The development of the axis vertebra: the key to a topographic classification of dens fractures

Matthias Gebauer · Michael Amling

Accepted: 23 September 2008 / Published online: 23 October 2008
© Springer-Verlag 2008

Concerning: Gebauer et al.: Subdental synchondrosis and anatomy of the axis in aging: a histomorphometric study on 30 autopsy cases. *Eur Spine J* 15(3):292–298, 2007.

Dear Editor,

Again, it is a great pleasure to answer to the response to the above-mentioned letter that was sent to the Journal editor in response to our recent paper by Gebauer et al. published in *Eur Spine J* entitled 'Subdental synchondrosis and anatomy of the axis in aging: a histomorphometric study on 30 autopsy cases' [9].

In their initial reply letter to the editor concerning our histomorphometric investigations on the subdental synchondrosis, Wang and coworker claimed that the three regions of the axis, namely, the dens, the basis of the dens and the corpus of the axis analyzed in our study have been incorrectly characterized.

On the basis of their CT and MRI studies, Wang and coworker came to the conclusions that (1) the basis of the dens has to be located between the level of the transverse ligament and the superior articular facets of the axis and that (2) the remnants of the subdental synchondrosis located below the level of the C1–C2 articulation must be located at the center of the axis body.

This reply to the letter to the editor refers to the article.
doi:[10.1007/s00586-008-0808-5](https://doi.org/10.1007/s00586-008-0808-5).

M. Gebauer · M. Amling
Center for Biomechanics and Skeletal Biology,
University Medical Center Hamburg-Eppendorf,
Hamburg, Germany

M. Gebauer · M. Amling (✉)
Department of Trauma-, Hand-, and Reconstructive Surgery,
University Medical Center Hamburg-Eppendorf,
Hamburg, Germany
e-mail: amling@uke.uni-hamburg.de

Thus, to convince the authors of the fact that their observations were incorrect, our previous reply letter contained a brief summary of the development of the axis [8].

Reading the response to our former reply letter we are now somehow surprised, as Wang and coworker do not seem to really comprehend the developmental issue. And again they are presenting false assertions writing '...Although there is no distinctively description of the exactly border of the axis body, we can at least know that the bony structure below the upper surface articulations of C2 belongs to the axis body. And this is generally accepted by clinical, radiological and morphological experts...'.

We are now delighted to end the discussion by giving a short overview of some significant publications on morphological aspects of the development of the axis vertebra.

First reports on the development of the axis date back to the 1950s [4, 5]. In 1952, Bailey described five primary ossification centers for the axis, all of which are present at birth [4].

By v. Torklus and Gehle's extensive studies on the upper cervical spine and its regional anatomy as well as pathology in the late 1960s, the development of the axis and by this the exact border of the axis body have been accurately defined [14–16]. They gave a detailed description on the ossification of the axis from five centers. (1) From the second fetal month on two postero-lateral centers form the arch of the axis by perichondral ossification. With their anterior expansions, both these postero-lateral centers contribute to the ossification of the vertebral body. (2) From the fifth fetal month on one median ossification center forms a significant portion of the osseous vertebral body. (3) Also from the fifth fetal month on two primary ossification centers emerge cranial of the median ossification center of the vertebral body. These two centers form

Fig. 1 **a** Frontal macroscopic view of a human axis specimen. **b** Frontal reformatted CT image of a typical 'subdental fracture'. Note that the fracture line in its most caudal point (green dotted line) reaches the basis of the dens. The fracture line almost touches the subdental synchondrosis located within the basis of the dens axis. The two white lines define the region between the level of the transverse ligament and the superior articular facets. Referring to v. Torklus and Gehle, this region is the neck of the dens (see **d**) and not the basis of the dens as it has been repeatedly stated by Wang and coworker. **c** According to Anderson and D'Alonso [3], the fracture in **b** would have been classified as a type III fracture. **d** Topography of the axis derived from its development as first described by v. Torklus and

Gehle [14–16]: 1 tip of the dens, 2 neck of the dens, 3 basis of the dens, 4 corpus of the dens. Note that the basis of the dens is obviously inferior located as it was assumed by Wang. In consideration of this topography, the classification of dens type III fractures by Anderson and D'Alonso [3] is questionable, as this fracture type specifies rather a dentobasal fracture than a fracture of the body or the corpus of C2. **e** Coronal (left panel) and sagittal (right panel) MR image of an adult axis from [6]. The subdental synchondrosis can be imagined by magnetic resonance tomography as a hypointense ring. Note the localization of the subdental synchondrosis well below the level of the superior articulating facets

the dens axis by cranial directed ossification, and they remain separated from the ossification center of the vertebral body by the subdental synchondrosis.

In particular, we would like to point at v. Torklus and Gehle's observation that the dividing line between the dens and the corpus of the axis—the subdental synchondrosis—is *not* located at the medial border of the superior articular facets of the axis, as it has been repeatedly stated by Wang et al. In fact, during development the dens together with the subdental synchondrosis countersink into the corpus of the axis. Accordingly, v. Torklus and Gehle regarded the part of the dens surrounded by the corpus of the axis as being an *independent anatomical structure*, which they named the *basis of the dens* (see additional Fig. 1a–d) [14, 16].

Consecutively, these findings have been confirmed by a number of researchers [1, 2, 7, 10, 11, 13]. Since these early observations it has been generally accepted that the subdental synchondrosis is a bipolar growth zone that contributes to the overall heights of the basis of the dens as well as of the vertebral body, and that it is consistently located below the level of C1–C2 articulation.

Finally, we would like to refer to a recent publication on the remnants of the subdental synchondrosis in adults by Cokluk et al. [6]. On the basis of 66 sagittal and coronal MR-images of the upper cervical spine of pediatric and adult individuals Cokluk and coworker again confirmed the

topography of the axis as described by v. Torklus and Gehle. They found that the remnant of the subdental synchondrosis can be imagined by magnetic resonance tomography as a hypointense ring. They further demonstrated that the subdental synchondrosis is located well below the level of the superior articulating facets (see Fig. 1e).

In summary, these topographic particularities of the axis vertebra and the subdental region lead to the necessity to reconsider the classification of dens type III fractures by Anderson and D'Alonso, as type III fractures are not inevitably fractures of the body or the corpus of C2 rather than fractures of the basis of the dens.

We thank the authors for this interesting discussion on the particularities of the subdental region of the axis.

References

1. Amling M, Hahn M, Wening VJ, Grote HJ, Delling G (1994) The microarchitecture of the axis as the predisposing factor for fracture of the base of the odontoid process: a histomorphometric analysis of twenty-two autopsy specimens. *J Bone Joint Surg Am* 76(12):1840–1846
2. Amling M, Pösl M, Wening VJ, Ritzel H, Hahn M, Delling G (1995) Structural heterogeneity within the axis: the main cause in the etiology of dens fractures: a histomorphometric analysis of 37

- normal and osteoporotic autopsy cases. *J Neurosurg* 83(2):330–335
3. Anderson LD, D'Alonzo RT (1974) Fractures of the odontoid process of the axis. *J Bone Joint Surg Am* 56(8):1663–1674
 4. Bailey DK (1952) The normal cervical spine in infants and children. *Radiology* 59:712–719
 5. Blockley NJ, Purser DW (1956) Fractures of the odontoid process of the axis. *J Bone Joint Surg Br* 38:794–817
 6. Cokluk C, Aydin K, Rakunt C, Iyigun O, Onder A (2006) The borders of the odontoid process of C2 in adults and in children including the estimation of odontoid/body ratio. *Eur Spine J* 15(3):278–282
 7. Dai L, Yuan W, Ni B, Jia L (2000) Os odontoideum: etiology, diagnosis, and management. *Surg Neurol* 53(2):106–108
 8. Gebauer M, Amling M (2008) Reply to the letter to the editor concerning Gebauer et al. subdental synchondrosis and anatomy of the axis in aging: a histomorphometric study on 30 autopsy cases. *Eur Spine J* 15(3):292–298
 9. Gebauer M, Lohse C, Barvencik F, Pogoda P, Rueger JM, Püschel K, Amling M (2006) Subdental synchondrosis and anatomy of the axis in aging: a histomorphometric study on 30 autopsy cases. *Eur Spine J* 15(3):292–298
 10. Gebauer M, Barvencik F, Beil FT, Lohse C, Pogoda P, Püschel K, Rueger JM, Amling M (2007) Subdental synchondrosis: computed tomographic and histologic investigation on morphological aspects of fracture at the base of the dens in 36 human axis specimens. *Unfallchirurg* 110(2):97–103
 11. Hubbard DO (1974) Injuries of the spine in children and adolescents. *Clin Orthop* 100:56–65
 12. Ogden JA (1984) Radiology of postnatal skeletal development: XII. The second cervical vertebra. *Skeletal Radiol* 12(3):169–177
 13. Sherburn EW, Day RA, Kaufman BA, Park TS (1996) Subdental synchondrosis fracture in children: the value of 3-dimensional computerized tomography. *Pediatr Neurosurg* 25(5):256–259
 14. Torklus D, Gehle W (1968) Das Os odontoideum als Okzipitalwirbelmanifestation. *Radiol Clin Biol* 37:321
 15. Torklus D, Gehle W (1969) Neue Perspektiven der Entwicklungsstörungen der oberen Halswirbelsäule. *Z Orthop* 105:78
 16. Torklus D, Nicola T (1972) The upper cervical spine: regional anatomy pathology and traumatology. Thieme, Stuttgart