# Optimizing treatment for odontoid fractures in the elderly: a balancing act with the patient at center stage

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# CHAPTER 1

# GENERAL INTRODUCTION AND OUTLINE OF THE THESIS

# GENERAL INTRODUCTION

## The odontoid process

The odontoid process is a bony projection extending from the superior aspect of the second cervical vertebra (the axis, or C2). Due to its shape, it is also referred to as the dens, derived from the Latin word for tooth. The odontoid process extends upwards into a recess in the anterior arch of the first cervical vertebra (the atlas, or C1), where it serves as a pivot point around which the atlas rotates (**Figure 1**).[1] It is encased by the transverse ligament posteriorly, and attaches to the skull base cranially through the apical and alar ligaments.[2] Rotational movements of the head (shaking 'no') primarily occur along the vertical axis defined by the odontoid process (**Figure 2**). The atlanto-axial joints form the most flexible spinal segment for axial rotation, accounting for over half of all cervical rotation movements.[2]

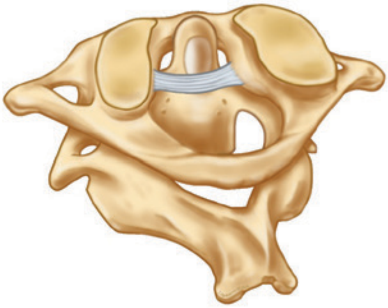

**Figure 1.** Left posterior-superior view of the atlas (above) and axis (below) vertebrae, showing the odontoid process on the superior aspect of the axis and the transverse ligament. Custom image by S. Blankevoort, 2024.

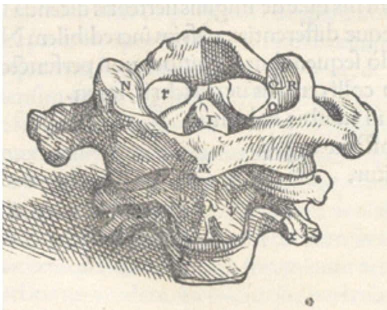

**Figure 2.** Likely the earliest anatomical description of the atlanto-axial region, based on direct observation and dissection, was published by Andreas Vesalius in 1543 in *De humani corporis fabrica libri septem*. Anterior-superior view. The accompanying descriptions demonstrate a profound understanding of anatomy and function. Reprinted with permission from Ghent University Library.

## Odontoid fractures

Fractures of the odontoid process are the most common cervical spine fractures, typically resulting from (minor) hyperextension or hyperflexion trauma.[3] Odontoid fractures may cause neck pain and atlanto-axial instability, though associated neurological deficits from spinal cord injury are rare (**Figure 3**).[4, 5] These fractures are particularly prevalent among elderly patients and have been associated with osteoporosis.[6] More than 70% of patients are aged 65 years or older, with over 40% aged 80 years or older.[7] Furthermore, elderly patients face an increased risk of complications and mortality. Overall one-year mortality rates as high as 30 percent have been reported in patients aged 65 and above, similar to those of hip fractures.[8]

The older population is projected to grow by 50% between 2016 and 2030.[9] As a result, the incidence and healthcare burden of odontoid fractures are also expected to rise.[7] From 2000 to 2010, the incidence of these fractures increased across all age groups in the United States, with the most rapid rise observed among patients over 84 years, reaching 9,77 hospitalizations per 10,000 individuals annually. During this period, estimated annual charges for inpatient care of patients with axis fractures increased 4.7-fold, surpassing 1.5 billion dollars in 2010 in the United States alone.[10] Both the rising incidence and higher costs per treatment contribute to an increase in healthcare expenses.[11]

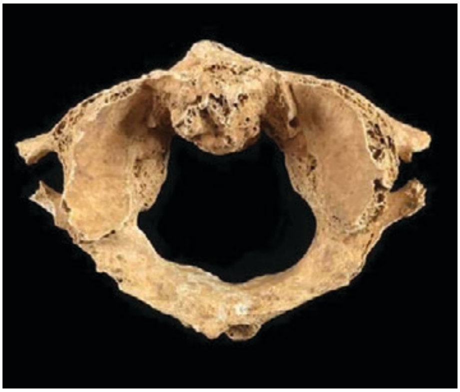

**Figure 3.** Presumably the oldest recorded odontoid fracture. Male, aged 50-60, medieval necropolis of Maro, Spain, 10th-11th CE. Superior view showing union of the odontoid process and the atlas, indicating long-term survival. Reprinted with publisher permission.

## Fracture classifications

The most commonly used classification for odontoid fractures was published by Anderson and d'Alonzo in 1974 (**Figure 4**).[12] In this classification, type I fractures occur at the upper part of the odontoid process itself, type II fractures occur at the junction of the odontoid process and the body of the axis, and type III fractures are essentially fractures through the body of the axis. Type I fractures are relatively rare, usually considered avulsion fractures involving the alar ligaments, have a favorable clinical course, and are therefore typically outside the scope of clinical research.[4] Type II fractures are generally considered the most unstable.[13]

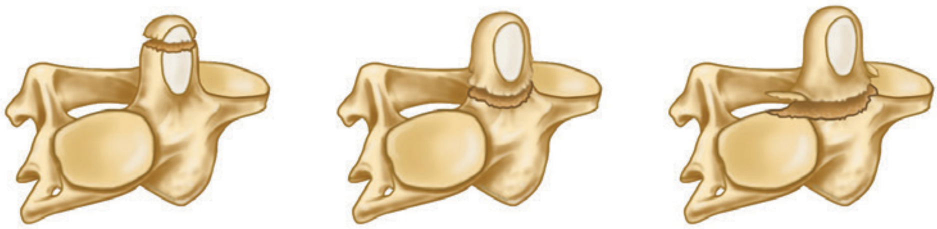

**Figure 4.** Right anterior-superior view of the axis depicting the Anderson and d'Alonzo classification. Fracture type I (left), type II (middle), and type III (right). Custom image by S. Blankevoort, 2024.

An alternative, though less commonly used, classification was proposed by Grauer et al. in 2005.[14] This classification aimed to provide a more precise distinction between type II and III fractures based on the presence or absence of facet joint involvement, and to aid treatment decisions. In this classification, type IIA fractures are horizontal non-displaced fractures, type IIB fractures follow an anterior-superior to posterior-inferior course or are displaced transverse fractures, type IIC fractures follow an anterior-inferior to posterior-superior course or are comminuted fractures, and type III fractures include at least one of the superior articular facets of the axis. A nearly identical classification was published in German by Eysel and Roosen in 1993.[15]

Besides the Anderson and D'Alonzo and Grauer classifications, up to nine other classification systems have been described in the literature. However, existing systems do not consider osteoporosis and the medical frailty of elderly patients, who represent a significant proportion of cases. Recommendations have been made for future classification systems to address these factors to better guide treatment for this population.[16]

## Treatment options

The treatment for odontoid fractures aims to achieve fracture healing and a favorable clinical outcome while minimizing complications. Treatment approaches can be either surgical or conservative in nature.

The most common surgical treatments include posterior atlanto-axial fusion and anterior odontoid screw fixation. Conservative treatment involves the use of a cervical collar or halo vest to immobilize the cervical spine, promoting fracture healing and preventing secondary fracture displacement.

## Surgical treatment

### *Posterior atlanto-axial fusion*

Posterior atlanto-axial (C1-C2) fusion provides immediate stabilization, although thereby limiting its rotational capacity. There are various methods for performing C1-C2 fusions.

In the commonly applied method described by Harms and Melcher in 2001, polyaxial screws are bilaterally inserted into the lateral masses (or arch) of the atlas and into the pars interarticularis of the axis. This can be done under X-ray guidance or intraoperative navigation. The screws are then connected by two rods (**Figure 5**).[17] A largely similar method using plating was previously described by Goel and Laheri in 1994.[18]

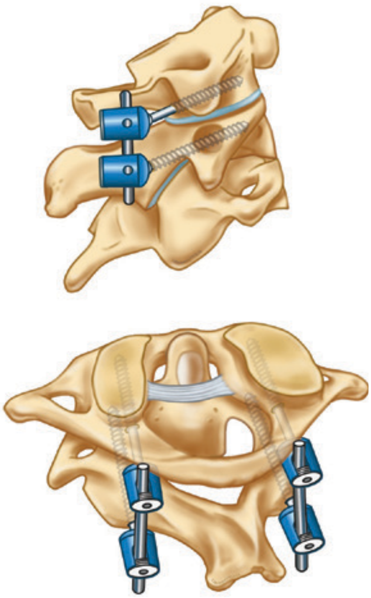

**Figure 5.** Right lateral view (above) and left posterior-superior view (below) illustrating posterior C1-C2 fusion as described by Harms and Melcher. Custom image by S. Blankevoort, 2024.

Transarticular C1-C2 fusion was described by Magerl and Seeman in 1986.[19] This technique is still used today, although it can be technically challenging and is not always feasible due to anatomical variations, such as a high-riding vertebral artery. Posterior interlaminar wiring with bone graft application was described by Gallie in 1939, and by Brooks and Jenkins in 1978.[20, 21] These wiring methods are still occasionally employed to facilitate osseous union, usually in conjunction with other fusion techniques.

Depending on the indication, C1-C2 fusion can be extended cranially to include the occiput or caudally to encompass the subaxial region. In elderly patients, posterior fusion has been associated with an increased risk of complications.[22]

*Anterior odontoid screw fixation*

Direct stabilization of odontoid fractures can be achieved by anterior odontoid screw fixation (**Figure 6**). This method was first described in 1980 by Nakanishi et al. in Japanese, although this paper did not receive widespread international recognition.[23, 24] Instead, a paper published by Böhler in 1982 gained international acclaim for this method.[25] During this procedure, a guided K-wire is first inserted into the inferior edge of the body of the axis. The screw trajectory is then drilled and tapped under X-ray guidance or intraoperative navigation. Finally, one or two screws are placed though the axis's body into the odontoid process to bridge the fracture.[26] These screws can be fully or partially threaded.[27] This procedure is particularly suitable for fracture lines perpendicular to the screw trajectory and preserves atlanto-axial movement. However, it has been associated with increased risk of complications in the elderly.[28, 29]

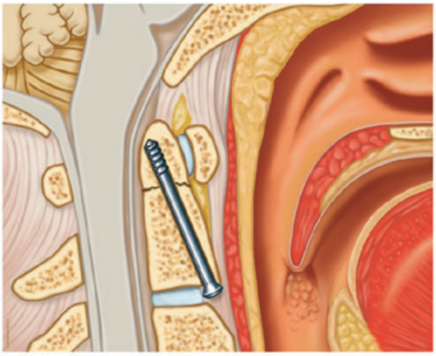

**Figure 6.** Right lateral view illustrating direct stabilization through anterior odontoid screw fixation. Custom image by S. Blankevoort, 2024.

## Conservative treatment

*Cervical collar*

A cervical collar is applied upon presentation to externally stabilize the neck (**Figure 7**). The collar restricts movement in the cervical spine, limiting flexion, extension, lateral bending, and rotation. Multiple manufacturers offer cervical collars, each featuring distinct designs, yet serving the same fundamental purpose. Regular follow-up visits throughout treatment are used to monitor clinical and radiological progress.

**Figure 7.** Left-anterior view depicting a patient wearing a cervical collar. Custom image by S. Blankevoort, 2024.

Cervical spine immobilization protocols are not standardized.[30] Some centers prescribe cervical collars for continuous wear, while others recommend their removal during bed rest to prevent pressure ulcers. The duration of collar immobilization varies between centers, but typically falls within the range of six to twelve weeks.[31] Recently, there has been growing discussion about whether collar treatment is necessary at all in elderly patients, with a current study comparing collar use to no immobilization in this population.[32]

*Halo vest*

A halo vest is applied upon presentation and provides rigid stabilization of the cervical spine by restricting movement in all directions (**Figure 8**). The halo ring, made of lightweight metal, is positioned around the head. Metal pins are inserted into the outer layer of the skull under local anesthesia, serving as anchor points for attaching the halo ring. The ring is then connected to a vest made of rigid material, secured tightly around the torso to provide additional support and stability. Similar to cervical collar treatment, the duration of immobilization varies between centers. Regular follow-up visits are conducted during treatment to monitor clinical and radiological progress. The use of the halo vest in treatment has decreased over the last decades.[10] In elderly patients, it has been associated with an increased risk of complications and mortality.[33]

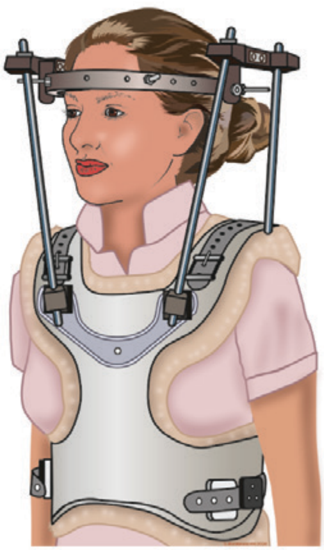

**Figure 8.** Left anterior view depicting a patient with a halo vest. Custom image by S. Blankevoort, 2024.

## THESIS OUTLINE



Elderly patients with odontoid fractures have a higher risk of impaired fracture healing and complications with both surgical and conservative treatments. Each treatment option presents its own perceived advantages and disadvantages. The most relevant outcome parameters remain uncertain, as there is insufficient evidence of a direct association between fracture healing and more favorable clinical outcomes. Additionally, it remains unclear whether historical concerns about secondary fracture displacement leading to spinal cord injury are justified. As a result, the optimal treatment remains a topic of debate.

This thesis aims to compare clinical and radiological outcomes of surgical and conservative treatments for odontoid fractures in the elderly:

- **Chapter 2** provides a systematic review and meta-analysis of the available literature.
- **Chapter 3** compares the outcomes of a low-threshold-for-surgery versus a primarily-conservative treatment strategy, utilizing historical practice variation in the Netherlands in a natural experimental design.
- **Chapter 4** presents the findings from an international prospective study comparing surgical and initial conservative treatments, representing the largest cohort available.
- **Chapter 5** explores the usability of Hounsfield unit measurements on baseline computed tomography scans to predict odontoid fracture union.
- **Chapter 6** provides a general discussion, also addressing the limitations, future perspectives, and direct clinical implications.
- **Chapter 7** provides an English summary.
- **Chapter 8** includes a Dutch summary.
- The **Appendices** contain a list of publications, acknowledgements, and author information.

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