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CT scans versus conventional tomography in acute fractures of the odontoid process

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Abstract Four different radiological diagnostic methods were compared as to their diagnostic relevance in the analysis of odontoid fractures. Thirty-one patients with fresh odontoid fractures were investigated using standard anteroposterior and lateral radiographs, conventional tomography, axial computerized tomography and two-dimensional reconstruction in the sagittal and the coronal planes. As a control, 13 patients without odontoid fractures were examined. The results of the different investigations were correlated with the actual (clinical and/or intra-operative) findings. The coefficients of correlation for the conventional tomography and two-dimensional reconstruction were $\kappa=0.774$ and $\kappa=0.907$, respectively. For conventional radiography and axial computerized tomography (CT), the coefficients were clearly lower, at $\kappa=0.364$ and $\kappa=0.627$, respectively. The less time-consuming CT examination with sagittal and coronal reconstructions is equivalent with respect to diagnostic accuracy and can, therefore, replace conven-

tional tomography in the evaluation of odontoid fractures.

Keywords Odontoid fractures · Radiography · Tomography · X-ray image processing · Computer-assisted

Introduction

Fractures of the odontoid process are dangerous injuries of the upper cervical spine, because of their potential instability. They account for 7–12% of acute cervical spine fractures [5, 9]. Most of these injuries are diagnosed on the basis of conventional radiographs, including anteroposterior (AP), lateral and transoral views [9]. Five to ten per-

cent of odontoid fractures require further diagnostic investigations for definitive diagnosis [7]. Conventional tomography in two planes is not only used for the exclusion, but also for the detailed visualization of the fracture, in particular, with regard to therapy planning [13, 17, 19]. Over the last two decades, computerized tomography (CT) has established itself as the standard diagnostic tool in the investigation of bony pathology in the cervical spine [5, 6, 11]. The data acquisition time has been drasti-

cally shortened with the use of spiral CT scanners, so that only a few minutes are required per examination. In comparison, the patient has to lie still for about 30 min for examination with the conventional tomography machine [19]. The quality of two-dimensional (2D) CT reconstructions can be optimized by adjusting the thickness of the cuts [1, 11, 18]. Fractures in the axial plane that can theoretically be missed by the older sequential CT scanning techniques are better visualized using the newer spiral technique, where the slice thickness can be adjusted to 1 mm each. Additionally, the soft tissues around the spine can be examined for evidence of trauma such as edema, hematoma or disc disruption [11]. Magnetic resonance imaging (MRI) is superior to CT in the evaluation of the soft tissues, especially for diagnosis of injury to neural structures. However, for the diagnosis of fresh odontoid fractures, i.e. detecting the interruption of the cortex, the fracture line and loose bone fragments, CT has been found to be better than MRI. There is still a role for MRI in the investigation of pathological fractures or odontoid non-unions [4, 20].

The purpose of this study was to assess the comparative value and therapeutic relevance of standard radiography, conventional complex motion tomography and computerized tomography with and without 2D reconstructions in the diagnosis of odontoid fractures.

Materials and methods

Over a 42-month period (from May 1995 to November 1998), 31 patients with acute odontoid fractures (diagnosis was made within 10 days of the injury) were included in this prospective study. The average age of the 15 women and 16 men was 56.8 years (median 58 years, SD 24.1 years, min. 18 years, max 88 years). Fractures secondary to pathological conditions such as

tumors or inflammatory diseases were excluded. Besides the conventional radiographic investigation (A/P, lateral and transoral views), spiral CT (Somatom Plus 4, Fa. Siemens, Erlangen, Germany) was performed using the following parameters: table advance 1.5 mm, slice thickness 1 mm. In all cases the scan included the segments from occiput to the C3 level. Reconstructions in the sagittal and coronal planes were calculated. Additionally, all patients underwent a conventional complex motion tomogram in two planes (56 kV, 64 mA, slice thickness 2 mm, exposure time: 5 s/slice, Optiplanimat, Fa. Siemens, Erlangen, Germany). Furthermore, a control group of 13 patients (11 men, 2 women; average age 48.7 years, median 45 years, SD 18.5 years, min. 27 years, max 83 years) without odontoid pathology were examined in an identical manner. Within this group, six patients had suffered a pars interarticularis fracture of C2 (Hangman's fracture), four patients had isolated C1 fractures, and three had neoplastic changes in the lateral body of C2.

Thus, five different clinically experienced observers (three orthopedic traumatologists and two radiologists) reviewed the radiological investigations of all 44 patients.

The observers in a random fashion reviewed each of the four investigations for every patient, so that each observer reviewed a total of 176 investigations independently. No information regarding the history of the patient was given. The presence of a fracture was judged as "certain yes", "probable", and "certain no" for each investigation. The results of the observers were statistically correlated with the actual findings using the κ test [12]. A fracture of the odontoid was ruled out in the absence of clinical symptoms and a normal plain tomogram. When the results of these investigations were questionable, functional examinations of the cervical spine with the help of fluoroscopy as well as follow-up examinations were performed to rule out instability. This was required in 4 of the 44 patients.

Specificities and sensitivities of the four different diagnostic modalities were calculated.

The fractures were classified according to the Anderson and d'Alonzo classification [3]. The interobserver reliability of this classification scheme was assessed. There were ten possible combinations for each diagnostic modality. The κ test was used to correlate the results between the different observers. At the same time, the observers rated the certainty of their finding as "uncertain", "probable", and "sure" (uncertain=0, probable=1, sure=2).

Table 1 Results of the observations made by the five judges using conventional tomography

	Fracture (n=31)			No fracture (n=13)		
	Certain no fracture	Probable fracture	Certain fracture	Certain no fracture	Probable fracture	Certain fracture
1	0	4	27	13	0	0
2	0	5	26	13	0	0
3	1	4	26	12	1	0
4	1	5	25	12	1	0
5	0	3	28	12	1	0

Table 2 Results of the observations made by the five judges using computed tomography (CT) reconstructions

	Fracture (n=31)			No fracture (n=13)		
	Certain no fracture	Probable fracture	Certain fracture	Certain no fracture	Probable fracture	Certain fracture
1	0	1	30	13	0	0
2	0	0	31	13	0	0
3	0	0	31	12	1	0
4	0	6	25	10	3	0
5	0	0	31	13	0	0

Table 3 Results of the observations made by the five judges using plain radiographs

	Fracture (<i>n</i> =31)			No fracture (<i>n</i> =13)		
	Certain no fracture	Probable fracture	Certain fracture	Certain no fracture	Probable fracture	Certain fracture
1	1	10	20	8	5	0
2	1	10	20	7	6	0
3	2	11	18	4	8	1
4	1	9	21	4	9	0
5	1	10	20	7	5	1

Table 4 Results of the observations made by the five judges using axial CT scans

	Fracture (<i>n</i> =31)			No fracture (<i>n</i> =13)		
	Certain no fracture	Probable fracture	Certain fracture	Certain no fracture	Probable fracture	Certain fracture
1	1	8	22	13	0	0
2	0	10	21	13	0	0
3	1	11	19	12	1	0
4	0	2	29	10	3	0
5	0	11	20	13	0	0

Table 5 Specificity and sensitivity of conventional tomography for diagnosis of acute fracture of the odontoid process: results of the five judges

Investigator	Specificity (%)	Sensitivity (%)	Concordance coeff. (Cohen's κ)
1	100	87.1	0.822
2	100	83.9	0.782
3	92.3	83.9	0.741
4	92.3	80.6	0.707
5	92.	90.3	0.819
Average	95.4	85.2	0.774

Table 6 Specificity and sensitivity of CT reconstruction for diagnosis of acute fracture of the odontoid process: results of the five judges

Investigator	Specificity (%)	Sensitivity (%)	Concordance coeff. (Cohen's κ)
1	100	96.8	0.951
2	100	100	1.000
3	92.3	100	0.950
4	76.9	80.6	0.635
5	100	100	1.000
Average	93.8	95.5	0.907

Table 7 Specificity and sensitivity of plain radiographs for diagnosis of acute fracture of the odontoid process: results of the five judges

Investigator	Specificity (%)	Sensitivity (%)	Concordance coeff. (Cohen's κ)
1	61.5	64.5	0.434
2	46.2	64.5	0.375
3	30.8	58.1	0.260
4	38.5	67.7	0.366
5	53.8	64.5	0.390
Average	46.2	63.8	0.364

Table 8 Specificity and sensitivity of axial CT scans for diagnosis of acute fracture of the odontoid process: results of the five judges

Investigator	Specificity (%)	Sensitivity (%)	Concordance coeff. (Cohen's κ)
1	100	71.0	0.648
2	100	67.7	0.623
3	92.3	61.3	0.533
4	76.9	90.3	0.735
5	100	64.5	0.596
Average	93.8	71.0	0.627

Results

All of the results for each observer are summarized in Table 1, Table 2, Table 3, and Table 4.

The average sensitivity and specificity for plain tomography were 85.2% and 95.4%, respectively (Table 5). For the CT reconstructions, the sensitivity and specificity were 95.5% and 93.8% (Table 6).

The average sensitivity for the recognition of a fracture with plain radiography alone was 63.8% and for axial CT cuts, 71%. The specificity for conventional X-rays was 46.2%, whereas it was 93.8% for the axial CT slices (Table 7, Table 8).

With respect to the correlation of the various diagnostic methods to the actual pathology, the coefficient of correlation was $\kappa=0.774$ for the conventional tomography and $\kappa=0.907$ for the CT reconstructions (Table 5, Table 6).

Table 9 Interobserver agreement among the five judges evaluated by Cohen's κ correlation test. In classifying the fractures according to Anderson and D'Alonzo [3], conventional tomography and CT reconstruction show a similar coefficient of correlation. The interobserver agreement with respect to the classification was lowest for the conventional radiographs and highest for the axial CT scans

Crosstab. investigator	Correlation coefficient Cohen's Kappa			
	CT reconstruction	Conventional tomography	Plain radiographs	Axial CT scan
1 to 2	0.881	0.886	0.728	0.828
1 to 3	0.823	0.942	0.667	0.994
1 to 4	0.572	0.525	0.552	0.661
1 to 5	0.764	0.769	0.536	0.940
2 to 3	0.941	0.826	0.887	0.882
2 to 4	0.572	0.644	0.351	0.599
2 to 5	0.704	0.830	0.333	0.824
3 to 4	0.642	0.698	0.540	0.711
3 to 5	0.704	0.717	0.549	0.883
4 to 5	0.642	0.591	0.655	0.768
Average	0.725	0.743	0.580	0.804

Table 10 Confidence levels for the classification of odontoid fractures after Anderson and D'Alonzo [3]

Investigator	CT reconstruction	Conventional tomography	Plain radiographs	Axial CT scans
1	1.65	1.61	0.90	1.10
2	1.68	1.68	0.77	0.65
3	1.58	1.61	0.77	0.65
4	1.65	1.65	0.90	0.74
5	1.68	1.74	0.81	0.71
Average	1.65	1.66	0.83	0.77

The conventional radiographs clearly had a poorer correlation, with a coefficient of 0.364, and the axial CT cuts correlated with a coefficient of 0.627 (Table 7, Table 8).

In the assessment of the fracture pattern none of the observers diagnosed a type 1 fracture according to the classification of Anderson and d'Alonzo.

The average coefficient of correlation for the interobserver comparison with regard to the fracture pattern was found to be $\kappa=0.580$ for the conventional radiographs and $\kappa=0.804$ for the axial CT cuts (Table 9).

The coefficients of correlation for conventional tomography and CT reconstruction were similar at $\kappa=0.743$ and $\kappa=0.725$, respectively.

The average confidence level, describing the certainty of their own assessment, was 1.65 for the CT reconstruction and 1.66 for the conventional tomography. The results for conventional radiographs (0.83) and the axial CT cuts (0.77) were clearly lower (Table 10).

Discussion

The radiological investigation of odontoid fractures includes A/P and lateral as well as transoral radiographs of the cervical spine (Fig. 1). The lateral view alone is diagnostic in 80% of odontoid fractures [7]. Conventional tomography is still considered the standard investigation of choice for these injuries when a more detailed work-up is required to clarify a questionable radiograph or to gain a better understanding of the fracture pattern [6]. Although conventional tomography delivers excellent visualization of the bony details, a single examination takes 20–30 min [19]. During this period, the patient should lie in the lateral decubitus position to get the optimal picture quality [7]. This is difficult or even impossible for many patients during the acute work-up of an odontoid fracture [1]. The advantages of the conventional tomogram as an adjunct to the usual investigations for cervical spine injuries are well documented in the literature [17, 19]. Investigations by Ehara et al. have shown that in 6% of cases the odontoid fracture was not seen on conventional radiographs and could only be visualized using tomography [7]. In addition, they also found that the fracture pattern could be better visualized with the tomogram, giving important information for the selection of the best therapeutic intervention.

Over the last two decades, CT has established itself as the new standard diagnostic tool for fractures of the spine [1, 8, 10, 16, 17, 22].

CT offers excellent definition of osseous structures and facilitates positioning of the patient compared to conventional tomography [2]. The short data acquisition times, especially with the newer spiral scanners, as well as the possibility of reconstructing the image in any plane, are considerable advantages of computer-assisted tomography. In this fashion, the upper cervical spine can be scanned in less than 2 min. The steadily improving software allows easier and faster manipulation of the acquired data [11]. On a modern scanner (Siemens Somatom Plus 4), approximately 10 min are required to obtain 2D reconstructions in addition to the 2 min scanning time.

To date, there are no scientific studies to validate the effectiveness of CT as a diagnostic tool for upper cervical fractures in comparison to conventional tomography. Because of the technical advantages of CT, it is of great clinical significance to compare it to conventional tomography in terms of demonstrating the exact fracture pattern. In the past, CT has been criticised for the potential of missing fractures that happen to run in the axial plane exactly between two cuts [6]. With the more modern spiral scanning technique, however, the entire region to be examined is scanned in a screw-like fashion, so that no gaps appear between cuts. As it is not possible to print out a spiral shaped picture, some information is lost during the printing of the axial cuts. Because of this, many authors insist on sagittal reconstructions [5, 11, 15, 18]. Fractures in the axial plane that are not visible on the print out of the

Fig. 1A–H A 19-year-old patient suffered an Anderson type 3 odontoid fracture after a motor vehicle accident. All investigators judged the presence of the fracture in all four different diagnostic modalities as “certain yes”. **A, B** Conventional radiographs with transoral (**A**) and lateral (**B**) projections reveal a dislocation of the odontoid process. **C, D** Axial computed tomographic (CT) scans through C2 bone window settings demonstrate a fracture involving the base of the odontoid process and the body of the axis. **E, F** Reconstructed images in the coronal (**E**) and sagittal (**F**) planes clearly show the direction of the fracture. **G, H** Conventional tomograms in coronal (**G**) and sagittal (**H**) planes provide the same type of information

axial pictures are thus visualised on the sagittal or coronal reconstructions.

The widespread suspicion that the radiation dose of a CT examination exceeds that of a conventional tomogram investigation is unfounded. The radiation dose for each CT cut is 0.03–0.04 Gy. A maximum twofold increase in the total dose per surface area, independent of the number of segments scanned, can be delivered due to minimal radiation scatter [14]. In contrast, the dose per cut with the conventional tomography machine is 0.011 Gy. However, it is important to bear in mind that the radiation dose increases in an arithmetic fashion, since the entire cervical spine is exposed to an extensively scattered radiation beam for every cut. In this manner, the dose for ten cuts with the conventional tomography machine is 0.11–0.13 Gy. The dose to the thyroid gland is therefore much lower for a CT examination than for a conventional tomogram examination [1].

Movement of the patient during a CT investigation can lead to misinterpretation of the pictures. The distorted images can simulate fractures when there are none present [18, 21]. In the patient population presented in this study, conventional tomography was found to have a lower specificity than the reconstructions of the CT. An intact odontoid, therefore, would be judged as such with greater probability on the basis of a CT reconstruction.

The small number of patients in this study ($N=44$), has to be viewed critically. However, other studies have similarly small numbers of patients, ranging from 3–50, and most of these are retrospective in nature [5, 7, 8, 15, 18].

Another criticism of this study is the manner in which the actual diagnosis is made. The definitive proof of a fracture is the direct visualisation of the fracture. This is rarely possible during anterior screw fixation, since usually only the bottom border of C2 for the entry point is visualised intra-operatively. With a posterior approach, the fracture is not seen either. Additionally, some of the fractures did not require operative treatment. As far as radiological investigations are concerned, conventional tomography has been considered the gold standard to rule out a fracture [1, 13, 19]. Still, there are fractures where the conventional tomogram is not clearly diagnostic (Fig. 2). In such cases, all the imaging investigations have to be considered together. Therefore, for the purpose of this study, the definitive diagnosis was taken to be the collective consensus of the five observers after reviewing all investigations for each patient (standard radiography, conventional

Fig. 2A–D A 79-year-old woman sustained a minimally displaced Anderson type 3 odontoid fracture after a fall. **A** The lateral projection of the conventional radiographs do not reveal any significant abnormalities. None of the investigators diagnosed a fracture on this image. **B** A minimally displaced odontoid process fracture may be suspected on the lateral view of the conventional tomogram. All investigators rated the presence of a fracture as “probable”. **C** On the axial CT cuts, a displaced fragment is visible at the posterior border of the odontoid process. One out of five investigators failed to diagnose a fracture on this scan; the other four investigators judged the fracture as “probable”. **D** The scans of the sagittal CT reconstructions clearly visualize the direction of the fracture. This image was rated by all observers concerning the presence of a fracture as “certain yes”

therefore assume that axial CT shows best whether or not the fracture extends into the basis of the odontoid. The lack of diagnostic confidence on part of the observers appears to be secondary to the fact that the information presented by sequential cuts only offers limited reliability. The diagnostic certainty was clearly higher with CT reconstructions (1.65) as well as for conventional tomography (1.66). The exact fracture configuration is important in the therapeutic decision making process, since the specific operative intervention depends on the morphology of the fracture.

tomography, axial CT and CT with reconstructions). In 4 of the 44 patients, functional fluoroscopic examinations were performed to rule out a fracture [8]. In these four patients, no fracture was found, even on follow-up examination. MRI can also be used as a diagnostic modality when the diagnosis is in question [4].

In considering the results, the axial cuts gave the best interobserver agreement with the fracture classification, with a coefficient of correlation of $\kappa=0.804$. However, the observers had the least confidence in their diagnosis with this modality, with a confidence level of 0.77. One can

Conclusion

On the basis of this study, it was demonstrated that a diagnosis of an odontoid fracture can be made using computer tomography, including sagittal and coronal reconstructions, with the same diagnostic certainty as using conventional tomography. Taking all factors into consideration, including radiation exposure and technical feasibility, one can conclude that CT with 2D reconstructions can replace conventional tomography as the gold standard in the diagnosis of odontoid fractures.

References

1. Acheson MB, Livingston R, Richardson ML, Stimac GK (1987) High-resolution CT scanning in the evaluation of cervical spine fractures: comparison with plain film examinations. *AJR* 148: 1179–1185
2. An HS (1998) Cervical spine trauma. *Spine* 23:2713–2719
3. Anderson LD, D'Alonzo RT (1974) Fractures of the odontoid process of the axis. *J Bone Joint Surg Am* 56: 1663–1674
4. Blacksin MF, Avagian P (1999) Computed tomographic and magnetic resonance imaging of chronic odontoid fractures. *Spine* 24:158–161
5. Castillo M, Mukherji SK (1996) Vertical fractures of the dens. *Am J Neuroradiol* 17:1627–1630
6. Clark CR, White AA (1985) Fractures of the dens. A multicenter study. *J Bone Joint Surg Am* 67:1340–1348
7. Ehara S, el Khoury GY, Clark CR (1992) Radiologic evaluation of dens fracture. Role of plain radiography and tomography. *Spine* 17:475–479
8. Greene KA, Dickman CA, Marciano FF, Drabier JB, Drayer BP, Sonntag VK (1994) Transverse atlantal ligament disruption associated with odontoid fractures. *Spine* 20:2307–2314
9. Greene KA, Dickman CA, Marciano FF, Drabier JB, Hadley MN, Sonntag VK (1997) Acute axis fractures. Analysis of management and outcome in 340 consecutive cases. *Spine* 22: 1843–1852
10. Jonsson H, Cesarini K, Sahlstedt B, Rauschning W (1994) Findings and outcome in whiplash-type neck distortions. *Spine* 19:2733–2743
11. Kaiser JA, Holland BA (1998) Imaging of the cervical spine. *Spine* 23:2701–2712
12. Lienert GA (1995) Cohens Kappa. In: *Verteilungsfreie Methoden der Biostatistik*, vol 2. Springer, Berlin Heidelberg New York, pp 636–643
13. Maravilla KR, Cooper PR, Sklar FH (1978) The influence of thin-section tomography on the treatment of cervical spine injuries. *Radiology* 127:131–139
14. Maue-Dickson W, Treffer M, Dickson DR (1979) Comparison of dosimetry and image quality in computed and conventional tomography. *Radiology* 131:509–514

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15. Nepper-Rasmussen J (1989) CT of dens axis fractures. *Neuroradiology* 31: 104–106
 16. Rizzolo SJ, Vaccaro AR, Cotler JM (1994) Cervical spine trauma. *Spine* 19:2288–2298
 17. Robotti GC, Steinsiepe K, Geissmann A (1986) Computertomographie bei Verletzung der Halswirbelsäule. *Rontgen BI* 39:19–32
 18. Rubinstein D, Escott EJ, Mestek MF (1996) Computed tomography of minimally displaced type II odontoid fractures. *J Trauma* (40):204–210
 19. Russin LD, Guinto FC (1976) Multidirectional tomography in cervical spine injury. *J Neurosurg* 45:9–11
 20. Schröder RJ, Vogl Th, Hidajat N, Schedel H, Südkamp N, Felix R (1995) Comparison of diagnostic value of CT and MRI in injuries of the cervical spine. *Aktuelle Radiol* 5:197–202
 21. Sutterlin CE, Gutentag I, Martinez CR, Rehtine GR (1989) False-positive diagnosis of an odontoid fracture by CT scan. *J Orthop Trauma* 4:348–351
 22. Weisskopf M, Hoffmann R, Südkamp NP, Haas NP (1996) Dens Fraktur und Mehrfachverletzung der Brustwirbelsäule nach Sturz aus großer Höhe. Diagnostischer Standard. *Unfallchirurgie* 99:520–524