Spinal Stenosis C1-2 Following Redo Surgery For Failed Odontoid Screw Fixation - Scrutinizing The Odontoid Fracture Classification

H Koller, V Kammermeier, A Assuncao, U Holz

Introdution
Posttraumatic cervical stenosis after malunion of an axis fractures is a rare but frightening entity. We present a case in which redislocation of a fracture of the axis body, supposed to as unstable odontoid type III fracture, was observed after anterior screw fixation causing asymptomatic spinal cord compression C1-2. Treatment modalities and a critical review of literature is proposed scrutinizing the lack of a comprehensive classification for fractures of the axis body and odontoid.

Case Report
In February 2004, a lady at the age of 39 driving home from work lost control of her car which overturned. She was admitted to a hospital and was diagnosed with an alleged unstable odontoid type III fracture according to the classification of Anderson and D’Alonzo (Fig.1).
Figure 1
The initial lateral X-ray depicted a slightly displaced oblique fracture of the axis body with posterior-anterior fracture course. It was diagnosed as unstable odontoid type III fracture.

She was treated with anterior odontoid screw fixation (Fig. 2) and the early clinical course was uneventful.

Figure 2
Postoperative X-ray after single lag-screw osteosynthesis depicted screw abutment at the disc space C2-3 and nonanatomic fracture reduction.

Four weeks later, without any further trauma, she came back to that hospital complaining about severe neck pain. As the fracture line transected in a vertical plane posteriorly to anteriorly, the lag screw and the proximal odontoid-corpus fragment became loose and shifted downwards, anteriorly to the axis vertebra (Fig. 3).
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Figure 3
Figure 3: Four weeks after odontoid screw fixation secondary displacement with slipping of the proximal fragment on the fixed distal fragment occurred, associated with cut-out of the odontoid screw.

To correct the painful malalignment and instability C1-2, an unusual anterior retropharyngeal fusion C2-3 using cancellous bone graft was performed. For buttress a constrained plate was utilized (Fig. 4 and 5).

Figure 4
Figure 4 & 5: Anterior revision surgery with removal of the odontoid screw and uncommon anterior fusion C2-3 was performed. Anatomical reduction was not achieved anymore and spinal stenosis C1-2 remained. Additionally, the patient was placed in a halo vest.
With the fibrous tissue between the fragments an anatomical reduction C1-2 could not be achieved anymore. Additionally, a halo vest was applied after the operation. As there was no definitive decision whether the fracture healed after 3.5 months, the patient was referred to our institution. The patient presented a left-sided Horner-syndrom existing since her first operation, posttraumatic decreasing paraesthesias of both hands, and after removal of the halo vest she showed significant weakness of posterior neck muscles as well as bulky scars at the pin-sites. There were no neurological signs of spinal cord compromise at that time. The CT- and MRI images performed depicted partial osseous fusion within the axis, partial fusion of the spondylodesis C2-3, and a fixed subluxation of the left lateral mass as well as an unchanged stenosis of the spinal canal at the level of the posterior axis wall and anterior ridge of the posterior atlas arch (Fig.6 and 7).
Figure 8
Figure 8 & 9: T2-weighted MRI-images depicted spinal stenosis C1-2 with hourglass-shape of the spinal cord inferior to the atlas arch, but without abruption of liquor space. There were no visible morphological signs of early myelophatic changes of the spinal cord.

Figure 10
Figure 10 & 11: CT with passive flexion and extension did not demonstrate dynamic spinal stenosis C1-2.

After halo removal, a semirigid collar was applied and rehabilitation started. To access the quality of progressed osseus consolidation C2 and stability of the anterior fusion C2-3, a dynamic CT was performed (Fig.10 and 11).
It demonstrated neither instability nor dynamic stenosis C1-2. To exclude pathologic changes of the spinal cord a MRI was done (Fig.8 and 9).

While it revealed atlantoaxial incongruency to some degree the sagittal stenosis C1-2 measured 7mm and a.p./transverse compression-ratio measured 0.61, whereas there was no abruption of liquor space. The neurophysiological examination demonstrated normally evoked nerve potentials. During physiotherapy, the patient achieved decreased pain levels during range of motion of the cervical spine under close inhospital observation, and her muscle atrophy slowly decreased. In consultation of the neurosurgeons and other colleagues no operative intervention was indicated at this time. The patient was released with close follow-up. After six months, she showed albeit painfree, but restricted range of motion, and no change in neurophysiological testings. After regaining better cervical muscle strenght, finally we performed a dynamic MRI to exclude functional spinal cord compression C1-2. As depicted in figure 12 and 13, there was no increase of spinal stenosis.
A prophylactic laminectomy and/or anterior redo surgery with implant removal, decompression and reconstruction, as well as its associated risks were discussed with our patient. As the patient denied any further surgery, she was discharged into close follow-up once a year, remained free of symptoms, and still denied prophylactic surgery.

In our terms, in the early setting this patient with a shearing fracture inside the axis vertebra should have undergone anatomic reduction and manually performed dynamix x-rays. If there would have been no interfragmentary instability, a semirigid collar is supposed to maintain fracture reduction and offer uneventful osseous union. If instability would have been present, an anterior odontoid screw fixation with a T-shaped buttress plate or fusion C1-2 would have been indicated. Apart good experiences with this algorithm, the evidence behind is to be scrutinized.

**DISCUSSION**

Within axis fractures odontoid ones are the most common (59%, [18]). Reviewing reports in literature which address the treatment options for odontoid fractures type II, type III, and fractures of the vertebral body C2 (VB-C2), there is a trend towards operative stabilization of type II fractures, which show an incidence of non- or fibrous-union of about 50-60% with conservative treatment [11,13,21,64,82,105]. Respecting fusion rates and potential pitfalls such as rupture of the transverse atlantal ligament (TAL) or a shearing fracture line [13,20,34,69,82,108], particularly anterior screw fixation in odontoid fractures type II, which avoids fusion C1-2, seems to be the golden standard. It results in primary stability in the vast majority [11,13,21,64,82,105], and osseous union occurs in up to 90% [11,23,64]. However, due to a lack of definition of remaining stability in various subtypes of odontoid type III fractures and fractures of the VB-C2, respectively, the indications for surgery in these fractures is not clarified until now [64].

**SURGICAL INDICATIONS FOR THE TREATMENT OF SPINAL STENOSIS C1-2**

A review of literature demonstrated that within all spinal cord injuries (SCI) of the upper cervical spine, odontoid lesions, and especially type III ones, contribute a minor part (0.3%) [18]. In the largest single institution series, Kathrein et al. from Innsbruck observed acute SCI in 13% (n=31) of 234 odontoid fractures. 10 were type III fractures [84]. Dai et al. reported about non-union in 51 odontoid type II and six type III fractures following conservative treatment. He observed secondary neurological impairment in 50 patients [29]. Also Rudzkie et al. reported on a late-onset myelopathy due to a conservatively treated odontoid type II fracture with symptomatic displaced non-union after 39 years [92]. Nevertheless, clinically manifested cervical myelopathy (CM) due to malunion of an odontoid or VB-C2 fracture with spinal stenosis C1-2 is a rare sequela, more often being discussed on the basis of congenital malformations C1-2 [13,20,34,69,82,104]. The combination of repeated hypoxia and impaction may be factors for development of CM [53]. Due to the scarcity value of our illustrative case the indications for revision of a malunited fracture of the VB-C2 with cervical stenosis in an asymptomatic patient was questioned:

Kerschbaumer et al. indicates operative revision in case of atlantoaxial kyphosis with persistent pain, neurological compromise and instability. If posterior atlanto-dental intervall is ≤14mm, or spinal cord stenosis is ≤6mm in dynamic flexion, there is also indication for revision [62]. Retrospective case reports concerning stenosis C1-2 due to nontraumatic diseases showed long-term onset of CM in patients, in which the spinal canal sized ≤ 7 to 8 mm. However, also in a selected review of literature patients with a sagittal diameter C1-2 of less and above 10 mm showed clinical manifestations of CM [46,69,72,77,92,104]. In a retrospective study on late-onset and progressive myelopathy secondary to
odontoid fractures by Crockard et al., cord ap-diameter ranged between 3.7-7mm (type II, n=15; type III, n=1) [8], whereas it did not change significantly between flexion and extension in dynamic CT-images or X-rays. There was no close relationship between the size of the spinal cord and clinical disability, but there was a close correlation between time delay to diagnosis. The implication behind this observation was, that non- or even mal-united odontoids may continue to damage the spinal cord which escaped primary insult. Malunion was supposed to be as unacceptable as nonunion, and surgery should be considered at least at the first signs of myelopathy, if not as a pre-emptive “strike”. Further on, in a study of natural course of clinically asymptomatic MR-detected spondylotic cervical cord compression, only electrophysiological abnormalities together with clinical signs of cervical radiculopathy could be worked out as a predictive value for manifestation in clinical course [13]. Concerning electrophysiological examinations, our patient showed no pathologies. Although we discussed prophylactic posterior and/or anterior decompression C1-2 with our referred patient on the basis of clinical experience and given experience in literature, we had to release the patient into close follow-up. If any change inbetween clinical and neurological course, or neurophysiological testings will evoke, decompression and stabilization is to be discussed again. It would prevent further progression and most often clinical manifestation of CM, if performed early [26,28,30,34,69,81,84,104].

**SCRUTINIZING THE ODONTOID FRACTURE CLASSIFICATION**

There is a widespread understanding that odontoid fractures can be classified describing their pathomorphological appearance according to Anderson and D’Alonzo [1]. Type I fractures are rare bony avulsions of the apex of the odontoid, they are discussed elsewhere [38]. Type II fractures show a mean incidence of about 70% (60-94%) and demonstrate as a fracture line traversing the odontoid either above or in its base horizontal or oblique antero-posterior or reversed. They are always extraarticular by nature. Particularly the latter oblique ones are not addressed in the original classification of Anderson and D’Alonzo [1]. In type III fractures, which show a mean incidence of 30% (6-40%), the fracture line extends into the axis body with/or without affecting the articular facets [64,81,123,132,24,40,46,94,106,116,58,94,105]. Actually, most odontoid fractures of type III resemble fractures of the VB-C2. Infrequently associated fractures and dislocations C1-2 are not reflected in current classifications concerning odontoid fractures [22,24,13,18,40,44,53,67,70,89,106]. Besides odontoid fractures and classical Hangman’s fractures as well, a considerable number of fracture variants of the VB-C2, such as atypical Hangman’s fractures and fractures of the lateral mass of C2 [10], exist, affecting all parts of the axis body [17,101,24,123,22,24,40,46,94,106,116,58,94,105]. Fractures traversing the body and the articular facets of the axis, as some type III odontoid fractures do so, result in miscellaneous fractures of the VB-C2. Hence, often it is difficult to clearly draw margins referring to existing classifications, applying straight treatment algorithms, and compare study outcomes. More often, some of these fractures are recognized as benign and summarized as ‘non-odontoid/non-Hangman’s fractures’ or as ‘miscellaneous fractures of the axis’ [10]. Retrospectively, our case emphasized a clinical problem: There still seems to be a lack of comprehensive classifications and treatment guidelines for fractures of VB-C2 and odontoid type III, respectively, which would facilitate treatment in institutions not regularly confronted with such fractures, and increase comparability of outcomes published. Numerous suggestions based on anatomical classifications exist [10,17,24,53,58,94,106,116,58,94,105]. Actually, none of these classifications offer reliable guidance for safe primary treatment modalities. Most often, a case specific assessment and biomechanical characterization of each individual C2-fracture is necessary, which demands major clinical experience.

**DEFINITION OF OSSEOUS INSTABILITY IN TRANSCORPORAL C2-FRACTURES**

In the opinion of most authors the classification of odontoid type II and III fractures of Anderson and D’Alonzo is a handy tool, but up to now, referring to miscellaneous morphologies of these fractures, it has been not possible to demonstrate predictable parameters of high value [10]:

Influencing criteria for instability are supposed to be the grade of dislocation, angulation, age of the patient and the fracture, neurological deficit, a compound fracture-zone, concomitant fractures C0-2, as well as the inability to achieve primary stability or maintain alignment with external immobilization. Furthermore, an oblique fracture line logically enables the fragments to shear at the fracture site, and thus rises nonunion rate with conservative treatment [61,11,24,42,24,14,37,51,16,88,89,100,80]. Ryan et al. demonstrated that in dislocated type II fractures, cross-sectional-area (CSA) of the fragments is smaller than estimated based on X-rays. Posterior dislocation of 39% reduced CSA about 50%.
Consequently, lateral displacement increased this value \( [10] \). However, it seems that there is no correlation with degree and direction of odontoid displacement and union rate. This depends on the fact that stability confirmed on static X-rays reveals alleged stable fractures that can displace and relocate easily \( [10] \). Also anatomical as well as numerical parameters have been suggested as factors for instability C1-2 in type III lesions \( [16,20,29,30,40,49,52,68,70,76,78,80,82,83,88] \), whereas Marton et al. emphasized, that those fractures traversing obliquely to the posterior part of the axis body and straight down anteriorly are more prone for secondary dislocation \( [36] \). A screw traversing the oblique fracture line cannot address resulting shear-forces sufficiently and tends to pull the proximal fragment distally \( [14] \), as it occurred in the case described. The same applies to fractures of the VB-C2 and can indicate posterior redo surgery with fusion C1-2 \( [26,33,44,56,73,77,82,86,93,101,108] \). Therefore, a posterior-anterior shearing fracture line is supposed to be a contraindication for anterior screw fixation, as it provokes screw breakage and loosening in these subtypes, especially in case of osteoporotic bone. However, a definite degree of angulation of the fracture course inside the body of C2, which will promote slippage of the proximal fragment onto the distal one, is to be determined, yet!

Isolated fractures of the lateral mass C2 have a low incidence and more often they are part of odontoid, Hangman's, or fractures of the VB-C2 \( [12,19,23,25,49,50,51,58,73,76,78,79,97,102] \). Ferrer underlines that type III lesions with transverse fractures of the VB-C2, those where the fracture line extends beyond the lateral masses, as it was in our case, and especially when associated with avulsion or collapse of the lateral mass of C2 are unstable. The possibility of obtaining a solid fusion with conservative methods is minimal, and anterior screw fixation should be avoided. These fractures are supposed to be prone for a high rate of non-anatomical osseous union with significant negative biomechanical consequences \( [14] \). The lateral mass fractures contribute to atlantoaxial instability in type II, type III fractures and discoligamentous stable fractures of the VB-C2. They also can demand secondary surgical stabilization \( [23,44,65,80,95,101] \).

Conclusively, the stability in odontoid fractures type III and VB-C2 should be assessed with recognition of associated C2-fractures, their fracture course in respect to gravity, and with manually performed dynamic X-rays, or during inhospital course with a semirigid cervical collar. If instability or a shearing fracture line is evident, surgical treatment such as primary intended anterior buttress plating or fusion C1-2 should be considered.

**TREATMENT OF OSSEOUS INSTABILITY IN TRANSCLORAL C2-FRACTURES**

The difference in bony surface-area between type II, and type III or fractures of the VB-C2 is significant \( [44] \). Thus most authors base their decision for conservative treatment on the fact that the latter ones affect a zone of large cancellous surface \( [44,51,52,72,73,76,78,82,83,88] \). Some authors recommend immobilization in the halo vest or cervicothoracic orthoses for 12 weeks and more \( [23,44,65,71,73,76,78,82,83,88] \) yielding union in 75% to 100% of cases \( [43,45,87,92,98] \). Other authors suppose them to heal sufficiently with a rigid or semi-rigid cervical collar \( [40,88,98] \), which resulted in osseous fusion in 50% to 100% \( [46,88] \), and with cervical traction in 88% to 100% \( [46,98] \). Additionally, the rate of nonunion in fractures of the VB-C2 is given with 1.6% to 10% \( [41,96] \), whereas De Morgues et al. observed nonunions in about 40% of 41 fractures of the VB-C2 following conservative treatment \( [34] \). Some more reports on their inherent problems exist \( [41,52,74,75,107] \).

It seems that proper healing of odontoid fractures type III and VB-C2 does not strongly depend on a conservative method chosen, but on the identification of aforementioned biomechanical characteristics. Another concern is, that only a few, but controversial follow-up results concerning functional outcome exist \( [46,85,101,108] \). Polin et al. observed no significant difference referring to union rate in patients treated with the halo or with more comfortable devices such as the Philadelphia collar, but he emphasized that treatment in the halo is associated with higher morbidity \( [46] \). Accordingly, many authors reported on morbidities and serious complications with the halo fixation \( [12,44,60,67,73,78,98,101,108] \). Furthermore, malunion and segmental deformation not related to initial dislocation and angulation after conservative treatment have been observed and criticized in a considerable number of patients \( [12,19,23,25,33,44,65,73,76,78,80,82,92,97] \). Malunion and atlantoaxial osteoarthritis due to an intraarticular fracture line \( [12,44,60,67] \), atlantoaxial kyphosis \( [46] \), pain and poor functional outcome \( [12,33,51,73,78] \) are well known complications, and in worst cases can cause CM in odontoid type III fractures and fractures of the VB-C2 \( [23,40,51,52,74,80,98,101,108,104] \). Cervical collars do not restrict cervical range of motion sufficiently \( [13,40,98,99] \), and movement at the fracture-site in the halo is common, too \( [98] \).
Accordingly, reports on secondary redislocation also after halo fixation exist and resulted in secondary surgical stabilization with anterior [24,59] or posterior fusion C1-2 [17,13,12,23,25,27,28,48,49,50,90]. The same holds true in miscellaneous fractures of the VB-C2 and increases the significance of inherent complications with conservative treatment in some of these fractures [41,40,85,21,24,62,105]. On the other hand, primary and secondary fusion C1-2 using wire based techniques, transarticular screws, or C1-2 lateral mass and pedicle fixations are recommended as safe procedures [20,85,91,103,107,111]. Nevertheless, fusion C1-2 significantly reduces range of motion for rotation of the cervical spine [14,28,67,68,109,110]. Oppositely, motion sparing techniques such as anterior screw fixation for type III lesions in selected cases was successfully performed by Julien et al. and others [17,80,113], whereas anterior stabilization utilizing a T-shaped buttress antiglide plate also resulted in a high rate of primary intended fusions [39,50].

In summary, fractures of the odontoid type III and VB-C2 seem not to be benign fractures, which cannot be treated either conservatively [23,13,30,50,91], nor with anterior odontoid screw fixation in general. They demand higher attention [12] and need a better subclassification than suggested [5]. This can guide to a primarily, anteriorly placed T-shaped antiglide plate, anterior or posterior fusion C1-2, or conservative treatment. The literature does not lack sufficient data for the treatment of the most common odontoid type II fractures and their variants. However, further research in fractures of the odontoid type III and VB-C2 is demanded. We recommend stop doing hanging on the description of ‘odontoid type III fractures’ and treatment with the halo device in such cases in general, but adaption of descriptions used and treatment algorithm applied to biomechanical characteristics of each fracture until a comprehensive classification is proven sufficient.

CONCLUSION
In view of the fact that we do not want to hang back on the ‘halo-solution’ in alleged unstable fractures of the axis in future years, there is a lack of a comprehensive classification for fractures of the axis body and odontoid, respectively, and a clear determination, wether there are fractures of the odontoid and VB-C2 which can be treated safely and primarily with semirigid external immobilization, and which fracture morphologies demand primary operative stabilization. The vast number of existing classifications of these fractures without clear treatment concepts emphasize the need for biomechanical investigations on bony parameters contributing to instability in discoligamentous stable fractures of the vertebral body C2.

Miscellaneous fractures inside the axis cause different angulations and sizes of the fragments. Thus, the influence of resulting different cross-sectional surface areas and corticocancellous surface-friction in respect of gravity might be key-questions in future research on these fractures. Biomechanical cadaver based studies, and particularly finite-element models [43,50] could resemble instruments for further investigation of interosseus stability in C2-fractures.

References
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Author Information

Heiko Koller, M.D.
Department for Trauma and Reconstructive Surgery, (Department for Traumatology and Sports Medicine), Katharinenhospital, (Paracelsus Medical University)

Volker Kammermeier, M.D.
Department for Trauma and Reconstructive Surgery, Katharinenhospital

Allan Assuncao, M.D.
Department for Trauma and Reconstructive Surgery, Katharinenhospital

Ulrich Holz
Professor, Department for Trauma and Reconstructive Surgery, Katharinenhospital