

Experimental investigation of the axis dens fracture

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Vertebra C2 causes numerous difficulties in post-traumatic stabilization because of a special character of injury resulting from its untypical structure due to its function. Understanding of the mechanism of C2 vertebra injury has a crucial importance for the treatment process and also for the development of new stabilization techniques in C2 vertebra dens (odontoid process) breakage. A series of endurance tests has been carried out to determine the value of force which breaks a vertebra dens and the character of a resulting breakage. The tests were carried out with the use of a material testing machine for nine section preparations. Cause and effect-type connections have been established between the results obtained and individual features of the vertebrae tested. The recognition of the value of injuring force makes predicting the occurrence of C2 vertebra injury resulting from a simulated bending mechanism possible.

Key words: cervical spine, strength analysis, odontoid fracture

1. Introduction

Most of spine injuries occur in the neck part. This segment is subjected to significant fatigue overload as well as immediate overload, thus it is highly prone to injuries [1].

Of all vertebrae it is C2 that is crucial for the rotating movement of a head and therefore the most overloaded with cyclical movements of a head. The research on vertebra C2 should be carried out because it is difficult to diagnose the injuries to the upper neck segment of the spine and the life-threatening neurological complications that accompany them [2]. An axis also causes difficulties in post-traumatic stabilization due to a special character of such an injury accompanied by untypical structure of the axis. In comparison with lower vertebrae its body is longer in the upwards direction where it forms a process called the odontoid process (dens). It is around the dens where the rotating movement of a head is made (figure 1).

The key question is determining the value of force which breaks the odontoid process. It will be determined based on the most common, the so-called bending mechanism.

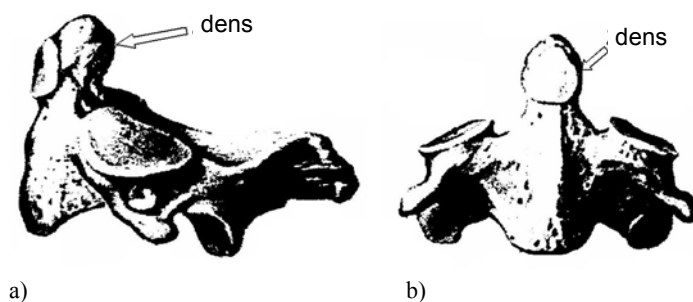


Fig. 1. The axis (C2) vertebrae: a) lateral (side) view, b) anterior (front) view [3]

A typical injury to vertebra C2 is a breakage of a dens, its localisation may vary [4]. A commonly used classification of breakages was made by Anderson and D'Alonzo who divided them into three types, depending on the course of breaking slit (figure 2):

- type I – when the upper part of a dens is broken and a slit runs diagonally from the dens top to the side;
- type II – when a dens is broken at the base, right over the place where it is connected with the axis vertebral body;
- type III – when the breakage occurs in the upper part of the axis vertebral body, the breakage lines often encompass the superior articular process.

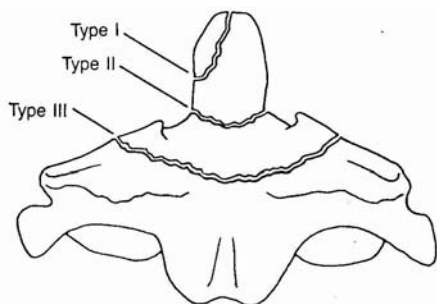


Fig. 2. The classification of odontoid process fracture [5]

Type I is rarely recognized due to its stable character [4]. Type II, the most common, is characterised by instability which usually has to be treated by an operation. Type III, a less common, due to a large break surface is characterised by high stability.

An injury to vertebra C2 dens is most often caused by traumatic forces in the apical-occipital area [2]. Thus, based on the direction of the forces involved, the breakages of axis dens can be divided into the following types:

- extension breakages – when the force causing an injury is exerted on the front side of vertebrae bodies;
- flexion breakages – when the force causing an injury is exerted on the back of a head;
- breakages without a displacement – when injury-causing forces of compression–rotation type prevail.

Statistically the injuries to vertebra C2 most often result from the extension mechanism (flexion type is less common) [4]. Then an injury force is exerted on the front arch of atlas C1 [2]. This way an axis dens is encompassed by an atlas arch, broken below the said arch and displaced backwards in relation to vertebra C2 body along the arch (figure 3). In other words, a dens is “cut off” by the atlas arch. Such an injury mechanism was copied in as much detail as possible in the experimental research.

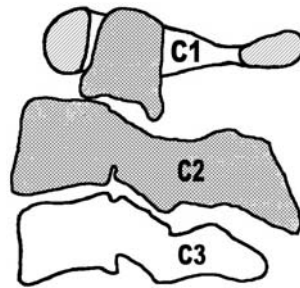


Fig. 3. Schema of an odontoid process fracture in extension mechanics [2]

Biomechanical examination of the axis breakage process belongs to the tasks rarely performed. A breakage endurance of vertebra C2 was tested by TEO et al. [6], who examined breakages due to hyperextension mechanism. In the analysis, however, geometrical features of the preparations examined were not taken into account.

Nevertheless such investigations have been carried out rather exceptionally and the majority of works relate to clinical analysis of existing injuries [7], [8], [9].

This is why the research deals with determining of the value of a force which breaks the vertebra odontoid process (from the bending mechanism) and the character of the resulting breakage. Additionally, a correlation between the value of a force causing injury to an axis dens and its geometric characteristics was sought.

2. Materials and methods

The research was conducted on nine section preparations of the human vertebrae C2 (table 1). Taking into consideration the origin of the materials, the series can be considered to be numerous. The preparations were kept in a double foil package at the temperature of $-20\text{ }^{\circ}\text{C}$. Before the analysis they were defrosted at room temperature and next soft tissues were removed without any damage to bone structure.

Table 1. The data of the specimens analysed

Specimen	Gender	Age
1	M	–
2	M	–
3	M	35
4	M	–
5	M	67
6	F	–
7	M	–
8	M	58
9	M	37

In order to analyse the effect of geometric properties of the vertebra on its capability of dislocating the force over the vertebra dens, four significant parameters were established (figure 4 and table 2).

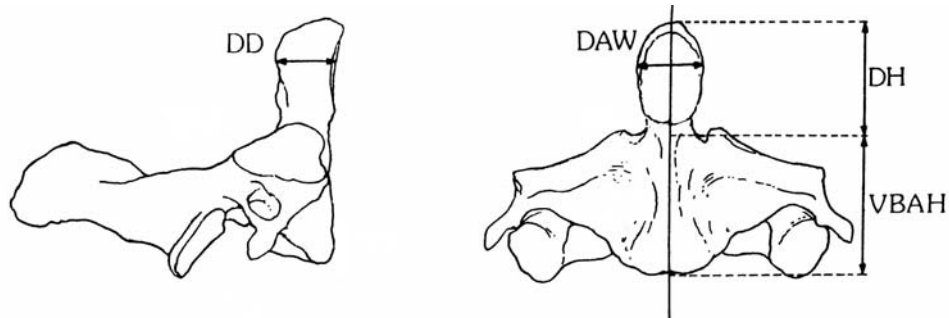


Fig. 4. Geometrical parameters of C2 vertebra: DD – dens diameter, DAW – dens maximum width, DH – dens height, DH + VBAH – total vertebra anterior height [10]

Table 2. Geometrical parameters of C2 vertebrae and the destructive strength F

Specimen	DD [mm]	DAW [mm]	DH [mm]	DH+VBAH [mm]	Destructive strength F [N]
1	13.60	12.50	19.90	40.60	1330
2	12.05	10.50	19.50	37.50	1210

3	12.60	10.40	19.70	43.50	1146
4	14.50	11.00	21.00	44.70	1493
5	13.05	10.25	20.25	40.45	1163
6	11.85	11.55	20.35	38.00	1473
7	14.80	11.90	22.85	48.20	1492
8	12.10	11.05	20.90	44.15	1057
9	11.20	11.10	21.50	45.60	717

The values of distinguished individual geometric features of preparations (DD – dens diameter, DAW – dens maximum width, DH – dens height, DH + VBAH – total vertebrae anterior height) do not deviate from statistical average values being published [11].

Endurance test was carried out with a material testing machine MTS MiniBionix 858. Elements enabling a proper assembly and load of preparations were designed for this purpose.

The examined vertebrae “armed” with screws were placed in the rings filled with polyester. When the filling set, the whole preparation was fixed with four screws to a special bed (figure 5), which enabled its mounting on an endurance machine.

The ninth preparation was examined first with the use of a punch with sharp edges, which resulted in cutting off an axis dens and not in the forecasted breakage. The other vertebrae were examined after the punch was modified (figure 5). In such a case, the edges were rounded and the working surface mapped the shape of a dens fovea of C1 vertebra arch (under anatomic conditions it collaborates with the frontal joint plane of a vertebra dens C2). Additionally, the working part of a punch was coated with silicone rubber.

The remaining eight preparations were examined on the stand prepared in the same manner as described, which ensured stable, inflexible fastening (figure 5).

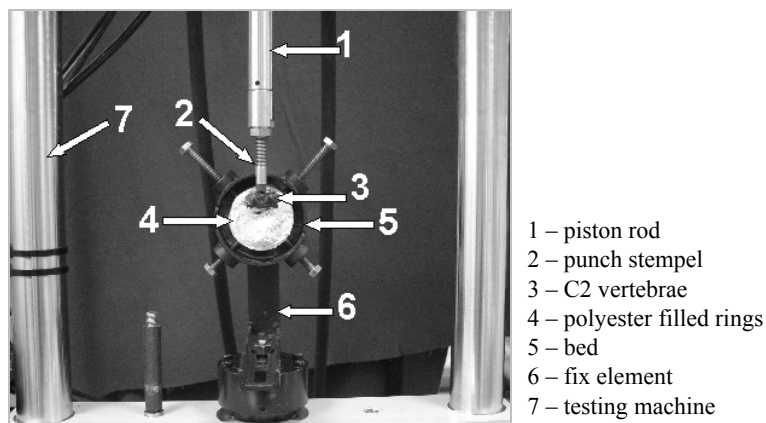


Fig. 5. The photo of set up

The experimental analysis was based on certain simplifications. The ligament apparatus collaborating with the vertebra dens was not represented, because its reproduction was too complex. It would be necessary to select it from among numerous anatomic connections; at first, however, one would have to establish the criteria for this selection, which was a troublesome task. Another problem would be the material and simulation of ligament connections. Thus the research was restricted to detailed mapping of the plane which exerts pressure directly on a vertebra dens and it was on this plane that the total value of load was concentrated, so the ligaments which also work in reality were disregarded. The load was placed directly by the punch made for the purpose. This element exerted pressure on the joint plane of a dens in its frontal part, exactly like in the case of the collaboration between vertebrae C1 and C2 in the most common injury of an axis, the so-called extension mechanism. The punch offset depended on the anterior position of facies articularis of an individual specimen. The value of force was increased until a breakage took place, while the machine was working in the mode of dislocation control at the velocity of 1 mm/min. So the research had quasi-dynamic character.

3. Analysis of results

In the course of analysis, a decision was made to reject the examination results of the ninth preparation, because the punch cut off the dens and did not cause the forecasted breakage of this preparation. The value of the force generated this way made only 52% of the maximum value of force measured for the other preparations examined with a modified punch.

The dependence of a force causing a breakage (damaging) F on the vertebra dens dislocation d was determined. It proved to be similar for all preparations. The characteristic curve representing this dependence is almost linear in the upper range of a damaging force and after exceeding its maximum value (i.e. after the breakage) it declines abruptly, so its shape resembles a typical shape of the curve for brittle material compression (figure 6).

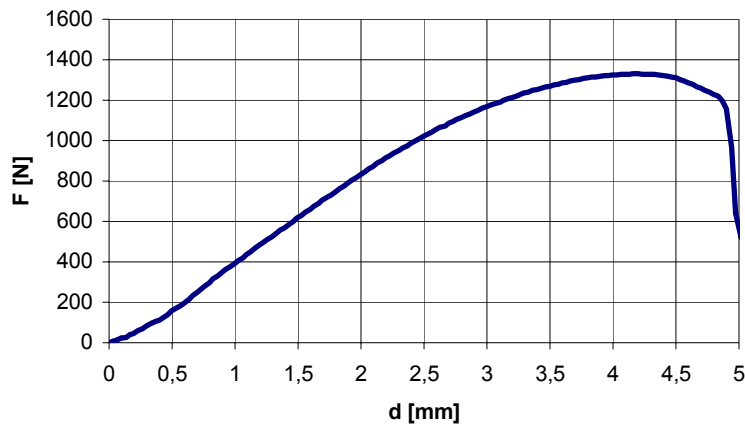


Fig. 6. Example of characteristic load–displacement curve recorded during one strength test

Maximum values of the corresponding parameters F and d and a breakage type for particular preparations were defined (table 3).

Six cases of the breakage of type II, which are most common in clinical practice, as well as two cases of breakage of type III were registered (figure 7). Maximum values of a force breaking vertebra C2 dens showed quite a significant discrepancy: from 1057 N to 1493 N (1295 N on an average), hence the difference was 29%. The values of the punch dislocations corresponding to maximum values of the damaging forces (at the breakage moment) are in the range of 3.26 mm–6.60 mm (4.55 mm on an average).

Table 3. The maximum values of destructive strength F and conventional stiffness coefficient C^*

Specimen	F [N]	C^* [N/mm]	Type of fracture
1	1330	451	II
2	1210	365	II
3	1146	432	III
4	1493	311	III
5	1163	391	II
6	1473	450	II
7	1492	362	II
8	1057	393	II
9	717	345	–

The slope of the curve representing linear regression for the initial, linear and established characteristic range was determined as well. Thus a parameter called a *con-*

ventional stiffness coefficient C^* (described by dimension N/mm) was introduced. It is valid for the linear range of characteristic elasticity (table 3).

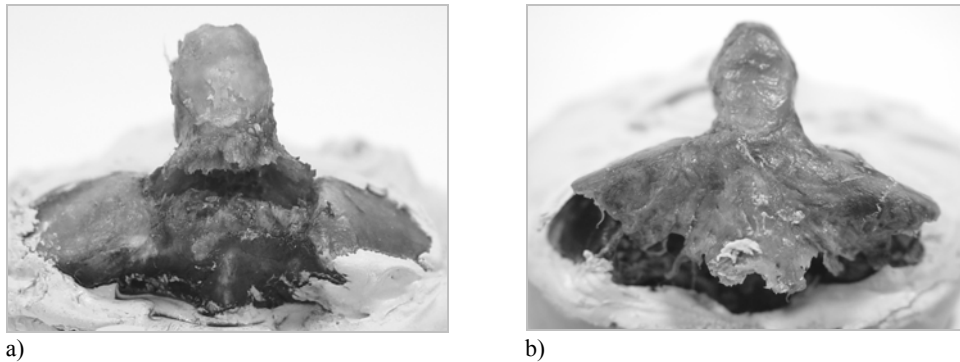


Fig. 7. The photos of vertebra C2 fracture: a) type II, b) type III

Maximum values of the damaging force F for all preparations are gathered in the form of a graph, where Roman numerals stand for a recognized breakage of types (II or III), while Arabic numerals (1–9) stand for specimen number (figure 8).

The dependence of a damaging force on the geometric parameters of vertebrae was determined as well (figure 9).

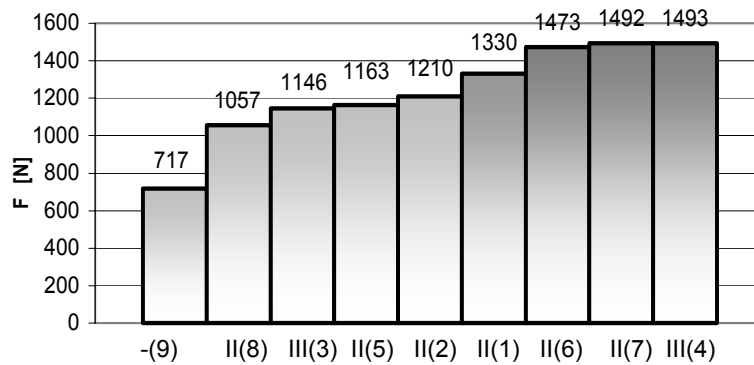


Fig. 8. Histogram of the maximum values of destructive strength (II–III – type of fracture, 1–9 – specimens)

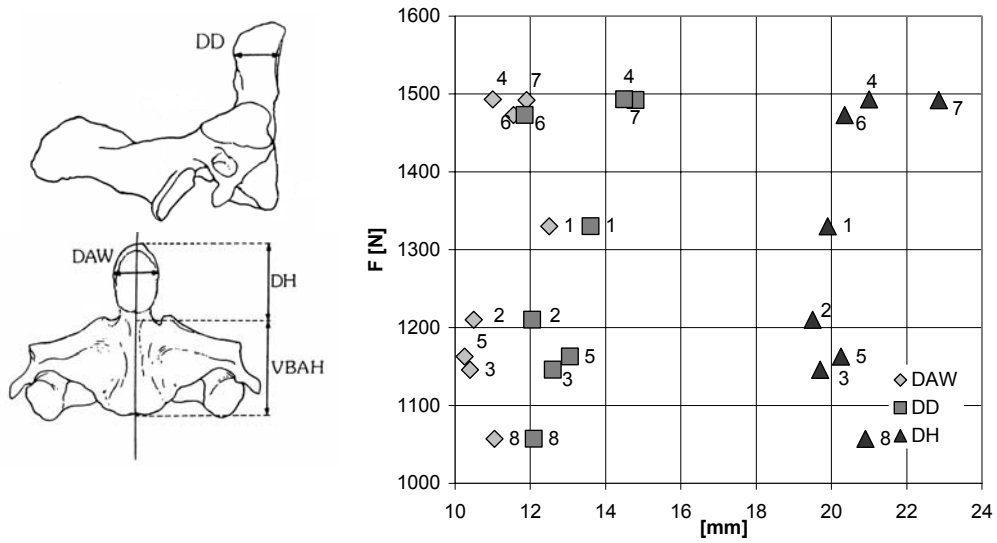


Fig. 9. Relationship between the destructive strength F and the geometrical parameters of vertebrae C2 (1–8 specimens)

The relationship between the conventional stiffness coefficient C^* and the corresponding maximum value of force P for the linear section of the preparations characteristics being examined is shown in figure 10.

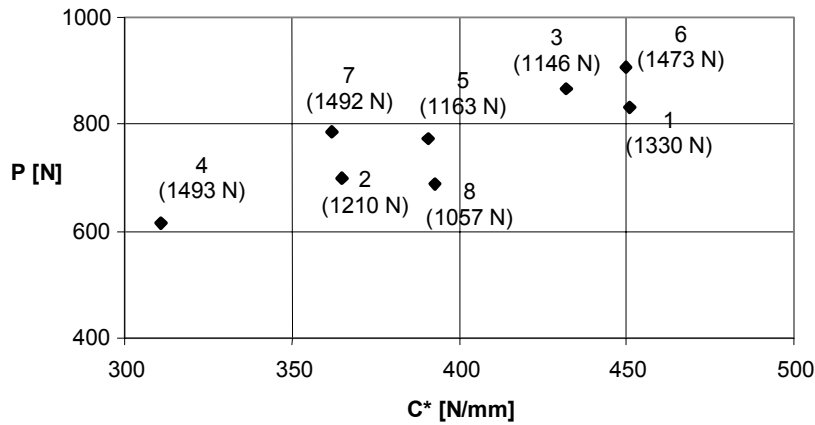


Fig. 10. The relationship between maximum values of the destructive strength P (linear segment of load–displacement curve is analysed) and the conventional stiffness coefficient C^*

4. Discussion and conclusions

Endurance tests made it possible to determine the value of the force breaking a dens of vertebra C2. The values obtained showed quite significant variation in particular preparations: from 1057 N to 1493 N (1295 N on an average), which is equivalent to 29% difference (figure 8). The values of endurance machine punch dislocation corresponding to maximum values of damaging forces (at the moment of breakage) fall in the range of 3.26 mm–6.60 mm (4.55 mm on an average, table 3). The range of the values obtained allows us to compare them with the values from previously published papers, but without taking into account other dependencies such as geometric characteristics of vertebrae [6].

Based on the endurance tests and measurements of geometric parameters of preparations we can conclude that the resistance of axis dens to breakage in the frontal plane (just like in the most common injuries to vertebra C2) is proportional to its width in saggital plane (DD) which has a considerable influence on the dens rigidity. The other geometric values such as dens width in frontal plane (DAW) or height (DH) do not seem to have any direct effect on the ability to dislocate force by the axis odontoid process (figure 9).

The introduced stiffness parameter C^* that affects a linearly elastic range of characteristics cannot be connected with the value of corresponding force P (figure 10) or maximum damaging force F in a mathematical relation.

Thus, taking into account the above results we can support the thesis that the difference in results for particular preparations and thus the differences in vertebra C2 resistance to breakage are dependent mainly on the structure of the latter and bone tissue properties of individual vertebrae. Unfortunately, on the basis of the research conducted, it is not possible to prove directly that there are connections between bone tissue structure and vertebrae resistance to breakage.

However, if we treat vertebra C2 as one of autonomic construction elements of a spine, we must admit that axis dens is capable of standing an elastic strain (at quasi-dynamic load) up to about 2.5 mm.

As a result of the research, in two cases breakages of type III were obtained, and in six cases – breakages of type II. Breakage of type II is the most common injury to vertebra C2 in clinical practice. It is usually a consequence of road accidents [3]. Breakage of type I did not take place, because such a breakage is the least frequent in clinical practice. This situation may prove that the mechanism of injury was reflected precisely. However, we did not find correlation between any evident geometric parameter and the fracture type.

There are plans to continue this research in the future and to extend it to a dynamic aspect.

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