary canal.

We found that the average EMH of all the atlas pedicles was 4.43 mm, which was in consistence with the study of Tan et al. [2] and Ma et al. [3], smaller than the data of Christensen et al. [9], and greater than the result of Lee et al. [10]. 23.3 % of the patients had EMH of the C1 pedicle of <4 mm, which indicated that 23.3 % of the population was not feasible for C1 pedicle screw placement because in order to obtaining excellent mechanical performance for the internal fixation construct, the size of the screws commonly used in clinical practice was 3.5 mm and a minimum of 4 mm of bone thickness would be required. The comparison of the EMH of the C1 pedicle and the percentage of specimens whose EMH of the C1 pedicle was <4 mm in various studies was shown in Table 2. The

average thickness in women was substantially less than that of men, so we should be more careful when performing C1 pedicle screw placement on female. The average IMH of all the atlas pedicles was 1.03 mm, which was significant less than the study of Tan et al. The major difference between Tan et al. and our study was that we discovered than some of the C1 pedicles consisting of only cortical bone without medullary canal (Fig. 4a). Several factors may contribute to the differences of various studies such as high variability of the anatomy of the atlas pedicle, different measuring manners, different subjects being studied, different sample size, and difference in race and ratio of male to female.

In this study, EMH was found to be positively correlated with IMH ($r = 0.804$). However, it was observed that in some cases, the medullary canal was very small and even disappeared in spite of a very large pedicle. Hence, the size of the medullary canal cannot be judged simply by the height of the pedicle. Preoperative CT scanning is needed to fully understand the dimensions of the atlas pedicle related to pedicle screw placement.

Theoretically, when IMH was ≥ 1 mm, which was near the dimension of the hand drill, the screw path in the bone could be readily created with a hand drill and the screw could be inserted easily (Fig. 3). When the IMH of the atlas pedicles was between 0 and 1 mm, which was significantly less than the dimension of the hand drill commonly used in clinical practice, the screw trajectory should be prepared with a smaller hand drill and tapped carefully. In order to avoid the fracture of the arch, placing the screws without previously tapping and with great force was not allowed. It was impossible to create a screw path with a hand drill when there was no medullary canal in the pedicles. The pedicle was filled with rigid cortical bone, without cancellous bony structure. When attempting pedicle screw placement, the hand drill was susceptible to slide and injury the surrounding structures such as the vertebral artery and surrounding venous plexus, so the cases without a medullary canal was not a good candidate for atlas pedicle screw placement (Fig. 4). For these atlases, C1 lateral mass screw fixation is recommended.

In this study, The EMH and the IMH of the C1 pedicles were measured by using CT images of the atlas, providing anatomic parameters for surgery. They both showed a certain correlation but with a high variability. Hence, the IMH could not be judged simply via the EMH of the pedicle. Before surgery, 3D CT reconstruction should be conducted to obtain data and establish individualized fixation strategy.

The limitation of this study was that we had not evaluated the reliability of the measurements. In a study using the same measuring method conducted by Busscher et al. [11], Kappa values for the intraclass correlations varied

Table 2 Comparison of the overall height of the C1 pedicle and the percentage of specimens whose EMH of the C1 pedicle was less than 4 mm in various studies

Study	Subject	Number of subjects	Measuring method	Height of the C1 pedicle	Percentage of <4 mm (%)
Tan et al. 2003 (28)	Dried human C1 specimen	50	CT and digital caliper	4.58 ± 0.65	8
Ma et al. 2005 (30)	Dried human C1 specimen	50	Digital caliper	4.25 ± 0.51	12
Lee et al. 2006 (31)	Dried human C1 specimen	709	Digital caliper	3.95 ± 0.96	53.8
Christensen et al. 2007 (32)	Dried human C1 specimen	120	Digital caliper	4.80 ± 0.93	19.2
Current study	Patients	120	CT	4.43 ± 1.18	23.3

Fig. 3 A patient with type II odontoid fracture, **a** the height of the medullary canal of the left and right side was 3.8 and 3.0 mm, respectively; **b** the pedicle screws were implanted successful in both sides **Fig. 4** A patient with atlantoaxial instability subluxation, **a** both the height of the atlas pedicle were 4.1 mm, and there was no medullary canal in the pedicle; **b** we failed the placement of pedicle screws in the pedicles bilaterally, and finally two lateral mass screws was used

from 0.83 to 1.00 ($P < 0.001$) and Kappa values for the interclass correlations varied from 0.83 to 0.99 ($P < 0.001$). So our study was reliable.

Conflict of interest None of the authors has any potential conflict of interest.

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