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ORIGINAL ARTICLE

Computed tomographic evaluation of odontoid process: implications for anterior screw fixation of odontoid fractures in an adult population

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Abstract
Introduction Odontoid diameter in some individuals may not be large enough to accommodate two 3.5-mm cortical screws for anterior odontoid fracture fixation. The study was performed to evaluate, in a Brazilian population, the diameter of the odontoid process and the feasibility of using two 3.5-mm cortical screws for anterior odontoid fracture fixation.
Materials and methods Computed tomographic (CT) scans of 88 adult patients (aged 18–78 years) were analyzed; 40 patients (45%) were male (mean age: 43.08 years) and 48 (55%) were female (mean age: 43.39 years). The minimum external and internal anteroposterior and transverse diameters of the odontoid process on sagittal and coronal planes were measured on CT multiplanar reconstructions of the cervical spine.
Results The mean value of the minimum external anteroposterior diameter was 10.83 ± 1.08 and 7.53 ± 1.10 mm for the minimum internal anteroposterior diameter. The mean value of the minimum external transverse diameter was 9.19 ± 0.91 and 6.07 ± 1.08 mm for the minimum internal transverse diameter. The mean AP diameter was significantly larger than the mean transverse diameter; 57 (65%) individuals had the minimum external transverse diameter >9.0 mm that would allow the insertion of two 3.5-mm cortical screws with tapping, and five (6%) individuals had the minimum internal transverse diameter >8.0 mm that would allow the insertion of two 3.5-mm cortical screws without tapping.
Conclusions The insertion of two 3.5-mm cortical screws was possible for anterior fixation of odontoid fracture in 57 (65%) individuals of our study, and there was no statistical difference between males and females.

Keywords Odontoid process · Dens · Quantitative computed tomography · Spiral computed · Fracture fixation · Internal · Orthopedic fixation devices

Introduction

The anterior fixation of odontoid fractures is the treatment of choice in selected patients with type II and III fractures according to Anderson and D'Alonzo classification [1], depending on fracture type, patient, and technical factors [2, 8]. This technique involves placement of one or two lag screws through the anterior inferior margin of the body of axis, directed superiorly into the dens and across the fracture side [3, 9]. Odontoid screw fixation enables a direct osteosynthesis of the fracture [3, 8, 9], spares atlantoaxial rotation, and provides optimum conditions for bone fusion with high fracture union rates [2, 7, 8].

The anterior odontoid screw fixation technique was originally described with two screws [3, 5]. However, there has been debate over whether one or two screws is optimal for fracture fixation [7, 12] and whether it is always

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possible to use two screws for anterior odontoid fixation [10, 14]. Insertion of two screws is difficult or even risky in certain patients [14]. As screws are placed side by side in the coronal or the transverse orientation, the transverse diameter is the critical anatomical dimension of the odontoid process for this technique [9, 10]. Nucci, based on mathematical calculations defined the smallest external transverse diameter of the odontoid process that would allow the introduction of two 3.5-mm cortical screws with tapping is 9.0 and 8.00 mm without tapping [10].

As the anatomic dimensions are critical factors in odontoid internal fixation with two screws, studies concerning the anatomical measurements of the odontoid in different populations were performed [10, 14]. Despite anterior odontoid screw fixation reports in the Brazilian population and the difficulty of inserting two screws in some patients [11, 12], morphology of the odontoid process has received little attention in morphometric studies to quantify aspects of the odontoid process related to the anterior odontoid screw fixation.

The goal of the study was to evaluate the diameter of the odontoid process and to observe the feasibility for anterior internal fixation of odontoid fractures using two 3.5-mm cortical screws with and without tapping.

Materials and methods

The local institutional review board (IRB) approved the study. Eighty-eight consecutive computed tomographic (CT) scans of cervical spine were used in the study based on volumetric data acquisition and isotropic multiplanar reconstructions. None of them had any problems related to the upper cervical spine. The presence of tumor, infection, severe degenerative disease, fractures, and congenital malformation were considered as exclusion criteria.

All patients were adults aged 18–78 years (mean: 43.08 ± 13.83). There were 40 men (aged 19–69, mean: 42.47 ± 15.56) and 48 women (aged 18–78, mean: 43.39 ± 12.31) (Table 1). CT scans were performed using a multiple row-detector helical scanner (SOMATOM Emotion 6—Siemens Medical System, Inc, Iselin, NJ). All measurements were performed in the multiplanar reconstruction (MPR) in the sagittal and the coronal planes. All the measurements were made perpendicular to the long axis of the odontoid process.

On the coronal and the sagittal planes, the minimum external and internal transverse and anteroposterior diameters were the selected parameters for evaluations (Figs. 1, 2). Measurements of the selected parameters for the study were performed manually with a digital cursor in the multiplanar reconstructions (MPR).

The minimum external transverse diameter (METD) of the odontoid process was defined as the smallest external dens measurement in the coronal plane (Fig. 1a). The minimum internal transverse diameter (MITD) was the smallest dens measurement in its internal cortex in the coronal plane (Fig. 1b). The minimum external anteroposterior diameter (MEAD) was the smallest external diameter in the sagittal plane (Fig. 2a), and the minimum internal anteroposterior diameter (MIAD) is the smallest measurement in its internal cortex in the sagittal plane (Fig. 2b).

Statistical comparisons between variables within gender were tested using Student's t test after verifying that the distribution of the variables was normal ($p < 0.05$ is significant). Fisher's exact test was used to examine the significance of the association between sex and METD smaller than 9 and 8 mm (Statistical Package for Social Sciences–SPSS Version 11.0).

Results

The mean values of AP diameters (MEAD) were significantly larger than those of transverse diameters (METD) ($p = 0.007$). The mean values of MEAD and MIAD were significantly larger in men ($p < 0.001$).

The mean values of METD were larger but not statistically significant in men ($p = 0.101$), while that of MITD was larger and statistically significant in men ($p < 0.016$).

Table 1 outlines all the minimum external and internal transverse and anteroposterior diameters. Table 2 outlines the mean values, standard deviation, range, and statistical comparison between the minimum external and internal transverse and AP diameters of all individuals and between men and women.

Minimum external transverse diameter (METD) bigger than 9.00 mm and suitable for placement of two 3.5-mm cortical screws with tapping [9] was observed in 57 (65%) of the individuals. 29 (72.5%) were males and 28 (58%) females, and there was no statistical difference between men and women ($p = 0.186$) (Figs. 3, 4).

The minimum internal transverse diameter bigger than 8.00 mm and suitable for placement of two 3.5-mm cortical screw without tapping was observed in 5 (6%) of the individuals. 4 (10%) individuals were male, 1 (2%) female, and there was no statistical significance between males and females ($p = 0.172$) (Fig. 5).

Discussion

There is no high- or moderate-quality evidence to guide surgical management of unstable type II odontoid fractures. The treatment has been recommended based on the

Table 1 Individual values of the minimum transverse and anteroposterior diameters of the odontoid process

No. of patients	Sex	Age	Minimum transverse diameter (mm)		Minimum anteroposterior diameter (mm)	
			External (METD)	Internal (MITD)	External (MEAD)	Internal (MIAD)
1	M	33	10.04	5.93	11.27	7.43
2	M	55	10.02	7.09	10.85	8.06
3	M	36	10.91	7.67	12.44	9.48
4	M	69	8.80	6.92	12.61	9.14
5	F	28	9.11	4.92	11.58	6.95
6	F	45	9.68	5.02	10.38	8.05
7	M	24	9.45	6.73	11.44	7.05
8	F	28	9.13	5.13	10.15	6.76
9	F	43	9.15	5.37	9.20	5.99
10	M	46	7.51	3.54	11.13	7.84
11	F	41	8.88	6.95	11.36	8.66
12	M	22	11.19	8.03	12.00	9.28
13	F	31	9.34	5.92	10.14	6.48
14	F	45	8.59	5.26	8.88	6.47
15	F	53	8.74	4.60	11.36	7.34
16	M	52	8.25	5.37	10.19	6.22
17	F	51	9.45	6.34	10.87	8.08
18	F	45	8.44	5.19	9.44	6.85
19	F	41	9.20	5.85	10.96	7.00
20	M	41	9.01	5.73	10.82	7.74
21	F	73	9.37	6.70	11.30	8.15
22	F	62	9.26	5.92	10.50	7.39
23	F	78	8.96	5.93	9.39	6.44
24	F	37	9.30	6.41	10.07	6.76
25	M	37	9.55	6.26	11.18	8.06
26	M	61	9.64	7.01	12.08	8.05
27	M	68	10.35	8.19	11.27	8.40
28	F	43	8.82	5.83	8.56	5.63
29	M	51	9.19	5.90	13.38	9.95
30	M	49	9.83	7.16	12.18	8.82
31	M	23	8.21	6.24	11.98	9.33
32	M	22	10.22	6.90	11.90	7.71
33	M	50	8.68	5.83	10.64	7.91
34	M	50	9.98	5.99	12.30	6.80
35	F	39	9.55	6.71	9.95	6.48
36	F	45	9.59	6.88	11.30	7.62
37	M	63	9.11	5.39	10.56	6.78
38	F	63	9.34	4.80	11.10	6.73
39	M	44	9.27	6.18	9.60	6.22
40	F	32	10.07	5.92	10.81	8.24
41	M	19	9.75	6.40	12.19	9.16
42	M	22	7.16	4.16	11.55	8.46
43	M	22	8.57	5.59	11.12	7.40
44	F	41	8.00	5.58	10.99	7.23
45	M	58	9.63	6.85	10.40	7.73
46	M	55	9.06	6.96	12.57	8.51
47	F	57	11.24	8.56	10.63	6.86

Table 1 continued

No. of patients	Sex	Age	Minimum transverse diameter (mm)		Minimum anteroposterior diameter (mm)	
			External (METD)	Internal (MITD)	External (MEAD)	Internal (MIAD)
48	M	20	9.73	7.08	10.91	8.26
49	F	27	8.20	5.46	11.41	7.62
50	F	40	9.12	6.91	10.36	7.53
51	F	54	9.55	6.88	9.39	6.40
52	F	51	9.43	4.85	10.09	6.58
53	F	57	9.11	7.22	10.26	7.76
54	F	24	9.74	5.60	12.11	8.56
55	F	43	8.77	5.61	10.68	8.47
56	F	47	8.27	5.69	9.50	6.60
57	F	41	8.57	4.73	9.73	6.45
58	F	57	7.23	4.78	9.85	6.48
59	F	44	9.13	6.68	9.05	5.96
60	F	49	9.14	6.35	9.38	6.39
61	F	38	8.65	4.32	9.05	4.43
62	F	22	8.28	5.60	9.89	6.90
63	M	39	8.66	5.04	11.45	7.84
64	F	56	8.51	5.05	10.11	7.56
65	M	34	10.82	7.41	12.48	8.54
66	F	48	9.45	6.95	12.09	8.21
67	M	65	9.77	6.52	11.23	7.23
68	M	51	5.90	3.58	11.26	8.27
69	F	18	8.20	5.43	9.46	5.88
70	M	30	11.56	8.60	11.37	8.00
71	M	45	9.81	6.98	12.15	9.38
72	M	28	9.16	6.03	11.45	8.48
73	M	26	9.37	7.49	12.10	8.59
74	F	44	8.26	5.01	9.74	6.89
75	F	33	9.08	5.69	10.49	7.77
76	M	24	10.32	6.79	12.12	8.28
77	M	48	8.26	5.41	11.51	8.81
78	F	46	10.65	7.19	10.32	6.43
79	F	35	9.20	5.24	8.90	5.71
80	M	60	9.09	5.76	12.40	8.35
81	F	35	8.80	5.45	9.63	9.90
82	F	51	9.23	5.10	10.79	6.26
83	F	42	9.22	7.25	9.75	6.81
84	F	26	8.77	5.84	9.03	6.04
85	M	68	7.80	4.26	11.81	7.43
86	F	34	8.15	4.47	9.46	6.03
87	M	54	9.99	8.28	12.19	9.62
88	M	35	10.78	7.40	11.36	8.21

combination of expert opinion, patient and surgeon choice, and the best available evidence [2, 4, 8, 11, 14]. The anterior or the posterior surgical decision-making should be based on parameters related to the fracture, bone quality of the patient, and technical factors [2, 4, 8, 11, 14].

Anterior screw fixation has been the method of choice for unstable type II and cephalad type III odontoid fractures [2, 4, 5, 8, 11]. Initially, it was proposed using the 2-screw technique considering that it would provide superior mechanical stability [2, 3]. Odontoid diameters of some

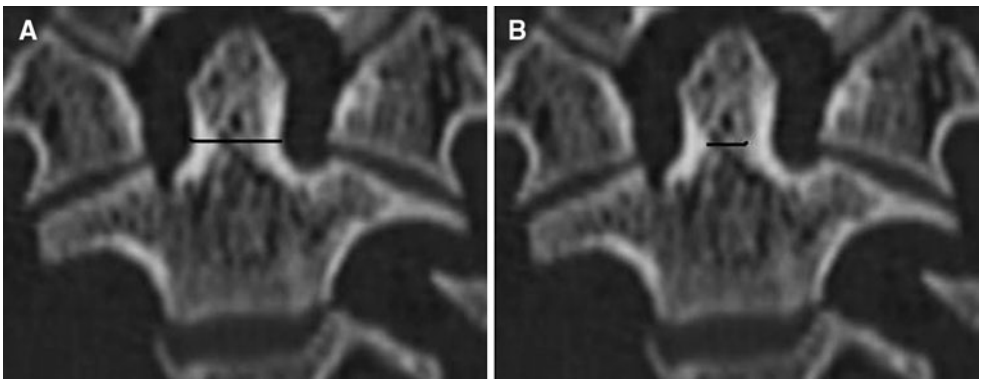

Fig. 1 Minimum external (**a**) and internal (**b**) transverse diameter of the odontoid process

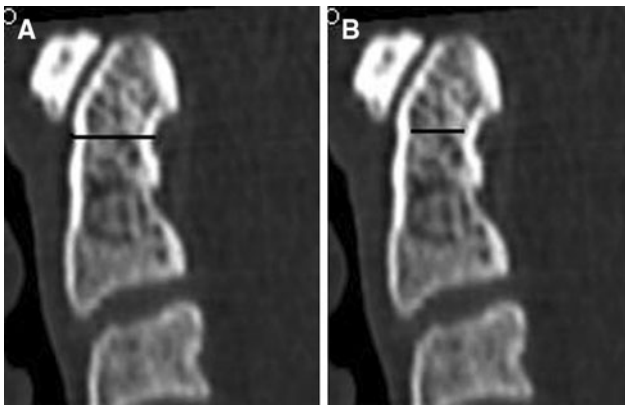

Fig. 2 Minimum external (**a**) and internal (**b**) anteroposterior diameter of the odontoid process

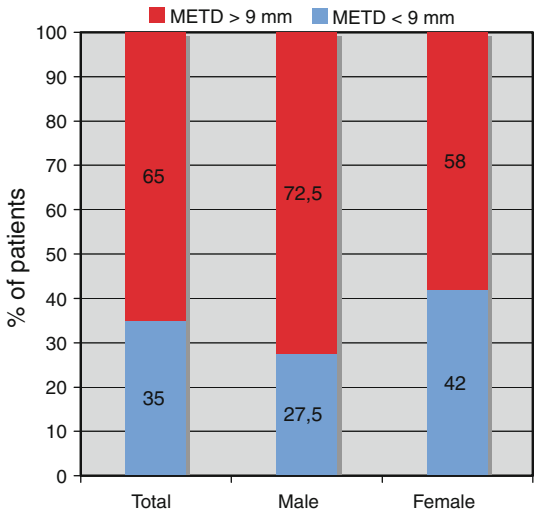

Fig. 3 Percentage of individuals with minimum external transverse diameter <9.0 mm

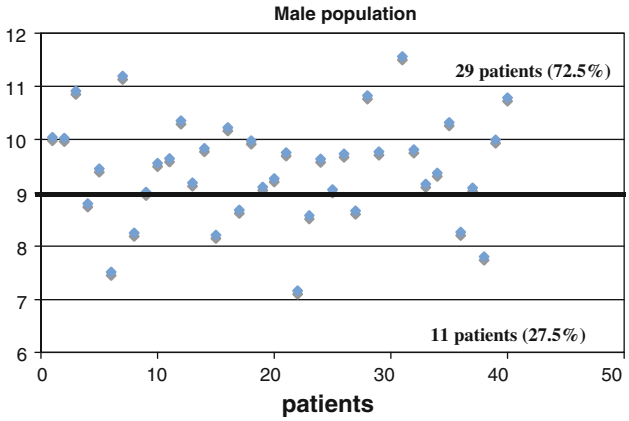

Fig. 4 Scattergraph demonstrating the minimum external transverse diameter (METD) of the odontoid process in the male and the female groups. The points below the *line* represent the 11 individuals in whom the odontoid was too small to accommodate two 3.5-mm screws

individuals may not be large enough to accommodate two 3.5-mm cortical screws. Insertion of two screws is difficult or even risky in certain patients. Although this technical difficulty has not been emphasized in the initial reports, it probably occurred with the use of the technique in different regions and was the motivation to perform quantitative morphometric studies related to the fixation of odontoid process [10, 14].

The smallest diameter of the odontoid process in the sagittal and coronal plane is located in the region of transverse ligament of the atlas [13]. The reported AP diameter of odontoid process is significantly larger than the transverse diameter [13, 14], and we also have observed this result. However, external AP diameter smaller than 9.00 mm was not observed in other studies [10, 14], and we had three females with MEAD smaller than 9 mm. The transverse diameter of the dens is the smallest diameter and is the critical diameter for the placement of two screws as they are placed side by side in the coronal or the transverse plane [10]. The smallest transverse diameter of the odontoid process for the placement of two 3.5-mm cortical screws is 9.0 mm with tapping and 8.0 mm without tapping [10]. The critical value of 9.0 mm considered that the inner

Table 2 Values of the parameters studied and comparison between men and women

	METD (mm)	MITD (mm)	MEAD (mm)	MIAD (mm)
Male (40)	9.36 ± 1.12 (5.9–11.56)	6.37 ± 1.20 (3.54–8.6)	11.59 ± 0.76 (9.6–13.38)	8.17 ± 0.89 (6.22–9.95)
Female (48)	9.04 ± 0.67 (7.23–11.24)	5.82 ± 0.90 (4.32–8.56)	10.20 ± 0.88 (8.56–12.11)	7.0 ± 0.97 (4.43–9.9)
Total (88)	9.19 ± 0.91 (5.59–11.56)	6.07 ± 1.08 (3.54–8.6)	10.83 ± 1.08 (8.56–13.38)	7.53 ± 1.10 (4.43–9.9)
	$p = 0.101$	$p = 0.016$*	$p < 0.001$*	$p < 0.001$*

* Means statistical difference between men and women groups

cortex of the odontoid process is tapped, leaving at least 0.5 mm of cortical bone outside the screws and a minimum of 1.0 mm of spacing between the implants. However, if the inner cortex is not tapped, the intramedullary diameter must be at least 8.0 mm to accommodate two screws, considering that the two implants lie up against the lateral cortex with 1.0 mm of distance between them [10].

According to the mentioned parameters, 65% of the individuals of our study had odontoid diameter suitable for two 3.5-mm cortical screw fixation with tapping. Higher percentages were observed in Caucasians (95%) [10] and Malaysians (72%) [14]. The smallest value of METD of our study was 5.59 mm (male), and it was lower than the smallest value observed in Malaysians and Caucasians [9, 10, 14]. Similar to our results, in both studies, there were no difference between males and females [9, 10, 14].

In our study, almost all (96%) the patients had MITD smaller than 8.00 mm, showing that the vast majority of the population does not accommodate two screws without tapping. In Caucasians, 67% of the population present this characteristic [10]. In both populations, there were great variabilities in cortical thickness. One possible reason for the smaller values found in our study compared to the literature [10, 14] may be that the measurements were performed based on the reconstructions in the sagittal and the coronal planes, which ensures that these values are actually the lowest in those planes. In other studies, measurements were made on axial slices [10, 14].

The minimum external and internal transverse diameter of odontoid process for insertion of two 3.5-mm cortical screw with or without tapping was proposed by Nucci et al. [10] and has been used as a reference value in other studies [14]. The critical value for two 3.5-mm cortical screw insertion with tapping was proposed considering the height of the odontoid fracture, the length of the screw, and the amount of lateral cortex penetration. The critical transverse diameter can be even bigger in patients with relative smaller odontoid height or more proximal odontoid fractures. The individual anatomy of the odontoid process and fracture localization should be considered in the preoperative patient evaluation.

The critical value of 8 mm of the internal transverse for insertion of two 3.5-mm cortical screws without tapping

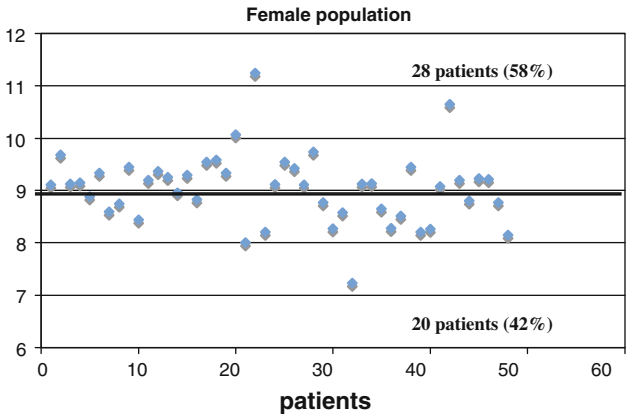

Fig. 5 Scattergraph demonstrating the minimum external transverse diameter (METD) of the odontoid process in the women's group. The points below the line represent the 20 patients in whom the odontoid was too small to accommodate two 3.5-mm screws

assumes that screw lie up against the lateral cortex. The percentage of individuals in our series was much smaller than values reported [10, 14], and the difference could be related to the method used to measure the internal diameter. The internal transverse diameter is actually the intramedullary odontoid canal, which is influenced by the thick irregular odontoid cortices [10, 13]. The odontoid process does not have a circular intramedullary canal, and the thickness and irregular areas of the transverse inner cortical diameter may lead to differences and lower values observed in our series. However, the smallest diameter observed in our series was 3.58 mm, and it would be feasible for one 3.5-mm cortical screw insertion.

The anterior fixation of odontoid process is a safe and effective method for the treatment of fractures, and good results are directly related to its correct indication [5, 6, 8] and correct performance of the surgical technique [2] so that the biomechanical principles can be correctly applied. Proper instrumentation of the odontoid fracture requires the screw acting as a lag screw pulling the fractured odontoid fragment against the body of axis. One or two screw techniques have been advocated [2, 7, 11, 12], and the results of our study indicate that in about one-third of patients, the dimensions of the odontoid process do not

allow the placement of two implants. An alternative for these patients is to use two screws of smaller diameter or a single screw. Two-screw fixation provides better stability in rotation and extension, but there are no significant differences in the union rate [7, 8, 12].

Considering the percentage of individuals observed in our study with odontoid diameter unsuitable for two 3.5-mm cortical screw insertion, in Brazilians, the preoperative evaluation of the odontoid process transverse diameter, mainly the external transverse diameter, should be performed to evaluate the safety and the feasibility of two-screw fixation technique. The surgeon should be aware and prepared to use an alternative technique instead of a two 3.5-mm cortical screw anterior odontoid fixation for surgical treatment of odontoid fractures.

Conclusions

About one-third of the patients in our population had the minimum external transverse diameter less than 9 mm, indicating impossibility for the introduction of the second implant within the odontoid process and the need for proper preoperative planning.

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

References

1. Anderson LD, D'Alonzo RT (1974) Fractures of the odontoid process of the axis. J Bone Joint Surg Am 56:1663–1674
2. Apfelbaum RI, Lonser RR, Veres R, Casey A (2000) Direct anterior screw fixation for recent and remote odontoid fractures. J Neurosurg 93:227–236
3. Bohler J (1982) Anterior stabilization for acute fractures and nonunions of the dens. J Bone Joint Surg Am 64:18–27
4. Grauer JN, Shafi B, Hilibrand A, Harrop JS, Kwon BK, Beiner JM, Albert TJ, Fehlings MG, Vaccaro AR (2005) Proposal of a modified, treatment-oriented classification of odontoid fractures. Spine J 5:123–129
5. Henry AD, Bohly J, Grosse A (1999) Fixation of odontoid fractures by an anterior screw. J Bone Joint Surg Br 81:472–477
6. Hubner AR, Spinelli LF, Grosse A (1999) Decisão no tratamento das fraturas do odontóide. COLUNA/COLUMNA 9:43–48
7. Jenkins JD, Coric D, Branch CL Jr (1998) A clinical comparison of one- and two-screw odontoid fixation. J Neurosurg 89:366–370
8. Maak TG, Grauer JN (2006) The contemporary treatment of odontoid injuries. Spine (Phila Pa 1976) 31:S53–S60
9. Nakanishi T, Sasaki T, Takahata T, Aoki Y, Sueyasu M, Uzawa M, Washiya S, Imanaka K (1980) Internal fixation of odontoid process. Orthop Surg Traumatol 23:399–406
10. Nucci RC, Seigal S, Merola AA, Gorup J, Mroczek KJ, Dryer J, Zipnick RI, Haher TR (1995) Computed tomographic evaluation of the normal adult odontoid. Implications for internal fixation. Spine (Phila Pa 1976) 20:264–270
11. Patel AA, Lindsey R, Bessey JT, Chapman J, Rampersaud R (2010) Surgical treatment of unstable type II odontoid fractures in skeletally mature individuals. Spine (Phila Pa 1976) 35:S209–S218
12. Sasso R, Doherty BJ, Crawford MJ, Heggeness MH (1993) Biomechanics of odontoid fracture fixation. Comparison of the one- and two-screw technique. Spine (Phila Pa 1976) 18:1950–1953
13. Schaffler MB, Alson MD, Heller JG, Garfin SR (1992) Morphology of the dens. A quantitative study. Spine (Phila Pa 1976) 17:738–743
14. Yusof MI, Yusof AH, Abdullah MS, Hussin TM (2007) Computed tomographic evaluation of the odontoid process for two-screw fixation in type-II fracture: a Malaysian perspective. J Orthop Surg (Hong Kong) 15:67–72