MANAGEMENT OF ACUTE ODONTOID FRACTURES

A doctoral thesis by
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To my parents – for what I am today

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Background

Odontoid fractures (OFx) comprise approximately 20% of all traumatic cervical spine fractures (CS-Fx). The incidence of OFx increases with age, and it is the most common CSFx in the elderly population. Until recently, primary surgical fixation was recommended for OFx type II and III with a major translation of the odontoid fragment regardless of the patient's age and for all OFx type II in patients ≥ 50 years. The main argument for this recommendation was an observed low bony fusion rate after external stabilization alone. This recommendation has been challenged in recent years due to the high surgical risk in these elderly, and often severely comorbid, patients. Some recent reports have also suggested that fibrous union of the odontoid fragment after 12-16 weeks of external immobilization may provide a long-term outcome equivalent to bony fusion. The objectives of this research study were to explore 1) compliance with current treatment recommendations for primary stabilization (surgical fixation versus external immobilization) and reasons for noncompliance and 2) long-term outcomes after “real life” management of OFx type II and III with respect to fusion (bony fusion, fibrous union, pseudarthrosis), new-onset spinal cord injury (SCI), neck pain, and conversion rate from primary external immobilization to surgical fixation. With “real life”, we mean the treatment actually given in a large consecutive cohort of patients with OFx in a defined population.

Methods

Paper I: This paper describes a population-based prospective registration of all traumatic OFx in the southeastern Norwegian population (3.0 million) from 2015 – 2018. A total of 336

patients with an OFx were prospectively registered. *Paper II – III:* These papers described an observational cohort study of all OFx type II and III patients diagnosed with cervical CT in the southeastern Norwegian population in the 8-year periods from 2009 to 2011 and 2013 to 2017. A total of 494 patients with OFx type II or III were prospectively registered. Papers I, II, and III were based on data extracted from our quality control database for acute CS-Fx (age, sex, comorbidities, injury mechanism, fracture morphology, and treatment). In addition, for papers II and III, long-term follow-up was performed from 2018 – 2019 and included clinical and radiological examinations. At the time of follow-up, the following outcome measures were collected: fusion status, crossover from primary conservative treatment to surgical fixation, new-onset SCI, and neck pain.

Results

Paper I: The incidence of OFx in Norway was 2.8/100,000 persons/year. The median age of the patients was 80 years, and 45% were female. Major comorbidities were present in 2/3 of the patients, and 1/3 needed assistance with ADL. The OFx were type II in 59% of cases and type III in 41% of cases. SCI due to OFx was registered in 4% of patients. The primary fracture treatment was rigid collar alone in 79% of patients and open surgical fixation in 21% of patients. The level of compliance with the treatment recommendations for OFx type II was low. The main deviation was the underuse of primary surgical fixation for OFx type II. Compliance with the treatment recommendations for OFx type III was high. Major comorbidities and an older age appeared to be significant factors contributing to the decision to refrain from the surgical fixation of OFx type II.

Paper II: In this study of 282 patients with OFx type II, 84% of patients were ≥ 65 years of age, and 67% had severe comorbidities. Primary treatment was external immobilization alone in

69% of patients and open surgical fixation in 31% of patients. At long-term follow-up, the fusion status was bony fusion in 39.2%, fibrous union in 57.3%, and pseudarthrosis in 3.5% of patients. The proportion of bony fusion was significantly higher in the primary surgical fixation group ($p=0.005$). No patients had new-onset SCI after the start of primary treatment. The proportion of crossover from primary external immobilization to surgery was 14.4%, and the proportion of revision surgery in the primary surgical group was 9.5%. There was no significant difference between the primary surgical fixation group and the primary conservative treatment group at long-term follow-up with respect to the proportion of pseudarthrosis and degree of neck pain. The results clearly indicate that fibrous union is an acceptable outcome after OFx type II and equivalent to bony fusion.

Paper III: In this consecutive series of 212 patients with acute OFx type III, the median patient age was 72 years, 56% had severe preinjury comorbidities (ASA score ≥ 3), and 22% lived dependently. Primary treatment was external immobilization alone in 95.3% and open surgical fixation in 4.7% of patients. Patients treated with primary external immobilization alone presented with significantly less dislocation of the odontoid fragment. Subsequent crossover to surgical fixation was performed in 5.4%. At long-term follow-up, 95.7% of patients had bony fusion of the OFx, 80.5% had minimal/no neck pain, and none developed new-onset SCI. There was no significant difference in long-term follow-up VAS between the primary external immobilization group and the primary surgical group. This management strategy resulted in a high bony fusion rate, a low rate of chronic neck pain and no patients with new-onset SCI.

Conclusions

- The incidence of OFx in Norway was 2.8/100,000 persons/year.

- The majority of patients with OFx are elderly and have severe comorbidities, and many are in a dependent living facility.
- The level of compliance with the treatment recommendations for OFx was low. The main deviation was the underuse of primary surgical fixation for OFx type II.
- Primary conservative treatment of elderly, comorbid patients with OFx type II appears to be safe and should be regarded as good clinical practice and not a violation of current treatment recommendations.
- Fibrous union is an acceptable outcome after OFx type II and is equivalent to bony fusion.
- Nonsurgical treatment of OFx type III is still the preferable option in the majority of patients.
- Comorbidities and age should be considered for inclusion in the decision tree for the choice of treatment for OFx in future guidelines.

Bakgrunn

Densfraktur (brudd i andre nakkevirvel) (OFx) utgjør omtrent 20% av alle traumatiske nakkefrakturer (CSFx). Forekomsten øker med alderen og er den vanligste nakkeskaden i den eldre befolkningen. Inntil nylig ble primær kirurgisk fiksering anbefalt for OFx type II og III med betydelig feilstilling av densfragmentet uavhengig av pasientens alder, og for alle OFx type II hos pasienter ≥ 50 år. Hovedargumentet for denne anbefalingen var påvist lav benet fusjon etter kun ekstern stabilisering. Denne anbefalingen har nylig blitt utfordret med bakgrunn i den høye kirurgiske risikoen hos disse eldre og ofte alvorlige komorbide pasientene. Noen ferske studier har også antydnet at en fibrøs fusjon av frakturkomplekset etter 12-16 uker med ekstern immobilisering kan gi et langsiktig gunstig utkomme tilsvarende benet fusjon. Målet med vårt prosjekt var å utforske: 1) etterlevelse av gjeldende behandlingsanbefalinger for primær stabilisering (kirurgisk fiksering versus ekstern immobilisering) og årsaker til manglende etterlevelse, 2) langsiktig utkomme etter faktisk håndtering i en klinisk hverdag av OFx type II og III med hensyn til type fusjon (benet fusjon, fibrøs fusjon, pseudartrose), nytilkommet ryggmargsskade (SCI), nakkesmerter og sekundær endring i behandling fra primær ekstern immobilisering til kirurgisk fiksering. Med «faktisk håndtering i en klinisk hverdag» mener vi behandlingen som faktisk blir gitt i en stor sammenhengende kohort av pasienter med OFx i en definert populasjon.

Metode

Artikkel I: Populasjonsbasert prospektiv registrering av alle traumatiske OFx i befolkningen i sørøst Norge (Helse Sørøst) (3,0 millioner) i perioden 2015 - 2018. 336 pasienter med OFx

ble prospektivt registrert. Artikkel II - III: Observasjonell kohort studie av alle pasienter med OFx type II- og III diagnostisert med cervikal CT i sørøst Norge i 8-årsperioden fra 2009 til 2011 og 2013 til 2017. 494 pasienter med OFx type II eller III ble prospektivt registrert. Artikkel I, II og III var basert på data hentet fra vårt kvalitetsregister for akutte nakkebrudd (alder, kjønn, komorbiditet, skademekanisme, brudd morfologi og behandling). I tillegg ble pasientene som inngår i artikkel II og III etterkontrollert klinisk og radiologisk for evaluering av fusjonsstatus, skifte fra primær konservativ behandling til kirurgisk fiksering, nyttilkommet SCI og nakkesmerter.

Resultat

Artikkel I: Forekomsten av OFx i Norge var 2,8 / 100 000 personer / år. Medianalderen til pasientene var 80 år, og 45% var kvinner. Alvorlig komorbiditet var tilstede hos 2/3 av pasientene, og 1/3 trengte hjelp med daglige gjøremål (ADL). OFx type II ble funnet hos 59% og type III hos 41%. SCI på grunn av OFx ble registrert hos 4%. Den primære bruddbehandlingen var kun stiv nakkekrage hos 79% av pasientene og åpen kirurgisk fiksering hos 21%. Etterlevelsen av behandlingsanbefalingene for OFx type II var lav. Hovedavviket var lite bruk av primær kirurgisk fiksering for OFx type II. Etterlevelsen av behandlingsanbefalingene for OFx type III var høy. Alvorlig komorbiditet og høy alder syntes å være viktige faktorer som bidro til beslutningen om å avstå fra kirurgisk fiksering av OFx type II.

Artikkel II: I denne studien av 282 pasienter med OFx type II var 84% av pasientene ≥ 65 år og 67% hadde alvorlig komorbiditet. Primærbehandling var ekstern immobilisering hos 69% og åpen kirurgisk fiksering hos 31% av pasientene. Ved langsiktig oppfølging fant vi benet fusjon hos 39,2% av pasientene, fibrøs fusjon hos 57,3% og pseudartrose hos 3,5%. Andelen benet

fusjon var signifikant høyere i den primære kirurgiske fiksasjonsgruppen ($p = 0,005$). Ingen pasienter hadde nytilkommet SCI etter primærbehandlingen. Andelen som ble konvertert fra primær ekstern immobilisering til kirurgi var 14,4%, mens andelen revisjonskirurgi i den primære kirurgiske gruppen var 9,5%. Det var ingen signifikant forskjell mellom den primære kirurgiske fiksasjonsgruppen og den primære konservative behandlingsgruppen ved langvarig oppfølging med hensyn på andel pseudartrose og grad av nakkesmerter. Resultatene indikerer sterkt at fibrøs fusjon er et akseptabelt resultat etter OFx type II, tilsvarende benet fusjon.

Artikkel III: I denne serien med 212 pasienter med akutt OFx type III var median pasientalder 72 år, 56% hadde alvorlig komorbiditet før skaden (ASA-score ≥ 3) og 22% var avhengige av hjelp til daglige gjøremål (ADL). Primærbehandling var ekstern immobilisering hos 95,3% av pasientene og åpen kirurgisk fiksering hos 4,7%. Pasienter behandlet med primær ekstern immobilisering hadde på diagnosetidspunktet signifikant mindre feilstilling av densfragmentet. Konvertering til kirurgisk fiksering ble gjort i 5,4% av tilfellene. Ved oppfølging i sen fase hadde 95,7% av pasientene benet fusjon av OFx, 80,5% hadde minimale/ingen nakkesmerter, og ingen utviklet nytilkommet SCI. Det var ingen signifikant forskjell i nakkesmerter (målt med VAS) ved sen oppfølging mellom den primære eksterne immobiliseringsgruppen og den primære kirurgiske gruppen. Denne behandlingsstrategien resulterte i høy benet fusjon, lav forekomst av sterke kroniske nakkesmerter og ingen pasienter med nytilkommet SCI.

Konklusjon

- Forekomsten av OFx i Norge var 2,8 / 100,000 personer / år.

- Flertallet av pasienter med OFx er eldre, har alvorlig komorbiditet og har behov for hjelp til daglige gjøremål.
- Nivået på etterlevelsen av behandlingsanbefalingene for OFx var lavt. Hovedavviket var lite bruk av primær kirurgisk fiksering for OFx type II.
- Primær konservativ behandling av eldre komorbide pasienter med OFx type II synes å være trygt og bør betraktes som god klinisk praksis og ikke som et brudd på gjeldende behandlingsanbefalinger.
- Fibrøs fusjon er et akseptabelt resultat etter OFx type II, tilsvarende benet fusjon.
- Ikke-kirurgisk behandling av OFx type III bør fortsatt være første valg hos de fleste pasienter.
- Komorbiditet og alder bør vurderes for inklusjon i beslutningstreet for valg av behandling for OFx i fremtidige retningslinjer.

LIST OF PAPERS

Paper I:

Rizvi SAM, Helseth E, Rønning P, Mirzamohammadi J, Harr ME, Brommeland T, Aarhus M, Høstmælingen CT, Ølstørn H, Rydning PNF, Mejlænder-Evjensvold M, Utheim N, Linnerud H.

Odontoid fractures: impact of age and comorbidities on surgical decision making.

BMC Surg. 2020 Oct 14;20(1):236. doi: 10.1186/s12893-020-00893-7. PMID: 33054819; PMCID: PMC7556921.

Paper II:

Rizvi SAM, Helseth E, Harr ME, Mirzamohammadi J, Rønning P, Mejlænder-Evjensvold M, Linnerud H.

Management and long-term outcome of type II acute odontoid fractures: a population-based consecutive series of 282 patients.

Spine J. 2021 Apr;21(4):627-637. doi: 10.1016/j.spinee.2020.11.012. Epub 2020 Dec 17. PMID: 33346157.

Paper III:

Rizvi SAM, Helseth E, Aarhus M, Harr ME, Mirzamohammadi J, Rønning P, Mejlænder-Evjensvold M, Linnerud H.

Favorable prognosis with nonsurgical management of type III acute odontoid fractures: a consecutive series of 212 patients.

Spine J. 2021 Feb 10:S1529-9430(21)00064-4. doi: 10.1016/j.spinee.2021.02.003. Epub ahead of print. PMID: 33577924.

LIST OF SELECTED ABBREVIATIONS

ADL	Activities of daily living
ASIA	American Spinal Injury Association
ALL	Anterior longitudinal ligament
ASA	American Society of Anesthesiologist
C2	Cervical vertebra no. 2
CS-Fx	Cervical spine fracture
CT	Computer tomography
CTA	Computed tomography angiography
GCS	Glasgow Coma Scale
HISS	Head injury severity scale
ICD	International Classification of Diseases
ICU	Intensive care unit
IQR	Interquartile range
MRI	Magnetic resonance imaging
OFx	Odontoid fracture
OUH	Oslo University Hospital
PLL	Posterior longitudinal ligament
RCT	Randomized controlled trial
ROM	Range of motion
SCI	Spinal cord injury
TBI	Traumatic brain injury
VAS	Visual Analog Scale

PART I: INTRODUCTION

ANATOMY OF THE CERVICAL SPINE

The bony parts of the cervical spine consist of seven vertebrae (C1-C7) (Figure 1) that are linked by intervertebral discs, ligaments, and muscles, which provide stability and mobility to the spine. The range of motion (ROM) of the cervical spine in a young person is ~ 80°-90° of flexion, ~70° of extension, ~20°-45° of lateral flexion, and ~90° of rotation to both sides [1].

The spinal cord is a continuation of the brain stem and is located within the spinal canal. In adults, the spinal cord extends down to the lower border of the first lumbar vertebra. Along its course in the spinal canal, the cord gives rise to 30 pairs of spinal nerves, 8 cervical, 12 thoracic, 5 lumbar and 5 sacral. The spinal cord is part of the central nervous system, while the spinal nerves are part of the peripheral nervous system. The spinal cord at the level of the cervical spine is vascularized by three vessels, the anterior spinal artery and the two posterior spinal arteries. The anterior spinal artery arises from the vertebral artery, and the posterior spinal arteries arise from the posterior inferior cerebellar artery. Figure 2 shows an MRI scan with a sagittal view of the spinal cord.

The vertebral arteries, which are branches of the left and right subclavian arteries, ascend in the neck through the transverse foramen of cervical vertebra C1-C6, enter intradurally in the craniocervical junction, and join to become the basilar artery in front of the pons (Figure 3).

Functionally, the upper cervical spine includes the occipital condyles (OC), vertebra C1, and vertebra C2. There are no intervertebral discs in the upper segment, and C1 and C2 are more specialized than the other cervical vertebrae. C1 (atlas) is ring-shaped and lacks a vertebral body, while C2 (axis) contains the characteristic odontoid process (Figure 4). The stability of

the OC-C1 joints (also called the YES joints) is maintained by continuous spinal ligaments from C1 to the skull base as well as ligaments running from C2 to the basal cranium (the alar ligaments and the apical odontoid ligament) (Figure 5). The inner anterior C1 ring also forms a joint with the C2 odontoid process, which is stabilized by the transverse ligament. This joint, and the almost horizontally oriented facet joints C1/C2 with high laxity ligaments, allows rotation of C1 around the odontoid of C2 (the NO joint). Posterior to the transverse ligament is the tectorial membrane, which is a prolongation of the posterior longitudinal ligament (PLL). A part of the tectorial membrane, the accessory atlantoaxial ligament, seems to participate in craniocervical stability and connects the posterior body of C2 to the lateral mass of C1. The upper cervical spine (C0-C2) is responsible for 50% of the total neck flexion-extension at the atlanto-occipital (OC-C1) joint and 50% of the total neck rotation at the atlanto-axial joint (C1-C2).

The odontoid process of C2 is vascularized by the posterior ascending and anterior ascending arteries from the vertebral arteries. The internal carotid artery gives vascularization through the cleft perforator vessels, which create a plexus at the base of the odontoid (Figure 6). A disruption in the blood supply that occurs with OFx type II leads to poorer bony fusion and a high rate of nonunion in these patients. OFx type III runs through cancellous bone with a rich blood supply, which is probably one of the reasons for the higher bony union rate in this fracture type.

Figure 1. Normal CT scan of the cervical spine, coronal view (A) and sagittal view (B).

Figure 2. MRI scan of the spinal cord in a sagittal view at the level of vertebra C2.

Figure 3. Normal CT precerebral angiography, coronal view.

Figure 4. Anterior (A) and sagittal (B) view of vertebra C2.

From Micheau A, Hoa D, e-Anatomy, www.imaaios.com, DOI: 10.37019/e-anatomy [2].

Permission granted 2nd February 2021.

Figure 5. Ligaments of the upper cervical spine, posterior (A) and sagittal (B) views. From Micheau A, Hoa D, e-Anatomy, www.imaaios.com, DOI: 10.37019/e-anatomy [2]. Permission granted 2nd February 2021.

Figure 6. The arterial supply of the odontoid process in anterior (A) and sagittal (B) views. From Schiff DC, Parke WW. The arterial supply of the odontoid process. *J Bone Joint Surg Am* 1973;55:1450–1464 [3]. Permission granted 3rd February 2021.

EMBRYOLOGY OF THE ODONTOID PROCESS

It is believed that in the 6th-7th week of embryological development, the odontoid process is detached from the anterior part of the first cervical vertebra (C1). The odontoid process then migrates caudally to join the second cervical vertebra (C2). The second vertebra (C2) is formed by six parts: the body, two neural arches, two half odontoid processes and a secondary ossification by ossiculum terminale at the apex of the odontoid process (Figure 7). The odontoid process is divided from the C2 body by synchondroses in the base until the age of 5-6 years old, and then we find gradual ossification of this part (Figure 8) [4]. Figure 9 shows a pediatric patient with OFx where the synchondroses are still visible.

Figure 7. CT scan of normal pediatric cervical spine, coronal view (A) and sagittal view (B).

Figure 8. Formation of C2 vertebra (A). Sagittal CT image: secondary ossification of the apex of the odontoid process (B). Axial CT image: primary ossification centers of the odontoid process (C).

From Akobo, S., Rizk, E., Loukas, M. et al. The odontoid process: a comprehensive review of its anatomy, embryology, and variations. *Childs Nerv Syst* **31**, 2025–2034 (2015) [4].

Permission granted 3rd February 2021.

Figure 9. CT scan of OFx type III in a pediatric patient, coronal view (A) and sagittal view (B).

EPIDEMIOLOGY OF ODONTOID FRACTURE

The reported incidence of traumatic cervical spine fractures (CS-Fx) in the Western general population ranges from 4 - 17/100,000/year [5-10]. The typical CS-Fx patient has historically been a young male injured in a road traffic accident. Recent reports and daily clinical practice give a clear indication of a change in the typical CS-Fx patient from a young male to an elderly male or female with comorbidities, similar to what has been observed for patients with traumatic brain injury (TBI) [5,6,11-13]. Recent Norwegian epidemiological studies have shown that OFx comprises approximately 20% of all CS-Fx [5,6]. OFx is the most common type of CS-Fx in the elderly population above 65 years of age and, in most cases, is caused by a low energy fall. Given the aging of the population worldwide, the incidence of fall-related CS-Fx, especially OFx, is expected to continue rising. This tendency of increasing incidence of C2 fractures in more recent decades has been supported by several publications [10,14-16]. This development might be countered by effective fall prevention measures. Defined risk factors for falls are age > 80 years, comorbidities, polypharmacy, impaired cognition, impaired hearing, and impaired vision [17-19].

The most feared complication of CS-Fx is SCI. Fracture dislocation at the C2 level carries a risk of SCI, and when a patient suffers a SCI at the C2 level, there is a high risk of lethal deficits with tetraparesis and insufficient respiration (Figure 10). The rate of concomitant SCI in patients with OFx is reported to be in the range of 2 – 13% [20-25]. Most reports are from subpopulations, and population-based data are sparse. SCI secondary to OFx occurs in most cases at the time of injury but can also be observed later in the treatment period, where the odontoid process is dislocated due to failure of primary conservative treatment or secondary displacement after fixation of the fracture. The fraction of OFx patients suffering SCI due to

insufficient stabilization is unknown. More reliable data are needed. The “true” incidence of OFx with concomitant SCI should also ideally involve autopsy material from trauma deaths at the scene [26-29].

Figure 10. Spinal cord injury at the C2 level on CT scan (A) and MRI scan (B).

CLASSIFICATION OF ODONTOID FRACTURE

The first to describe a classification system for OFx was Schatzker et al in 1971, who divided the fractures into high or low depending on whether the fracture line was above or below the accessory ligament [30]. In 1973, Roy Camille suggested classifying OFx according to the direction of the fracture lines: backwards sloping, forwards sloping, and horizontal fractures [31-33]. In 1974, Anderson and D'Alonzo proposed classifying OFx into types I, II, and III, where type I fractures involve the tip of the odontoid, which are rare, while in type II the fracture line traverses the base of the odontoid process, and in type III the fracture line extends into the body of C2 without specifying involvement of the C1/C2 joint (Figure 11) [34].

*Figure 11. Classification of OFx according Anderson and D'Alonzo.
From Grauer JN, Shafi B, Hilibrand AS, et al. Proposal of a modified, treatment-oriented classification of odontoid fractures. Spine J. 2005 Mar-Apr;5(2):123-9 [35]. Permission granted 15th February 2021.*

OFx type II and III are unstable fractures. In 1988, Hadley et al described a subtype of OFx type II, subtype IIa, which is a comminuted fracture with associated free fragments at the base of the odontoid. This injury was interpreted to be highly unstable and required early surgery [36]. In 2005, Grauer et al proposed a modification of the Anderson and D'Alonzo classification, including fracture line involvement of the C1/C2 facet joint in a coronal view and the direction of the fracture line in a sagittal view [35]. If the fracture line crossed one or both facet joints for C1/C2, the fracture was classified as a type OFx III fracture, and otherwise it was a type II fracture (Figure 12). This distinction led to a more exact division between OFx type II and III fractures.

Figure 12. Distinction between OFx type II and III. The left illustration shows OFx type III according to the classification from Anderson and D'Alonzo but OFx type II according to the classification by Grauer et al. The right illustration shows OFx type III according to both classification systems.

From Grauer JN, Shafi B, Hilibrand AS, et al. Proposal of a modified, treatment-oriented classification of odontoid fractures. Spine J. 2005 Mar-Apr;5(2):123-9 [35]. Permission granted 15th February 2021.

Grauer et al further subclassified OFx type II into three different subgroups depending on the fracture pattern in the sagittal view, which serves as a basis to recommend a surgical approach (Figures 13 - 16). A type IIA fracture is a horizontal fracture line, up to 1 mm displaced. A type IIB fracture has a fracture line from anterosuperior to posteroinferior or a horizontal fracture line above 1 mm displaced. A type IIC fracture has a fracture line from anteroinferior to posterosuperior or a comminuted OFx type II. Figure 17 shows a CT scan of an OFx type III fracture according to the Anderson and D'Alonzo and Grauer classification.

Figure 13. Subdivision of OFx type II.

From Grauer JN, Shafi B, Hilibrand AS, et al. Proposal of a modified, treatment-oriented classification of odontoid fractures. Spine J. 2005 Mar-Apr;5(2):123-9 [35]. Permission granted 15th February 2021

Figure 14. OFx type IIA according to Grauer classification, coronal view (A), sagittal view (B).

Figure 15. OFx type IIB according to Grauer classification, coronal view (A), sagittal view (B).

Figure 16. OFx type IIC according to Grauer classification, coronal view (A), sagittal view (B).

Figure 17. OFx type III according to Anderson and D'Alonzo and Grauer classification, coronal view (A), sagittal view (B)

SYMPTOMS, SIGNS, AND DIAGNOSIS OF ODONTOID FRACTURE

The majority of patients with acute traumatic OFx present with pain localized in the upper portion of the neck, which increases in intensity with the use of neck muscles and neck movement. A few patients have no or only minor neck pain immediately after the injury, which can result in a diagnostic delay. Spinal cord injury (SCI) is reported in 2 – 13% of patients with OFx [20-25]. SCIs are classified according to the ASIA Impairment Scale (AIS) [37].

- Grade A: The impairment is complete. There is no motor or sensory function in the sacral segments.
- Grade B: The impairment is incomplete. Sensory function, but not motor function, is preserved below the neurological level*, and some sensation is preserved in sacral segments S4 and S5.
- Grade C: The impairment is incomplete. Motor function is preserved below the neurological level, but more than half of the key muscles below the neurological level have a muscle grade less than 3 (i.e., they are not strong enough to move against gravity).
- Grade D: The impairment is incomplete. Motor function is preserved below the neurological level, and at least half of the key muscles below the neurological level have a muscle grade of 3 or more (i.e., the joints can be moved against gravity).
- Grade E: The patient's functions are normal. All motor and sensory functions are unhindered.

* Neurological Level of Injury: The **most caudal** (lowest) level at which both motor and sensory modalities are intact on both sides of the body

A severe SCI at the C2 level (e.g., secondary to a displaced OFx) is often associated with quadriplegia and insufficient respiration (Figure 10). A few patients with OFx die immediately at the scene of the accident due to injury to the upper SCI causing respiratory and cardiac arrest [26-29]. Patients with OFx can have swallowing difficulties or hoarseness secondary to prevertebral hematoma, fracture displacement, or cervical immobilization [38].

Radiological examination of the neck after trauma is strongly recommended in patients who have [39-41]:

- Neck pain
- Neurological deficits or a history of transient neurological symptoms after trauma
- Midline cervical spine tenderness (increased by touching and palpation, different from neck pain where it persists without touching and palpation)
- Significant injury (high energy trauma)
- Reduced alert or unconscious patients who cannot be assessed
- Multitraumatic injury which distract neck examination
- Patients $\geq$ 65 years of age and significant signs of direct trauma towards the head/neck

There are several imaging modalities that can be used in the diagnosis of cervical spine injuries:

- *Plain X-ray* is no longer recommended for clearing cervical spine injuries [42,43] due to the high risk of missing injuries [44]. Flexion/extension X-ray is not recommended

as the primary modality due to the potential risk of increased dislocation causing SCI [44,45].

- *Computed tomography (CT)* with reconstructions in three planes (coronal view, sagittal view, and axial view) is the recommended primary imaging modality to diagnose CS-Fx [43,45,46]. CT diagnoses bone injuries, dislocations, and malalignments. Information about disco-ligamentous injuries and SCI is only indirect [45]. There are some concerns regarding the radiation dose with repeated CT scans.
- *Magnetic resonance imaging (MRI)* is the preferred imaging modality with respect to disco-ligamentous injuries and SCI [47]. MRI is mandatory in patients with signs of SCI. In cases with clinical signs of significant cervical neck injury and normal neck CT, an MRI scan should be performed to look for disco-ligamentous injuries.
- Vertebral artery injury is not rare in cervical trauma patients. The expanded Denver criteria recommend computed tomography angiography (CTA) in all patients with cervical fracture [48,49]. Such a liberal screening policy may result in overtriage and unnecessary radiation exposure.

NEXUS and the Canadian C-spine rule are the most commonly used scales for cervical spine clearance [40,41]. There is some concern regarding the reliability of these rules [50]. Missed injuries can be a consequence of several factors, especially physiological changes in elderly individuals, which include cognitive decline and musculoskeletal changes [50-52]. Therefore, it has been suggested to be liberal with imaging the cervical spine after trauma in elderly individuals ≥ 65 years, even with low-energy mechanisms [44,50,51].

TREATMENT OPTIONS FOR ODONTOID FRACTURE

The main treatment aims for acute OFx are to restore alignment, prevent secondary dislocation, prevent secondary SCI, and achieve stable permanent fusion [34,35]. Achieving these goals is associated with good functional outcomes and low grade neck pain.

Conservative treatment

External immobilization of OFx can be achieved with a halo vest or stiff neck collar (Figure 18). Halo vest is associated with a high bony fusion rate, up to 70 – 80% [38,53,54]. Halo vest use is associated with many complications, such as local wound infection, pin loosening, pressure wounds, pin penetration of the cranium and subdural abscess, swallowing difficulties, and acute psychosis [24,38,53,55-59]. For these reasons, halo vest use has declined worldwide and has not been used for many years in some departments (e.g., OUH).

External immobilization of OFx with a stiff (rigid) neck collar is easier to apply and better tolerated by patients. Systematic reviews comparing halo vests and stiff neck collars have not shown significant differences with respect to bony fusion rates, but the complication rate is significantly higher for halo vests [59]. There are different types of neck collars, and the most common are Aspen, Vista, Malibu, Philadelphia, or Miami J collars. At OUH, we use the Miami J Collar. Potential problems with stiff neck collar are compression of jugular veins in patients with concomitant TBI, pressure injury on the skin, and atrophy of cervical muscles and ligaments [60,61].

Figure 18. Halo vest, front view (A). Hard collar, front view and back view (B).

Copyright by AO Foundation, Switzerland. Source: AO Surgery Reference, www.aosurgery.org/ [62]. Permission granted 9th April 2021.

The level of evidence for the duration of external immobilization for OFx is poor. Many studies evaluate the success of external immobilization without providing information on the duration of treatment. In studies where the duration of external immobilization was included, the length of external immobilization was reported to range from 10 to 14 weeks [58,60,63].

Surgical treatment

Several surgical techniques are used for internal stabilization of OFx. Below is a brief overview of the most commonly used techniques.

- Anterior odontoid screw fixation (Figure 19) was first described by Nakanishi in 1980 [64] and followed up by several authors, such as Bohler in 1982 and Borne in 1988 [65,66]. The advantages of this procedure are surgery in the supine position, usually limited perioperative blood loss, and preserved motion in the C1/C2 joint. The surgical approach can be challenging if the patient is obese and has a short neck. Contraindications for this technique are a comminution fracture of the C2 body, OFx

type IIC, disrupted transverse ligament, grave osteoporosis, or an “old fracture” [63,65]. A dislocated fracture must be realigned before screw placement, which is not always possible. The standard procedure is performed with one compression screw penetrating the bony cortex at the tip of the odontoid. Some studies report better stability and higher fusion rates using two screws compared to one [67-69], whereas others report up to a 96% bony union rate with one screw fixation [70]. The anterior screw fixation technique should not be used in nonunion (pseudarthrosis) patients due to the very low rate of healing [63]. Bony fusion rates after anterior screw fixation are reported to range from 73 to 100% [71].

- Posterior sublaminar wiring with grafts placed between the C1 and C2 spinous processes was first described by Gallie in the late 1930s (Figure 20) [72,73]. This technique depends on an intact C1 ring, which is important to know because 5 – 53% of patients with OFx also have a fracture in C1 [74-76]. The surgery is performed in the prone position, which is associated with prolonged surgery and increased pressure on anterior structures of the body. The posterior wiring restricts motion between the C1 and C2 joints. The sublaminar placement of the wires can potentially create an SCI [77]. The main advantages of this technique are high fusion rates > 97% [73] and the ability to reduce almost any atlantoaxial subluxation [78]. Compared to posterior screw fixation, the sublaminar wiring technique is associated with less blood loss, shorter surgery time, and less perioperative radiation exposure [79].
- Posterior transarticular C1-C2 screw fixation was described by Magerl and Seeman (Figure 21) [80,81]. In recent decades, this procedure has become more commonly used than wiring as it provides more immediate stabilization. The path of the vertebral artery and subluxation between C1-C2 can represent a contraindication for

this technique [82]. All patients should undergo CTA before surgery to visualize the path of the vertebral artery. The procedure is performed in a prone position. The bony fusion rate with this procedure is > 95%, and the rate of neurological and vascular injuries is low [83,84].

- In 2001, Harms and Melcher described posterior fusion of the C1 lateral masses and the C2 pedicles with polyaxial screws and rods (now often called the Harms technique). The main advantages of this technique are the reduction of C1/C2, strong biomechanical stability, and protection of the C1/C2 joint, enabling later screw removal to regain C1/C2 motion (Figure 22) [82]. Despite these advantages, the technique is technically demanding and carries a risk of perioperative bleeding, injury to the C2 root with later occipital neuralgia, and SCI [85]. The surgery is done in a prone position. The bony fusion rate is reported to be ~100% [82,85]. The implementation of spinal navigation for screw insertion has increased the use of the Harms technique and reduced the rate of screw malposition [86].
- Occipitocervical fusion of an OFx can be considered if the fracture is part of a complex injury in the upper cervical spine with severe ligamentous injury (Figure 23) [87]. The procedure is performed with the patient in the prone position, resulting in high stability in the craniocervical junction [88], but results in severe restriction of range of motion (ROM) and is only used as a last resort strategy in complicated high-neck trauma patients [89]. Occipitocervical fusion carries a risk of vertebral artery injury, venous bleeding, and C2 neuropathy [88]. The fusion rate after occipitocervical fixation is reported to range from 95 to 100% [90].

In the last decade, the introduction of spinal navigation has improved the accuracy and safety of some of these procedures and resulted in less intraoperative radiation exposure to the patient and the surgical team [91]. Screw placement using a combination of spinal navigation and robots has recently been tested but has thus far not gained widespread use (Figure 24 - 25) [92,93].

Figure 19. OFx treated with one single odontoid screw. Preoperative (A), postoperative compression screw penetrating the bony cortex at the tip of the odontoid (B), and 3D scan (C).

Figure 20. OFx treated with posterior wiring. Preoperative (A), postoperative 3D (B), postoperative midsagittal (C), right side sagittal view (D), and left side sagittal view (E).

Figure 21. Magerl's transarticular screw technique for atlantoaxial stabilization, lateral view (A) and posterior view (B).

From Chen Q, Brahimaj BC, Khanna R, Kerolus MG, Tan LA, David BT, Fessler RG. Posterior atlantoaxial fusion: a comprehensive review of surgical techniques and relevant vascular anomalies. *J Spine Surg.* 2020 Mar;6(1):164-180. doi: 10.21037/jss.2020.03.05 [94].

Permission granted 14th April 2021.

Figure 22. OFx treated with posterior osteosynthesis ad modum Harms. Preoperative (A), postoperative 3D (B), postoperative midsagittal (C), right side sagittal view (D), and left side sagittal view (E).

Figure 23. OFx treated with posterior osteosynthesis occipito-cervical fixation. Preoperative (A), postoperative 3D (B), postoperative midsagittal (C), right side sagittal view (D), and left side sagittal view (E).

Figure 24. Spinal navigation (A) and intraoperative image guidance for cervical spine surgery used in subaxial fixation (B).

Figure 25. Robot-assisted anterior screw fixation with TiRobot.

From Tian W, Wang H, Liu YJ. Robot-assisted Anterior Odontoid Screw Fixation: A Case Report. Orthop Surg. 2016 Aug;8(3):400-4 [92]. Permission granted 24th March 2021

Choosing the appropriate surgical technique can be challenging, and currently, there is no level I evidence to guide us. It is well known that anterior odontoid screw fixation preserves normal atlantoaxial rotation but has a higher rate of nonbony fusion. On the other hand, posterior fixation provides better stability and a higher bony fusion rate but is more demanding for frail, elderly patients because of the prone position, longer surgery time, and higher blood loss. In 2017, Petterson et al performed a retrospective analysis of a prospective database showing that an anterior approach for surgery had shorter surgical times but higher revision rates than a posterior approach for surgery [95]. Two meta-analyses have shown that posterior screw fixation has a higher bony fusion rate in elderly patients than anterior screw fixation [71,96]. Today, the most commonly used anterior

technique is single odontoid screw fixation, and the most commonly used posterior fixations are transarticular fixation of C1-C2 or Harms fixation.

External immobilization after surgery

There is a large variation in practice regarding the use of cervical orthosis after OFx fixation surgery, from no orthosis to orthosis for 4-12 weeks. Currently, there is no level I evidence to guide us regarding the postoperative use of cervical orthosis.

AVAILABLE TREATMENT RECOMMENDATIONS FOR ODONTOID FRACTURE

OFx Type I

OFx type I can be treated with external immobilization only, and the published fusion rates are excellent. If an OFx type I is present in the setting of occipitocervical instability, the latter will dictate the treatment measures. There is no controversy regarding OFx type I [35,63,69,97].

OFx Type II

OFx Type II are unstable and in need of stabilization. The treatment options are external immobilization or surgical fixation. At present, there are no generally accepted guidelines regarding the choice of immobilization for this fracture type. The main recommendation has been surgical treatment in all patients above 50 years with OFx Type II and for significantly dislocated OFx type II in patients younger than 50 years of age [98,99]. The main reason for this recommendation is the observed low bony fusion rates after treatment with external immobilization alone in OFx Type II. Despite this recommendation, several studies describe a low rate of surgery for OFx Type II in the elderly population [20,21,100-102]. Publications recommending primary surgery for all OFx type II often mention the high comorbidity in elderly patients but omit the inclusion of age and comorbidity in their treatment recommendations [24,38,68].

This situation represents a challenge during treatment decisions because the majority of patients with OFx are elderly and have severe comorbidities. Elderly individuals have a higher risk of surgical complications and death [103]. Some studies have challenged the recommendation and indicated that fibrous union (nonbony stable fusion) in the elderly

population can be an acceptable outcome if it provides long-term stability [104-106]. Fibrous union has been defined as the lack of pathological movement of the odontoid fragment on flexion/extension X-ray at 12-16 weeks despite the absence of radiologically evident bony fusion [104,107,108]. A concern in accepting fibrous union as an acceptable outcome is the unknown potential for late development of new-onset SCI or persistent severe neck pain due to pseudarthrosis [109,110]. Fibrous union can be accepted as a sufficient outcome in OFx patients with high surgical risk if the rate of new-onset SCI is close to zero and the rate of long-term severe neck pain is low. Recently, some groups reported that older age and comorbidities should be considered independent variables in the treatment algorithms for OFx and that stable fibrous union should be regarded as an acceptable outcome [23,104,105,111].

The evidence that forms the basis of the recommendation for primary surgical treatment is mostly level II or III evidence. The need for class I evidence in the management of OFx is indeed important, but such information is difficult to obtain. Many patients are too old and frail to tolerate general anesthesia, and comparing two groups in randomized controlled trials would be biased by the need to eliminate a major portion of the patients because of their medical complexity. With the lack of RCTs, large population-based cohort series including all patients will provide important insight regarding outcomes following different treatment modalities, even though it is not class I evidence. However, ongoing studies will hopefully provide class I and II research [112-114].

OFx Type III

OFx type III is an unstable fracture in need of stabilization. In contrast to OFx type II, there is a generally accepted consensus to use primary external immobilization of OFx type III, except for patients with major displacement of the odontoid fragment [38]. Bony fusion rates after external immobilization alone are reported to be significantly higher for OFx type III than for type II because of the larger surface of cancellous bone and the rich blood supply in OFx type III [115]. Surgery is recommended primarily if the displacement of the odontoid fragment is ≥ 5 mm anteriorly or ≥ 3 mm posteriorly or if the angulation is $\geq 11^\circ$ in either the anterior or posterior direction [116,117]. If external immobilization treatment fails, the patient should be considered for surgery.

PREVENTION OF NECK TRAUMA IN ELDERLY PATIENTS

Falls are the most common trauma causing OFx, especially in the elderly. The World Health Organization has described several risk factors for falls, including polypharmacy, comorbidity, age over 80, cognitive impairment, impaired vision and hearing, and environmental factors [17-19]. Fall prevention interventions in elderly individuals may include the following:

- a healthier lifestyle with exercise
- balance exercise
- vitamin supplements
- critical revision of all prescriptions
- modification of the environment
- vision correction
- hearing aids
- walking support

Such interventions reduce falls in the elderly population [17,18,51,101,118-120].

Osteoporosis is an important public health problem as the population ages. With increasing age, the reabsorption of bone is increased, and the formation of new bone is decreased. This process leads to thinner and more fragile bone. Kaesmacher et al published a retrospective study in 2017 in which they measured cervical bone mineral density in all patients admitted with a cervical spine injury. They found significantly lower cervical bone mineral density in old OFx patients compared to patients with other cervical spine injuries [121]. The European League Against Rheumatism (EULAR) and the European Federation of National Associations

of Orthopaedics and Traumatology (EFORT) recommend the use of pharmacological treatment of osteoporosis to reduce the risk of vertebral, nonvertebral, and hip fractures [122].

FRAILITY

Frailty has recently been described as an age-associated syndrome in older people that makes them more vulnerable [123]. Frailty leads to an increased risk of poor outcomes, including mortality, in the setting of acute disease and injury. Frail patients present with weakness and reduced tolerance to medical and surgical treatment. Comorbidities are the causes of frailty, whereas disability is a consequence of frailty [123]. The frailty index was developed by Rockwood et al. in Canada to describe a multidimensional approach to mapping deficits in elderly people, which included diseases, signs and symptoms, laboratory abnormalities, and disabilities in activities of daily living [124]. Several frailty indexes have been created to find a measure of physiological reserve capacity, as there is no clear clinical definition of frailty [125,126]. Some indexes emphasize comorbidities, but as Rockwood describes, it should be a multidimensional approach to frailty. Frailty indexes have been described to be a predictor of morbidity and mortality. In recent years, several studies have been published where they use a frailty index as a tool to identify the risk of complications in patients [127-129]. Several studies on patients with OFx explain frailty as a separate, independent risk factor for increased complications and poor outcomes [128,130], but no generally accepted index has been validated in OFx patients. As OFx is the most common CS-Fx in the elderly population, many patients will be too frail to tolerate anesthesia and surgical treatment. As a result, inclusion in RCTs is expected to be biased because of the need to exclude a major portion of frail patients. Including all patients in a surgical/nonsurgical “lottery” would be considered unethical by most spinal surgeons. It would strengthen management of OFx patients if a frailty index was developed and validated for these patients to support decisions about OFx treatment.

It is well known that surgical risk is increased in the elderly population due to poor bone health and comorbidities. As a result of an aging population, more elderly people are undergoing emergency surgery. Castillo-Angeles et al. published a cross-sectional study in 2020 in which they analyzed over 800,000 patients undergoing emergency surgery. They concluded that frailty was significantly associated with mortality even when it was a low-risk surgical procedure [131]. Other studies have also shown that frailty is associated with postoperative mortality [132]. If surgery is considered in elderly patients, the risk of anesthesia and surgery should be assessed individually. Spine surgery in elderly patients demands longer hospital stays, and mortality and complication rates are increased [133].

Paper I:

The aims were to study the epidemiology of OFx in Southeast Norway, compliance with current treatment recommendations for primary stabilization (surgical fixation versus external immobilization) and reasons for noncompliance.

Our main hypotheses were

- OFx is mainly diagnosed in elderly patients, often with severe comorbidities
- Open surgical fixation is less frequently performed than recommended
- Surgical fixation is in many cases not performed due to older age and severe comorbidities.

Paper II:

The aims of this study were to study the long-term outcomes after conservative and surgical treatment for OFx type II and to evaluate whether our current practice of a low rate of surgical fixation in elderly patients provides an acceptable outcome. The main outcome measures are the rate of conversion to surgery, rate of new-onset SCI, rate of stable fusion, and neck pain.

Our main hypotheses were

- Primary conservative treatment of OFx type II can be an acceptable alternative to primary surgery in older patients with comorbidities if the rate of conversion to

surgery is low, the rate of new-onset SCI is low, the rate of stable fusion is high, and the rate of severe neck pain is low.

Paper III:

The aims of this paper were to study the long-term outcomes after conservative and surgical treatment for OFx type III and to evaluate whether our current practice of a low rate of surgical fixation in elderly patients provides an acceptable outcome. The main outcome measures were the rate of conversion from external immobilization to surgery, rate of new-onset SCI, rate of stable fusion, and neck pain.

Our main hypotheses were

- Primary external immobilization of most OFx type III is associated with satisfactory outcomes, both regarding fusion rates and clinical parameters.

PART III: MATERIALS AND METHODS

PATIENTS

Paper I: All patients in the southeastern Norwegian population (3.0 million) diagnosed with a traumatic OFx in the period from 2015 to 2018 (N = 336) were included. Only patients with a unique, 11-digit Norwegian Social Security Number living in Southeast Norway were included. The following patients were excluded: 1. Patients with pathological fracture, and 2. patients with delayed diagnosis not having started primary treatment within 90 days of trauma.

Paper II: All OFx type II patients diagnosed by cervical CT in Southeast Norway in the eight-year period from 2009 – 2011 and 2013 – 2017 (N = 282). The year 2012 was omitted due to incomplete registration that year. Only patients with a unique, 11-digit Norwegian Social Security Number living in Southeast Norway were included. The following patients were excluded: 1. Patients with pathological fracture, and 2. patients with delayed diagnosis not having started primary treatment within 90 days of trauma.

Paper III: All OFx type III patients diagnosed with cervical CT in Southeast Norway in the eight-year period from 2009 – 2011 and 2013 – 2017 (N = 212). The year 2012 was omitted due to incomplete registration that year. Only patients with a unique, 11-digit Norwegian Social Security Number living in Southeast Norway were included. The following patients were excluded: 1. Patients with pathological fracture, and 2. patients with delayed diagnosis not having started primary treatment within 90 days of trauma.

ETHICS

All studies were approved by the data protection official (DPO) at Oslo University Hospital (OUH - DPO approval no 2016/7495) and the Regional Ethical Committee (approval no 2018/1887). Written informed consent was obtained from patients participating in the long-term follow-up studies. Paper I was classified as a quality control study based on registry data, and informed consent was waived. The OUH quality database for acute CS-Fx is maintained by the Department of Neurosurgery (OUH - DPO approval no 2014/12304).

STUDY DESIGN

Paper I: Population-based, prospective registration of all traumatic OFx in the southeastern Norwegian population (3.0 million) from 2015 to 2018.

Papers II and III: The main aims of these studies were to evaluate outcomes after conservative and surgical treatment of OFx. Ideally, these evaluations should have been done in randomized controlled trials (RCTs) where patients are allocated randomly to different treatment groups. Randomization ensures that the risk of bias and confounding is minimized. This method is the gold standard in epidemiological research for evaluating interventions in groups and finding a causal link between the intervention and the outcome. RCTs are considered level 1 evidence. A large fraction of OFx patients are old with significant comorbidities, making randomization into a conservative arm and a surgery arm very difficult. Most likely, >50% of the patients will be excluded. Therefore, we decided to use an observational cohort study method for papers II and III.

An observational cohort study is used when the aim is to study whether exposures are associated with disease. In a prospective, observational cohort study, a group of subjects are followed over time. Exposure is registered at the start of the study. The advantage of a prospective cohort study is that several exposures and outcomes can be studied, but follow-up is necessary. In a retrospective (historical) cohort study, groups of subjects are identified using preexisting data on exposed and unexposed individuals in the past, regardless of outcome status. According to The Centre for Evidence-Based Medicine, cohort studies are level 2 evidence.

The Centre for Evidence-Based Medicine, Oxford in 2009 [134]:

- 1a: Systematic reviews (with homogeneity) of randomized controlled trials
- 1b: Individual randomized controlled trials (with narrow confidence intervals)
- 1c: All or none randomized controlled trials
- 2a: Systematic reviews (with homogeneity) of cohort studies
- 2b: Individual cohort study or low-quality randomized controlled trials (e.g., <80% follow-up)
- 2c: "Outcomes" Research; ecological studies
- 3a: Systematic review (with homogeneity) of case-control studies
- 3b: Individual case-control study
- 4: Case-series (and poor-quality cohort and case-control studies)
- 5: Expert opinion without explicit critical appraisal, or based on physiology, bench research, or "first principles".

Paper I:

Population-based, prospective observational cohort study

The data were retrieved from our quality control database for traumatic CS-Fx in southeastern Norway. In this database, all patients with CS-Fx (C0/C1 to C7/Th1) who were diagnosed in our health region were prospectively registered. The database contains information on age, sex, comorbidities, injury mechanism, fracture morphology, and treatment. Incidence, demographics, and treatment of OFx are presented.

Previous treatment recommendations for OFx included primary surgical fixation for OFx type II and III fractures with major displacement of the odontoid fragment, regardless of the patient's age, and for all OFx type II patients aged ≥ 50 years. For the remaining patients with OFx, primary external immobilization is recommended. Major sagittal displacement of the odontoid fragment was defined as a translation ≥ 5 mm anterior or ≥ 3 mm posterior.

Compliance with these recommendations was estimated, and reasons for noncompliance were categorized as follows: surgery was not performed due to high age and/or comorbidities, the diagnosis was delayed >12 weeks, or the presence of a nonsurvivable injury.

Data were summarized as frequencies and means or medians according to the distribution of the variables. Pearson's chi-squared tests were used to compare differences in frequencies between groups because our data are nonnormally distributed data. This test is a robust test with respect to the distribution of the data because it does not require equality

of variances among groups. The Kruskal-Wallis test was used to compare the distributions between multiple groups. This test is a nonparametric alternative to one-way ANOVA. In the Kruskal-Wallis test, we do not have to make any assumptions regarding whether it is a continuous or a categorical variable. The Poisson model is a method for count data and is often used in large cohort studies. This model is used in regression analysis to identify which variables have an impact on a topic of interest. It is often used when the outcome variable is a count variable. A Poisson model was used to investigate the effect of age on the incidence of injury in the different age groups. The logistic regression model is an important tool in the analysis of epidemiological data where the interest is to analyze an outcome. Both uni- and multivariate logistic regression models were fitted for binary dependent variables. The advantage is avoiding confounding effects by analyzing all variables together. R package v3.6 was used for statistical analyses. P-values less than 0.05 were considered significant.

Paper II and III

Prospective observational cohort studies

The present studies were based on data extracted from our quality control database for acute CS-Fx (age, sex, comorbidities, injury mechanism, fracture morphology, and treatment). In addition, long-term follow-up was performed from 2018 to 2019 and included clinical and radiological examinations. At the time of follow-up, the following outcome measures were collected: fusion status, crossover from primary conservative treatment to surgical fixation, new-onset SCI, and neck pain.

Bony fusion at the end of primary treatment was defined as either bone trabecula traversing the fracture line on cervical CT and/or posterior fusion in the graft after surgery.

We used the following criteria to define fibrous union at the end of primary treatment. If criteria 1-4 were fulfilled, we concluded that fibrous union had occurred, and dynamic flexion/extension studies were not performed. If the patient failed on criteria 2, 3, or 4, a dynamic flexion/extension X-ray was performed. If movement of the odontoid fragment in the anterior-posterior direction during the dynamic flexion/extension study was ≤ 2 mm, we concluded that fibrous union had occurred.

1. Lack of bone trabecula traversing the fracture line on cervical CT
2. No change in the position of the odontoid fragment on cervical CT at the end of primary treatment
3. Neck pain ≤ 3 on a VAS and no new-onset myelopathy at the end of primary treatment and before collar removal
4. No increase in neck pain after collar removal
5. No pathological movement of the odontoid fragment (≤ 2 mm) during the dynamic flexion/extension X-ray performed at 12-16 weeks

Pseudarthrosis at the end of primary treatment was defined as > 2 mm movement of the odontoid fragment in the anterior-posterior direction during the dynamic flexion/extension study. This definition of pseudarthrosis deviates slightly from the most commonly used definition, and we use the phrase before 6 months has elapsed from the start of treatment.

Frailty was not a concept used by our research group at the start of these studies. Preinjury clinical status/functioning of the included patients is described by the variables age in years,

living status at time of injury (home – self-reliant, home – with assistance or institutionalized), and preinjury American Society of Anesthesiologists (ASA) score [135].

Data are described by counts, percentages, medians, means, ranges, and standard deviations where appropriate. Overall survival (OS) analyses were performed using Kaplan-Meier curves, which measured survival from the time of surgery to the time of death. For nonnormally distributed data, we used the Mann-Whitney U-test between two independent samples. The Mann-Whitney U-test is a nonparametric alternative to the t-test, which is frequently used. Instead of comparing the means of two groups, medians were compared. A paired Wilcoxon signed-rank test was used for paired data when participants were measured under two different conditions (e.g., major displacement and failure of primary external immobilization). This test compares ranks and not the means and is a nonparametric alternative to repeated measures t-tests. Spearman's rank-order correlation was used to determine the association and strength between ordinal variables that were used in nonparametric data. We used this test to determine the association between age and NDI. A p-value < 0.05 was considered statistically significant. The statistical analyses were performed using SPSS v25.0 (SPSS Inc., Chicago, IL, USA).

Paper I: Odontoid fractures: Impact of age and comorbidities on surgical decision making

Three hundred thirty-six patients with OFx were diagnosed in the southeastern Norwegian population (3.0 million) from 2015 to 2018, resulting in an overall incidence of 2.8/100,000 persons/year. The median patient age was 80 years (range 6–100 years), and 150/336 (44.6%) were females. The number of OFx increased with age (incidence rate ratio 2.5 for 10-year increments, 95% CI 2.3–2.9, $p < 0.001$) (Figure 26). Preinjury major comorbidities (ASA ≥ 3) were present in 213 (63.7%) of the patients, and 115 (34.3%) required assistance with ADL. Increasing age was significantly associated with both a greater number of comorbidities ($p < 0.001$) and a need for assistance with ADLs ($p < 0.001$). According to the Anderson and D’Alonzo classification, the OFx was type II in 199 patients (59%) and type III in 137 patients (41%). The primary fracture treatment was rigid collar alone in 79% of patients and open surgical fixation in 21% of patients. In the multivariate analysis, the following parameters were significantly associated with surgery as the primary treatment: independent living, less serious comorbidities prior to the injury, OFx type II, and major sagittal translation of the odontoid fragment. Conversion from external immobilization alone to subsequent open surgical fixation occurred in 10% of patients. Significant differences in the conversion rate were not observed between patients with OFx type II and III fractures. The level of compliance with the treatment recommendations for OFx was low (Table 1). The main deviation was the underuse of primary surgical fixation for OFx type II. The most common reasons listed for choosing primary external immobilization instead of primary surgical fixation were older age and comorbidities.

Figure 26 - Number of OFx in groups by age and sex.

	Surgery	Conservative	% Compliance
Type II fx in patients aged <50 y without major translation	1/9	8/9	89%
Type II fx in patients aged <50 y with major translation	2/3	1/3	67%
Type II fx in patients aged ≥50 y	61/184	123/184	33%
Type III fx without major translation	2/116	114/116	98%
Type III fx with major translation	4/21	17/21	19%

Table 1 - Rate of compliance with published treatment recommendations for OFx. Green indicates compliance, and red indicates noncompliance.

Paper II: Management and long-term outcome of type II acute odontoid fractures: A population-based consecutive series of 282 patients

During the eight-year study period, we registered 282 consecutive patients with OFx type II, and 54% were males, 84% were ≥ 65 years of age, and 51% were ≥ 80 years of age. Severe comorbidities (American Society of Anesthesiologists, ASA ≥ 3) were seen in 67%, whereas dependent living was registered in 32% of patients. Severe comorbidities and dependent living were significantly associated with increasing age ($p < 0.001$). SCI secondary to the OFx was seen in 5.3% of cases. Primary treatment of the OFx was conservative (external immobilization alone) in 193 patients (68.4%), open surgical fixation in 87 patients (30.9%), and no treatment in two critically injured patients (Figure 27).

Figure 27 - Number of OFx type II by age group according to primary treatment strategy.

At the time of long-term follow-up, 125 patients had died, 9 patients declined their invitation to follow-up, and 5 patients did not respond. Thus, 143 patients were available for follow-up

with a median follow-up time of 39 months (range 5-115 months). At long-term follow-up, the fusion status was bony fusion in 39.2% of patients, fibrous union in 57.3% of patients, and pseudarthrosis in 3.5% of patients. The proportion of bony fusion was significantly higher in the primary surgical fixation group ($p=0.005$). No patients had new-onset SCI presenting after the start of primary treatment. The proportion of crossover from primary external immobilization to surgery was 14.4%, whereas the proportion of revision surgery in the primary surgical group was 9.5%. There was no significant difference between the primary surgical fixation group and the primary conservative treatment group at long-term follow-up with respect to the proportion of pseudarthrosis and degree of neck pain.

Paper III: Favorable prognosis with nonsurgical management of type III acute odontoid fractures: a consecutive series of 212 patients

In this consecutive series of 212 patients with acute OFx type III, the median patient age was 72 years, 56% had severe preinjury comorbidities (ASA score ≥ 3), and 22% lived dependently. Severe comorbidities and dependent living were significantly associated with increasing age ($p<0.001$). The trauma mechanism was fall injury in 82% of patients. The median age of patients injured by falls was significantly higher than that of patients with a nonfall injury ($p<0.001$). At the time of diagnosis, 4% had an OFx-related SCI. Primary treatment was external immobilization alone in 95.3% and open surgical fixation in 4.7% of patients (Figure 28). Patients treated with primary external immobilization alone presented with significantly less translation of the odontoid fragment ($p<0.001$) and less angulation of the odontoid fragment ($p=0.025$) than patients treated with primary surgery. Subsequent crossover to surgical fixation was performed in 5.4% of patients.

Figure 28 - Number of OFx type III by age group according to primary treatment strategy.

At the long-term follow-up, 95.7% of patients had bony fusion of the OFx, 80.5% had minimal/no neck pain, and none developed new-onset SCI. There was no significant difference in long-term follow-up VAS ($p=0.444$) or NDI ($p=0.562$) between the primary external immobilization group and the primary surgical group.

Study designs

Paper I: A prospective observational cohort study of all patients with traumatic OFx in the southeastern Norwegian population (3.0 million) from 2015 to 2018 is presented. This study provided epidemiological information describing patients with OFx and their primary treatment. In addition, treatment strategies were analyzed against demographics, comorbidity burden (ASA), and dependency (ADL). Compliance with the available treatment recommendations is unknown but suspected to be low in subgroups of patients with OFx. The data provided us with the opportunity to describe compliance with these treatment recommendations in this defined population and to see if age and comorbidity covaries with surgical decision making. The limitations and possible disadvantages of this study design are related to the fact that the data are merely descriptive and offer no information on whether these treatment strategies were successful. Data describe a current treatment practice within a department, and factors available for consideration, such as age and comorbidity, could be linked to hidden confounders that are difficult to validate in a descriptive cohort study.

Papers II and III: We collected consecutive patients between 2009 and 2017 and analyzed multiple outcomes in all OFx patients diagnosed and treated within the defined time period. These papers both describe observational cohort studies where outcomes after conservative and surgical treatment of OFx were recorded. The most common and superior method used to eliminate bias is an RCT. However, this method can only be used if the majority of patients in question are suitable for any of the treatment options that are to be studied. In our

opinion, patients with OFx are an example of a patient group where RCTs have large limitations because a large fraction of the patients are too old, sick, and frail to be randomized to surgical treatment. Several studies have been published regarding the underrepresentation of elderly individuals in randomized controlled studies [136-138]. With this issue in mind, a large, population-based cohort series including all patients is important for providing insight into outcomes following different treatment modalities, even though this type of study is not considered class I evidence. The advantage of chosen study method is that it includes large patient cohorts from a defined total population, providing us data on essentially all patients with OFx type II and III within this population in the defined timeframe without bias. We analyzed outcomes after different treatment strategies. The main disadvantage is that the data based on selection for treatment have been provided by a single center. Treatment will always be based on the best judgment of the treating surgeon, both in terms of surgical versus nonsurgical treatment and regarding the choice of surgical technique. There will always be room for divergent judgment between physicians, but most often, a treatment culture is formed within a department. Another limitation is loss at follow-up, primarily because a large fraction of patients died between the time of injury and planned follow-up, leading to missing data. This latter issue must be considered an unavoidable limitation regardless of the study method in this type of patient cohort.

Epidemiology

The incidence of traumatic cervical spine fractures (CS-Fx) in the Norwegian population is reported to be 15/100,000 persons/year [5]. Twenty percent of these fractures are OFx of cervical vertebra 2 (C2). The incidence of OFx in our population was 2.8/100,000

persons/year, which is within the range of previously published studies [5,6,25,102]. The number of OFx increased with age (incidence rate ratio 2.5 for 10-year increments, 95% CI 2.3–2.9, $p < 0.001$). A slight female predominance among older OFx patients has been observed in several studies [24,139,140]. The typical OFx patient in our population was an elderly male or female patient with major comorbidities. The pace of population aging is now much faster than in the past half-century [18], and thus, fall-related OFx are expected to continue rising. We have found that many patients with OFx are considered too frail to tolerate general anesthesia and surgical treatment, and our data clearly reveal that age and comorbidities have an impact on surgical decision-making for patients with OFx. We believe that these findings are also valid for many other countries, especially Western countries.

The most common trauma mechanism in our cohorts was falls (mostly in elderly patients), followed by motorized vehicle accidents (mostly in younger patients). With the increase in life expectancy observed in many countries, awareness of fall risk and preventive programs should be developed as a standard in public health care for the elderly. Fall-related injuries are major reasons for dysfunction, increased need for health care, and death. Preventive intervention includes a healthier lifestyle with exercise, optimal medications, and evaluation of needs for visual or walking aids [17,18,51,101,118-120].

Current treatment recommendations

There is no controversy in considering all acute OFx types II and III as unstable fractures in need of stabilization. However, there is a clear discrepancy between the type of immobilization recommended and clinical practice (paper I). In the following section, we

provide a short summary of the current treatment recommendations for OFx types II and III and a discussion of the potential shortcomings of these recommendations.

OFx type II: Despite the lack of Level 1 evidence, leading spine authorities have recommended surgical fixation for all patients with OFx type II over the age of 50 years. Comorbidity and advanced age were not included in the decision tree. Over the years, several authors have mentioned that “the risks of surgery in the elderly and/or comorbid patients with OFx must be carefully considered on a case-by-case basis” [104,141]. The authors have often defined the elderly as patients ≥ 75 years of age in this context (the WHO definition of elderly is ≥ 65 years). In our cohort, $> 60\%$ of the patients with OFx Type II were ≥ 75 years of age, $2/3$ of the patients had severe comorbidities, and some of these severely comorbid patients were younger than 75 years of age. In other words, nearly 70% of our patients were in the category “treatment should be carefully considered case-by-case”. This situation is probably the main reason why this recommendation never has gained general acceptance and compliance. Another major shortcoming of this treatment recommendation for OFx type II is that it is merely based on the higher bony fusion rate observed after surgical fixation compared to treatment with external immobilization alone. Emerging evidence of fibrous union as an acceptable outcome in elderly patients has not been considered when making these recommendations. Some series have shown lower mortality in elderly patients with OFx type II after surgical fixation compared to external immobilization [106,142,143]. However, this difference is most likely due to selection bias.

OFx type III: It is generally accepted that most OFx Type III fractures can be successfully treated with external immobilization because of the observed high bony fusion rate [23,38,116,117]. Our study confirms successful outcomes after conservative treatment of

most OFX type III. There is no need for revision of treatment recommendations for OFx type III. The excellent outcomes after conservative treatment for OFx type III were achieved using a rigid collar (Miami J), supporting the choice of external immobilization with rigid collar and not use of a Halo vest [38,56,57,59].

Facts (knowledge gained from papers I – III) to consider when revising treatment recommendations for OFx

Paper I – OFx: Major comorbidities were present in approximately 2/3 of the patients, 1/3 needed assistance with ADL, and more than half of the patients were ≥ 80 years of age. Surgery was performed in only 21% of patients. The low use of surgery in our study was associated with older age and comorbidities. Surgery is not a reasonable option for many of these patients.

Paper II - OFx II: We again revealed poor compliance with current treatment recommendations. Despite this poor compliance, good clinical outcomes were registered in the vast majority of patients after conservative management. A large fraction of patients with OFx type II were old with severe comorbidities, in need of help with activities of daily living, and were considered too frail to tolerate anesthesia and surgery. The rate of crossover from external immobilization to surgery in OFx type II was low. Fibrous union was not associated with an increased risk of new-onset SCI or persistent neck pain compared to bony fusion. Thus, fibrous union should be regarded as an acceptable outcome after treatment of OFx type II.

Paper III - OFx III: We found good compliance with current guidelines except for patients with significantly displaced OFx. In this latter group, only 25% were treated with primary surgery despite the recommendation for surgical fixation. Outcomes for patients with OFx type III were excellent using current recommendations, even for the majority of patients with major displacement where we refrained from surgery. To the best of our knowledge, a long-term follow-up of patients with OFx type III has not been published. Our study shows that there is a low rate of crossover from external immobilization to surgery in OFx type III, a very high long-term bony fusion rate, a low rate of long-term severe neck pain, and no cases of new-onset SCI. Our results support the recommendation for external immobilization as the first choice of treatment for OFx type III and that even patients with significant fracture displacement that are not eligible for surgery will most likely achieve a favorable outcome with conservative treatment.

[Suggested revision of treatment recommendations for OFx based on papers I - III](#)

OFx type II: Poor compliance to current guidelines. Revision is needed to include measures of frailty (e.g., age, comorbidities, dependency, measures of physiological reserve capacity), and bony fusion and fibrous union should both be regarded as acceptable outcomes.

OFx type III: Good compliance to current guidelines. Outcomes are excellent using current recommendations. There is no need for revision of recommendations based on our studies. Refraining from surgery in patients with OFx type III with significant displacement, when anesthesia and surgery are considered too risky, will provide a favorable outcome in most cases.

Other considerations that should be reflected in the treatment decision

Frailty was mentioned in an earlier section in this thesis. We still lack a generally accepted and validated criterion for use in patients with OFx. All surgeons know that there is more surgical tolerability in an elderly patient than what is reflected merely by a list of comorbidities and ASA scores. We can meet two elderly patients with approximately the same list of chronic diseases and medication, but where one has a healthy skin tone, normal weight, is alert in communication and has a firm hand grip, the other might be underweight with loose skin (as in dehydrated and/or rapid weight loss), has cognitive impairment, a slight speech dyspnea and needs a walking aid because of general muscle atrophy, not SCI. It will be reasonable to consider these two patients differently in terms of ability to tolerate treatment, even though the difference is not reflected in ASA scores. This is where more multidimensional criteria for physiological reserves, such as a frailty index, would be of interest as a more objective replacement, or rather a supplement, to the “clinical eye”.

Excruciating mechanical neck pain. A minority of acute OFx patients have such severe mechanical neck pain that mobilizing them with a collar can be difficult, even sometimes impossible, despite proper pain medication. These patients should be considered for early surgery, even if the position of the odontoid on images is acceptable and even if the risk of surgery is considered high. An elderly patient who cannot be mobilized bears a high risk of secondary morbidity and mortality, which again justifies the higher treatment risk.

In the following figure 29, we present a flowchart for suggested treatment recommendations for OFx:

Paper I:

Major comorbidities and older age appear to be significant factors contributing to physicians' decisions to refrain from surgical fixation of OFx. Hence, comorbidities and age should be considered for inclusion in the decision tree for the choice of treatment for OFx in future guidelines.

Paper II:

In this population-based, observational cohort study of 282 consecutive patients suffering a OFx type II, 84% of patients were ≥ 65 years of age, and 67% had severe comorbidities. Primary treatment was external immobilization alone in 69% and open surgical fixation in 31% of patients. The proportion of crossover from primary external immobilization to surgery was 14.4%, whereas the proportion of revision surgery in the primary surgical group was 9.5%. None of the patients developed new-onset SCI after initiation of treatment, and only 3% reported severe neck pain at the time of follow-up. Fibrous union should be regarded as an acceptable outcome after treatment of OFx type II. Primary conservative treatment of elderly comorbid patients with OFx type II appears to be safe and should be regarded as good clinical practice and not a violation of current treatment recommendations.

Paper III:

In this population-based observational cohort study of 212 consecutive patients with traumatic OFx type III, primary treatment was external immobilization alone in ~95% of patients. The proportion of crossover from primary external immobilization to surgery was 5.4%. Our management strategy resulted in very good long-term outcomes with a high bony fusion rate, a low rate of chronic neck pain, and no patients with new-onset SCI, reaffirming that nonsurgical treatment is still the preferable option in the majority of patients with OFx type III, both for nondisplaced and significantly displaced fractures in elderly patients with severe comorbidities.

- The patient outcomes in our cohorts were favorable despite the low compliance with the current treatment recommendations for OFx. Fibrous union should be recognized as a satisfactory outcome in elderly comorbid patients.
- Parameters beyond the fracture morphology and age should be considered for inclusion in the decision tree for the choice of treatment for OFx, such as comorbidities and physiological reserve capacity (frailty).
- An easy-to-use frailty index will hopefully be developed. Simple factors should be included, such as unintentional weight loss, feeling exhausted, simple cognitive score, functional health with respect to ADL, weak grip strength, slow walking speed, and low physical activity and general muscle mass.
- Courses in fall prevention interventions in the elderly should be implemented, e.g., training programs for physicians in general medical practice. General practitioners could annually invite patients > 70 years to come for checkups, such as the infant healthcare program for children. Elderly individuals should be offered help and advice from general practitioners, nurses, and physiotherapists. The main subject to consider is fall prevention measures.
- There are ongoing RCTs and multicenter cohort study (not population-based) on OFx treatment that we strongly support [112-114]. However, because of reasons previously mentioned, population-based cohort studies can provide significant information when all OFx patients from a general population are included. Our results are based on a single center study. Additional population-based cohort studies from other centers or multicenter studies would be of significant value.

PART VIII: REFERENCE LIST

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RESEARCH ARTICLE

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Odontoid fractures: impact of age and comorbidities on surgical decision making

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Abstract

Background: Surgical fixation is recommended for type II and III odontoid fractures (OFx) with major translation of the odontoid fragment, regardless of the patient's age, and for all type II OFx in patients aged ≥ 50 years. The level of compliance with this recommendation is unknown, and our hypothesis is that open surgical fixation is less frequently performed than recommended. We suspect that this discrepancy might be due to the older age and comorbidities among patients with OFx.

Methods: We present a prospective observational cohort study of all patients in the southeastern Norwegian population (3.0 million) diagnosed with a traumatic OFx in the period from 2015 to 2018.

Results: Three hundred thirty-six patients with an OFx were diagnosed, resulting in an overall incidence of 2.8/100000 persons/year. The median age of the patients was 80 years, and 45% were females. According to the Anderson and D'Alonzo classification, the OFx were type II in 199 patients (59%) and type III in 137 patients (41%). The primary fracture treatment was rigid collar alone in 79% of patients and open surgical fixation in 21%. In the multivariate analysis, the following parameters were significantly associated with surgery as the primary treatment: independent living, less serious comorbidities prior to the injury, type II OFx and major sagittal translation of the odontoid fragment. Conversion from external immobilization alone to subsequent open surgical fixation was performed in 10% of patients. Significant differences in the conversion rate were not observed between patients with type II and III fractures. The level of compliance with the treatment recommendations for OFx was low. The main deviation was the underuse of primary surgical fixation for type II OFx. The most common reasons listed for choosing primary external immobilization instead of primary surgical fixation were an older age and comorbidities.

Conclusion: Major comorbidities and an older age appear to be significant factors contributing to physicians' decision to refrain from the surgical fixation of OFx. Hence, comorbidities and age should be considered for inclusion in the decision tree for the choice of treatment for OFx in future guidelines.

Keywords: Spinal fractures/epidemiology, Odontoid process/injury, Age factors, Comorbidity, Risk factors, Spinal fractures/surgery, Guideline adherence

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Background

The incidence of traumatic cervical spine fractures (CS-fx) in the Norwegian population is 15/100,000/year [1]. Twenty percent of these fractures are odontoid fractures (OFx) of cervical vertebra 2 (C2) [2]. The incidence of this injury increases with age, making OFx the most common CS-fx in the elderly population [2–4]. OFx are subdivided into types I, II and III according to the classification proposed by Anderson and D'Alonzo [5]. Type I fractures are very rare and do not require stabilization, while type II and III fractures are common and considered unstable.

A minor proportion of patients with OFx die immediately at the scene of the accident due to severe fracture dislocation with subsequent injury to the upper spinal cord, causing tetraplegia and respiratory arrest [6–8]. However, the majority of patients present with an OFx after trauma with various degrees of neck pain. When left untreated, these patients are at risk of fracture dislocation with secondary spinal cord injury (SCI) or persistent and severe neck pain due to chronic instability/pseudarthrosis. The aims of treatment are to preserve neurological function, provide pain relief and establish bony fusion. A consensus for the management of OFx is currently lacking, and the choice of treatment has mainly been guided by the fracture type (II or III), magnitude and direction of displacement of the OFx fragment, patient age and the knowledge of variations in bony fusion rates after the use of different treatment options [9–11].

Several publications recommend primary surgical fixation for type II and III OFx with major translation of the odontoid fragment, regardless of the patient's age, and for all type II OFx in patients aged ≥ 50 years [4, 11–14]. For the remaining patients, primary external immobilization is advised. These previous recommendations do not consider the effects of an older age and comorbidities of the patients, nor the possibility of a stable fibrous union as a satisfactory result of treatment. Recent reports have questioned these previous recommendations and advocate that patient age and comorbidities should be included in future treatment algorithms and that a stable fibrous union should be regarded as an acceptable outcome [15–18].

The recommendation of surgery for all patients aged ≥ 50 years with OFx type II is a subject of debate, since most of these fractures occur in the elderly with major comorbidities and increased risks of surgical morbidity and mortality [16, 19, 20]. The bony fusion rate of OFx type II in patients aged ≥ 50 years is higher after surgical fixation than after external immobilization in a rigid collar or Halo-vest for 12 weeks [11, 13, 21]. However, according to recent reports, many patients will exhibit a stable fibrous union of the OFx after 12 weeks of external mobilization, despite the lack of bony fusion [15–18]. This fibrous

union is defined by a lack of pathological movement of the odontoid fragment upon dynamic flexion and extension studies performed under fluoroscopic guidance, despite the absence of radiological bony fusion.

The level of compliance with the aforementioned treatment recommendations in our department is unknown. In the current study, we present updated epidemiological data on OFx in a defined population of 3.0 million people. The effects of the fracture type, displacement of the odontoid fragment, patient age and comorbidities on the rate of open surgical fixation are discussed. Our hypothesis is that open surgical fixation is less frequently performed than recommended, and we suspect that this discrepancy might be due to the older age and comorbidities observed in patients with OFx.

Methods

Oslo University Hospital (OUH) is a level 1 trauma centre located in Oslo, Norway and the only major trauma care facility in the Southeastern Norwegian Regional Health Authority (Norwegian: Helse Sør-Øst RHF). OUH is the only hospital in this region with neurosurgical service. In 2017, the southeastern region of Norway had 2.95 million inhabitants with the following age distribution: 1913884 aged 0–49 years, 381,157 aged 50–59 years, 318,407 aged 60–69 years, 215,141 aged 70–79 years, 97,333 aged 80–89 years and 24,623 aged > 90 years [22]. OUH performs $> 95\%$ of the trauma-related neurosurgical procedures in this population, including all surgeries for cervical spine injury. Twenty hospitals within our region with general and/or orthopaedic surgeons and radiological services refer patients with head and cervical spine injuries to OUH. The patients are either admitted to OUH for treatment or are managed locally when the neurosurgical team at OUH has decided that conservative treatment is indicated. We use a rigid collar for external immobilization. Treatment with a Halo-vest was discontinued in our region several years ago.

This study employed a prospective observational cohort design and examined all patients in the southeastern Norwegian population diagnosed with a traumatic OFx in the period from 2015 to 2018. The data were retrieved from our quality control database for traumatic CS-fx in southeastern Norway. In this database, all patients with CS-fx (C0/C1 to C7/Th1) who were diagnosed using cervical CT within our region are prospectively registered. Only patients with an 11-digit unique Norwegian social security number who were living within the region were included. The database was approved by the OUH - Data Protection Officer (PVO) (approval no 2014/12304), generated in Medinsight, and run by the Department of Neurosurgery. The present study, which is based on data extracted from this quality

database, was approved by OUH-PVO, and consent was waived by our Institutional Review Board (approval no 18/02167).

For this study, the following data were extracted from the database: date of injury, injury mechanism, gender, age at the time of injury, living status at the time of injury (home – care for self, home – with assistance, or institutionalized), pre-injury American Society of Anesthesiologists (ASA) score [23], type of OFx (types I–III) according to the classifications proposed by Anderson and D'Alonzo [5] and Grauer et al. [24], sagittal displacement of the odontoid fragment (direction and magnitude), presence of other cervical fractures (yes/no), multi-trauma (yes/no), Head Injury Severity Score (HISS) [25], presence of a concomitant thoracolumbar fracture (yes/no), presence of a SCI (yes/no), treatment (external immobilization with rigid collar alone or open surgical fixation), compliance with the previous treatment recommendations for OFx with respect to surgical fixation (yes/no) and reason for non-compliance based on a chart review.

The pre-injury ASA score was defined as follows: 1. a normal healthy patient, 2. a patient with a mild systemic disease, 3. a patient with a severe systemic disease, 4. a patient with severe systemic disease that is a constant threat to life, and 5. a moribund patient who is not expected to survive without surgery.

Previous treatment recommendations for OFx include primary surgical fixation for type II and III fractures with major displacement of the odontoid fragment, regardless of the patient's age, and for all type II fractures in patients aged ≥ 50 years. For the remaining patients with OFx, primary external immobilization is recommended.

Major sagittal displacement of the odontoid fragment was defined as a translation ≥ 5 mm anterior or ≥ 3 mm posterior [13].

Reasons for non-compliance were categorized as follows: surgery was not performed due to an older age and/or comorbidities, the diagnosis was delayed > 12 weeks, or the presence of a non-survivable injury.

Multi-trauma was defined as a simultaneous traumatic brain injury (mild, moderate or severe), and/or radiology-proven (X-ray, CT or ultrasound) injury in one or more of the following regions: face, thoracolumbar spine, thorax, abdomen, pelvic or extremities. Skin injuries were not registered.

Statistical analysis

Data were summarized as frequencies and means or medians, according to the distribution of the variables. Pearson's chi-squared test was used to compare differences in frequencies between groups. The Kruskal-Wallis test was used to compare the distributions between multiple groups. A Poisson model was used to

investigate the effect of age on the incidence of injury in the different age groups. Both uni- and multivariate logistic regression models were fitted for binary dependent variables. The R package v3.6 was used for statistical analyses. *P*-values less than 0.05 were considered significant.

Results

In our defined population of 3.0 million people in southeastern Norway, 336 patients with an OFx were prospectively registered during a 4 year period from 2015 to 2018, resulting in an overall OFx incidence of 2.8/100000 persons/year. However, the incidence in the elderly was considerably higher (Fig. 1a).

Patient characteristics and injury descriptions are presented in Table 1. The median patient age was 80 years (range 6–100 years), and 150/336 (44.6%) were females. The number of OFx increased with age (incidence rate ratio 2.5 for 10 year increments, 95% CI 2.3–2.9, $p < 0.001$). A male predominance was observed in younger patients, while a gradual shift to a female predominance was observed among older patients (Fig. 1b). The OFx were classified as type II fractures in 199 patients (59.2%) and type III fractures in 137 patients (40.8%). Type II OFx were more frequent than type III OFx ($p < 0.001$). Major sagittal translation was observed in 48/196 (24.5%) of patients with a type II OFx and 21/137 (15.3%) of patients with a type III OFx. Translation data were missing for 3 patients (Table 2).

Pre-injury major comorbidities (ASA ≥ 3) were present in 213 (63.7%) of the patients, and 115 (34.3%) required assistance with ADL (Table 1). An increasing age was significantly associated with both a greater number of comorbidities ($p < 0.001$) and a need for assistance with ADL ($p < 0.001$). Furthermore, a significant association was observed between a high ASA score and the need for assistance with ADL ($p = 0.02$).

The most common trauma mechanism was falls (85.7%), followed by motorized vehicle accidents (4.8%) and bicycle accidents (4.5%) (Table 1). The fraction of fall-related injuries increased significantly with 10 year increments in age (1.71, 95% CI (1.42–2.08), $p < 0.001$), from 53% in the group aged < 50 years to 95% in patients aged > 80 years. Multi-trauma was registered in 142 patients (42.6%). SCI due to OFx was present in 13 patients (3.9%).

The primary fracture treatment was a rigid collar alone in 266 patients (79.2%) and open surgical fixation followed by external immobilization in 70 patients (20.8%). In the univariate analysis, the following parameters were significantly associated with the use of surgery as the primary treatment: male sex, young age, independent living, pre-injury ASA score of 1–2, type II OFx and major sagittal translation of the odontoid fragment

Fig. 1 a: Age-adjusted incidence rates (x/100000 persons/year). b: Number of odontoid fractures in groups stratified according to age and gender

(Table 2). In the multivariate analysis, the following parameters remained significantly associated with the use of surgery as the primary treatment: independent living, pre-injury ASA score of 1–2, type II OFx and major sagittal translation of the odontoid fragment (Table 2). Male sex and age were not associated with the use of surgery as the primary treatment in the multivariate analysis.

Conversion from external immobilization alone to subsequent open surgical fixation was performed in 26/266 patients (9.8%) due to increased dislocation, severe neck pain hindering mobilization or pseudarthrosis. Treatment conversion was performed in 15/135 (11.1%) of patients with a type II OFx compared with 11/131 (8.4%) of patients with a type III OFx. This difference in conversion between patients with type II and III fractures was insignificant ($p = 0.618$).

Our compliance with the aforementioned previous treatment recommendations for OFx is presented in

Table 3 and appears to be low. The three largest patient categories in our series were patients aged ≥ 50 years with a type II fx (category 1, $n = 184$), patients with a type III fx without major translation (category 2, $n = 116$), and patients with a type III fx with major translation (category 3, $n = 21$). For patients in category 1, the recommended treatment is primary surgical fixation, but this procedure was only performed in 33% of patients. For patients in category 2, the recommended treatment is primary external immobilization, which was performed in 98% of patients. For patients in category 3, the recommended treatment is primary surgical fixation, but it was only performed in 19% of patients. The main deviation from the previous guidelines was the underuse of primary surgical fixation. Based on chart reviews, the reasons listed for choosing primary external immobilization instead of primary surgical fixation included a combination of age and comorbidities in 122 patients, lethal injury in 8 patients and delayed diagnosis in 8 patients (Table 4).

Table 1 Patient characteristics

		336 (100%)
Sex	Male	186 (55.4)
	Female	150 (44.6)
Age group (years)	0–49	19 (5.7)
	50–59	16 (4.8)
	60–69	49 (14.6)
	70–79	78 (23.2)
	80–89	109 (32.4)
	90+	65 (19.3)
Pre-injury ASA score ^a	ASA score of 1	33 (9.8)
	ASA score of 2	89 (26.5)
	ASA score of 3	187 (55.7)
	ASA score of 4	26 (7.7)
	Not available	1 (0.3)
Dependence in daily life	Home – independent	220 (65.5)
	Home – with assistance	62 (18.5)
	Institution	53 (15.8)
	Not available	1 (0.3)
Injury mechanism	Fall	288 (85.7)
	Motorized vehicle (MV)	16 (4.8)
	Bicycle	15 (4.5)
	Pedestrian hit by MV or bicycle	5 (1.4)
	Other	12 (3.6)
Odontoid fracture	Type II	199 (59.2)
	Type III	137 (40.8)
Other spine fractures	C1	64 (19.1)
	C0 (occipital condyle)	9 (2.7)
	C3 – Th1	27 (8.1)
	Thoracolumbar	30 (8.9)
Spinal cord injury (SCI)	Odontoid fx	13 (3.9)
	Other cervical fx	1 (0.3)
	Thoracolumbar fx	2 (0.6)
Multi-trauma	Yes	143 (42.6)
	TBI ^b - Mild	91 (27.1)
	TBI - Moderate	11 (3.3)
	TBI - Severe	9 (2.7)
	Face	29 (8.6)
	Thoracolumbar fx	30 (8.9)
	Thorax	29 (8.6)
	Abdomen	5 (1.5)
	Pelvic	5 (1.5)
	Extremity	27 (8.0)

^aASA American Society of Anesthesiologists^bTBI Traumatic Brain Injury

Discussion

As shown in the present study, the estimated incidence of traumatic OFx in the southeastern Norwegian population is 2.8/100000 persons/year. The fractures mainly occurred in elderly patients with significant comorbidities. The primary treatment was external immobilization alone in 79% and open surgical fixation in 21%. In the multivariate analysis, independent living, pre-injury ASA scores of 1–2, type II OFx and major sagittal translation of the odontoid fragment were significantly associated with the use of surgery as the primary treatment. The low rate of surgery is intriguing, since previous reports have documented that the bony fusion rate is higher after surgical fixation than after external immobilization alone.

Epidemiology

A specific International Classification of Disease (ICD) code is not available for OFx [26]. This fracture shares the ICD-10 code S12.1 with all other forms of C2 fractures. This finding is important, since the majority of previous epidemiological studies report the incidence of all types of C2 fractures and not odontoid fractures exclusively, as they are based on the extraction of ICD codes from registries. A Swedish nationwide registry study conducted from 1997 to 2014 reported that the incidence of C2 fractures increased from 3/100000 persons/year in 1997 to 6/100000 persons/year in 2014 [27]. These numbers are not directly comparable to our results, as the C2 fractures were not sub-typed. Another Swedish regional study estimated the incidence of OFx in the period from 2002 to 2014 to be 3/100000 persons/year [3]. Based on a United States nationwide registry on hospitalized patients for the period from 2000 to 2010, the incidence of C2 fractures is approximately 1/100000 persons/year [28]. A reasonable conclusion would be that the Norwegian incidence of OFx of 2.8/100000 persons/year is within the range of previously published results, although these studies provide a limited basis for comparison.

The median age of our patients was 80 years, and the frequency of OFx increased with increasing age in our study population. This finding is consistent with numerous other reports [3, 27–30]. The reported increase in incidence of OFx and C2 fractures in the geriatric population during the few last decades cannot be explained simply by an extended life expectancy. One can argue that the use of CT instead of plain X-ray as the primary diagnostic tool probably explains phenomenon portion of this increase [27–30].

A slight male predominance (55%) was observed in our patients with OFx. However, this predominance disappeared with increasing age, and among patients aged > 90 years, the number of women with an OFx

Table 2 Uni- and multivariate analyses of variables potentially associated with the use of surgery as the primary treatment

Variable		Primary conservative treatment N (%)	Primary surgery N (%)	OR ^a (univariate)	OR (multivariate)
Sex	Female	129 (86.0)	21 (14.0)	–	–
	Male	137 (73.7)	49 (26.3)	2.20 (1.26–3.93, $p = 0.006$)	1.44 (0.71–2.95, $p = 0.311$)
Age	Mean (SD ^b)	78.3 (16.1)	71.0 (11.4)	0.97 (0.96–0.99, $p = 0.001$)	1.00 (0.98–1.02, $p = 0.904$)
Functional status	Dependent	110 (95.7)	5 (4.3)	–	–
	Independent	155 (70.5)	65 (29.5)	9.23 (3.95–27.01, $p < 0.001$)	5.86 (2.15–19.08, $p = 0.001$)
ASA ^c score	ASA score of 1–2	77 (63.6)	44 (36.4)	–	–
	ASA score of 3–4	189 (87.9)	26 (12.1)	0.24 (0.14–0.42, $p < 0.001$)	0.30 (0.13–0.65, $p = 0.003$)
Odontoid fracture type	Type II	136 (68.0)	64 (32.0)	–	–
	Type III	130 (95.6)	6 (4.4)	0.10 (0.04–0.22, $p < 0.001$)	0.08 (0.03–0.19, $p < 0.001$)
Odontoid translation	None-Mild	225 (85.2)	39 (14.8)	–	–
	Major ^d	38 (55.1)	31 (44.9)	4.71 (2.63–8.47, $p < 0.001$)	5.59 (2.70–11.99, $p < 0.001$)

^aOR Odds ratio^bSD Standard deviation^cASA American Society of Anesthesiologists^dMajor odontoid translation - ≥ 5 mm anterior or ≥ 3 mm posterior

outnumbered men. This result corresponds to the increasing proportion of women in the older age groups of the population [22]. Similar findings have also been reported by other groups [27, 31].

An increasing age was significantly associated with a greater number of comorbidities, as measured using the pre-injury ASA score, and the need for assistance with ADL. Previous studies have also documented increased numbers of comorbidities among geriatric patients sustaining OFx [32–37]. Age and comorbidities are of course linked to some extent, but we postulate that they act as separate risk factors for OFx. The risk of healthy

older people to suffer an OFx is probably lower than older people with comorbidities. Illness often leads to inactivity or a neurological disability, which pre-disposes an individual to osteoporosis and an increased risk of unintended falls [38]. A higher burden of disease will lead to the use of medications in many cases, and several classes of medications are associated with an increased risk of falls in the elderly [39]. The WHO has defined risk factors for falls, including polypharmacy treatment, comorbidities, an age > 80 years, and impaired cognition and vision [40]. The presence of a medical comorbidity may also predispose patients to an increased risk of

Table 3 Rate of compliance with published treatment recommendations for odontoid fractures [4, 11–14]. Green indicates compliance and red indicates non-compliance. Translation data were missing for 3 patients who were treated conservatively

	Surgery	Conservative	% Compliance
Type II fx in patients aged < 50 y without major translation	1/9	8/9	89 %
Type II fx in patients aged < 50 y with major translation	2/3	1/3	67 %
Type II fx in patients aged ≥ 50 y	61/184	123/184	33 %
Type III fx without major translation	2/116	114/116	98 %
Type III fx with major translation	4/21	17/21	19 %

Table 4 Rate of non-compliance with published treatment recommendations for odontoid fractures, and reasons why primary external immobilization was chosen instead of primary surgical fixation [4, 11–14]

	Reason for non-compliance	N (%)
Compliant		195 (58.0)
Non-compliant	Age/comorbidities	122 (36.3)
	Lethal injury	8 (2.4)
	Delayed diagnosis	8 (2.4)
Missing data		3 (0.9)

complications in the setting of fracture care, such as thromboembolic disease, cardiac events and infections. The in-hospital mortality rates in this patient group, regardless of the choice of treatment, have been reported to be as high as 10–25% [33, 35, 37, 41, 42], and 1-year mortality rates are 20–50% [19, 20, 37, 42, 43]. The principal causes of death are related to their comorbidities and not the injury itself for the majority of patients with OFx [19, 20]. This high burden of disease represents a major concern in many of these patients regarding whether they will be able to tolerate general anaesthesia and open surgery.

The most common trauma mechanism among our patients was falls (85.7%), followed by motorized vehicle accidents (4.8%) and bicycle accidents (4.5%). The fraction of fall-related injuries was 53% in the group aged < 50 years and 95% in patients aged > 80 years. Several authors have identified falls as the major trauma mechanism in elderly patients suffering an OFx, particularly falls from a standing height [15, 31, 42, 44–46].

Fracture morphology

In our cohort of patients with OFx, 59% had type II fractures and 41% had type III fractures. Interestingly, type I fractures were not observed. Our proportion of patients with type II OFx is somewhat lower than the values reported from the UK and Sweden. In a UK study, type II and type III OFx constituted 84 and 16% of the injuries, respectively [31], while a Swedish study reported 1% type I, 69% type II and 29% type III fractures [3]. All studies, including ours, used the Anderson and D'Alonzo classification with the Grauer modification.

SCI secondary to dislocation of the odontoid fragment was observed in 13 patients (3.9%) in our series. Other researchers have reported a rate of SCI in patients with OFx or all C2 fractures ranging from 2 to 6% [27, 37, 42, 47]. The number of SCIs after OFx may be higher than reported, since a severe SCI at the C2 level may be fatal at the scene of the accident [6–8, 48].

Treatment

The main treatment goals for patients with OFx are to preserve the neurological function, relieve pain and establish a stable fusion. To date, no real consensus has been achieved and class I evidence for the management of these fractures is lacking [9, 11]. Historically, “stable fusion” has been rated synonymously with bony fusion. Recent publications have proposed that age and comorbidities should be emphasized as independent variables in treatment algorithms for OFx and that a fibrous union might be a valid result of treatment in these patients [16, 33, 41, 49–52].

External immobilization is typically achieved using a Halo-vest or stiff neck collar. A meta-analysis of 12 studies (714 fractures) comparing the Halo-vest with collar immobilization identified an equivalent rate of non-union between the treatment groups, but the number of complications more than doubled in patients treated with Halo-vests [53]. Thus, when choosing conservative treatment, a reasonable approach is to primarily use a rigid neck collar. When surgery is chosen, the evidence is in favour of performing a posterior screw fixation if the goal is bony fusion, which has historically been the definition of a successful treatment [10].

Most likely, a large proportion of elderly patients and patients with comorbidities presenting with OFx have not been included in randomized control trials (RCTs) comparing conservative and surgical treatment for OFx due to the high surgical risks. In non-randomized cohort studies, a high potential for selection bias exists because surgeons tend to select healthier patients for surgery. This bias in the published literature should always be considered when evaluating reported outcomes after the treatment of odontoid fractures in the geriatric population.

Rate of surgery in southeastern Norway

Despite the evidence for a superior bony fusion rate after the surgical fixation of OFx, we have suspected that the rate of surgery for these fractures in our department is low. We also postulated that the reasons for this potentially low rate of surgery were the older age and comorbidities among the patients. These hypotheses were verified in this study, as we chose surgery as the primary treatment for 21% of the total patients, and surgery was chosen more often for patients with type II OFx than type III OFx. The largest group in which we refrained from treating the patients according to previous recommendations was patients with a type II OFx aged > 50 years. The low use of primary surgical fixation in our study was clearly associated with an older age and comorbidities. The main concern with this low rate of surgery is a potentially high rate of treatment failure after external immobilization alone. In our series, the failure

of external immobilization alone leading to subsequent open surgical fixation occurred in 9.8% of patients. Primary external immobilization of type II OFx was not associated with a higher rate of conversion to open surgical fixation compared to type III OFx (11.1% versus 8.4%). A 9.8% failure rate may be considered high. However, 90.2% of the patients selected for external immobilization were successfully treated, most of whom were high risk candidates for surgery due to age and severe comorbidities.

The high rate of clinically successful treatment with external immobilization alone, despite the expected low rate of bony fusion, indicates that stable fibrous union is an acceptable outcome.

Reported rates of surgery for OFx vary considerably, but many series present a low surgery rate (12–28%) in elderly patients [37, 41, 42]. A few publications present a higher surgery rate, with 46–53% of patients in all age groups undergoing surgery for type II OFx and 13–19% of patients undergoing surgery for type III OFx [3, 31]. Studies reporting on all C2 fractures in the elderly in the United States show a surgery rate of 10–16% [54, 55]. Because the majority of C2 fractures in the elderly are type II OFx, the findings imply a low surgical treatment rate in the elderly with this type of fracture.

Limitations of the study

This study only presents epidemiological data and a description of our current treatment practice for patients with OFx. Based on the results of the present study, we are unable to conclusively determine whether this low rate of surgery is acceptable or represents a suboptimal practice.

We hope to answer this important question with our large observational cohort study of > 500 consecutive patients with OFx who were treated from 2009 to 2017. The data from the follow-up of this cohort are now being processed and we believe that the results will provide important insights into management of these fractures.

Conclusions

In southeastern Norway, 21% of patients with OFx were treated with primary open surgical fixation. Major comorbidities (ASA $\geq$ 3) were present prior to trauma in approximately 2/3 of the patients, 1/3 needed assistance with ADL, and more than half of the patients were $\geq$ 80 years of age.

Major comorbidities and an older age appear to be significant factors contributing to the decision to refrain from the surgical fixation of OFx. Hence, comorbidities and age should probably be considered for inclusion in the decision tree for the choice of treatment for OFx in future guidelines.

Abbreviations

CS-fx: Cervical spine fractures; OFx: Odontoid fractures; C2: Cervical vertebra 2; SCI: Spinal cord injury; OUH: Oslo University Hospital; ASA: American Society of Anesthesiologist; HISS: Head Injury Severity Scale; ADL: Activities of daily living; ICD: International Classification of Disease

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Authors' contributions

Research design: SAMR, EH, HL. Acquisition of data: SAMR, EH, HL, JM, MEH, TB, PNFR, MA, CTH, HØ, MM-E, NCU. Interpretation of data: SAMR, EH, HL, PR. All authors revised and approved the final submitted manuscript.

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Availability of data and materials

Our database contains sensible data which might provide insight in clinical and personnel information about our patients and lead to identification of patients. According to organization restrictions and regulations the data cannot be made public available. Data are however available from the authors upon reasonable request and with permission of the Data Protection Officer at OUH.

Ethics approval and consent to participate

The database was approved by the OUH - Data Protection Officer (PVO) (approval no 2014/12304). The present study, which is based on data extracted from this quality database, was approved by OUH-PVO, and consent was waived by our Institutional Review Board (approval no 18/02167).

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Clinical Study

Management and long-term outcome of type II acute odontoid fractures: a population-based consecutive series of 282 patients

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Abstract

BACKGROUND CONTEXT: The surgical fixation rate of type II odontoid fracture (OFx) in the elderly (≥ 65 years) is much lower than expected if the treatment adheres to current general treatment recommendations. Outcome data after conservative treatment for elderly patients with these fractures are sparse.

PURPOSE: The main aim of this study was to determine the long-term outcome after conservative and surgical treatments of type II OFx (all age-groups) to evaluate whether nonoperative treatment yields an acceptable outcome.

STUDY DESIGN/SETTING: Retrospective study based on a prospective database.

PATIENT SAMPLE: Two hundred eighty-two consecutive patients with type II OFx treated at Oslo University Hospital over an 8-year period.

OUTCOME MEASURES: Long-term rates of bony fusion, fibrous union, pseudarthrosis, crossover from primary conservative treatment to surgical fixation, new-onset spinal cord injury (SCI), and neck pain were the outcome measures used.

METHODS: The present study was based on data extracted from our quality control database for acute cervical spine fractures. All ages were included. In addition, long-term follow-up of alive patients was performed during the years 2018–2019. The follow-up included neurological examination, radiological examination, and scoring of bony fusion status, crossover from primary conservative treatment to surgical fixation, new-onset SCI, neck pain, and Neck Disability Index (NDI score). Data are described by counts, percentages, medians, means, ranges and standard deviations where appropriate. For statistical analyses the Mann-Whitney *U* test, Wilcoxon signed-rank test, and *t* tests were used.

RESULTS: During the eight-year study period, we registered 282 consecutive patients with type II OFx; 54% were males, patient age ranged from 15 to 101 years, 84% were ≥ 65 years of age (WHO definition of elderly), and 51% were ≥ 80 years of age. Severe comorbidities (American Society of Anesthesiologists, ASA ≥ 3) were seen in 67%, whereas nonindependent living was registered in 32%. Severe comorbidities and nonindependent living were significantly associated with increasing age ($p < .001$). SCI secondary to the OFx was seen in 5.3%. Primary treatment of the OFx was

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conservative (external immobilization alone) in 193 patients (68.4%), open surgical fixation in 87 patients (30.9%), and no treatment in two critically injured patients. At the time of long-term follow-up, 125 patients had died, nine patients declined the invitation to follow-up, and five patients did not respond. Thus, 143 patients were available for follow-up with a median follow-up time of 39 months (range 5–115 months). At long-term follow-up, the fusion status was bony fusion in 39.2% of patients, fibrous union in 57.3%, and pseudarthrosis in 3.5%. The proportion of bony fusion was significantly higher in the primary surgical fixation group ($p=.005$). No patients had new-onset SCI presenting after the start of primary treatment. The proportion of crossover from primary external immobilization to surgery was 14.4%, whereas proportion of revision surgery in the primary surgical group was 9.5%. There was no significant difference between the primary surgical fixation group and the primary conservative treatment group at long-term follow-up with respect to the proportion of pseudarthrosis and degree of neck pain.

CONCLUSIONS: Primary conservative treatment of elderly patients with type II OFx appears to be safe and should be regarded a viable treatment option. © 2020 Elsevier Inc. All rights reserved.

Keywords: Fusion rate; Odontoid fracture; Outcome; Surgery; Trauma

Introduction

Odontoid fractures (OFx) comprise approximately ~20% of all traumatic cervical spine fractures (CSFx) [1]. The incidence increases with age and are the most common CSFx in the elderly population [1,2]. OFx are subdivided according to the Anderson and D'Alonzo/Grauer classifications into types I, II, and III [3,4]. In type II, the fracture line traverses the base of the odontoid process [3]. Type II fractures are the most common OFx and are unstable injuries.

Until recently, primary surgical fixation was recommended for type II fractures, especially in patients' ≥ 50 years [5–7]. The main argument for this recommendation was an observed low bony fusion rate after external stabilization alone [6]. This recommendation has in recent years been challenged due to the high surgical risk in these elderly and often severely comorbid patients [8]. Some recent reports indicate that many patients with type II OFx, when treated with external immobilization alone for 12 to 16 weeks, achieve stability without bony fusion on computed tomography (CT) (fibrous union) [9–11]. This “fibrous union” has been defined as the lack of pathological movement of the odontoid fragment on flexion/extension x-ray at 12 to 16 weeks, despite the absence of radiologically evident bony fusion [8,12,13].

We have recently shown that primary surgical fixation of type II OFx was only performed in 33% of our patients in the 4-year time period 2015–2018 [14]. The reasons given for choosing primary external immobilization instead of primary surgical fixation for these patients were a combination of age and comorbidity in 88%, nonsurvivable injury in 6% and delayed diagnosis in 6%. This treatment practice raises several important questions: what is the rate of crossover from primary external immobilization to surgical fixation?; what is the rate of new-onset spinal cord injury (SCI) due to insufficient stabilization with external immobilization alone compared with surgical fixation?; is a stable fibrous union at 3 to 4 months still stable years later? These

questions should be answered to accept fibrous union as an acceptable outcome after external immobilization alone.

The main aims of this study were to determine the proportion of bony fusion and fibrous union after both primary surgical fixation and primary external immobilization of type II OFx, the proportion and reasons for crossover from primary external immobilization to surgical fixation, and the proportion of new-onset SCI due to insufficient stabilization with external immobilization compared to surgical fixation. The results will be discussed in order to determine whether fibrous union at 3 to 4 months is a stable, lasting and acceptable outcome in the long-term.

Materials and methods

Oslo University Hospital (OUH) is a level 1 trauma center situated in Oslo and is the only major trauma-care facility in the South-Eastern Norway Regional Health Authority (Norwegian: Helse Sør-Øst RHF) with 3.0 million inhabitants (2018). OUH is the only hospital in this region with neurosurgical service and performs >95% of trauma-related neurosurgical procedures in this population, including all procedures for cervical spine injuries. There are 20 hospitals within our region with general and/or orthopedic surgeons and radiological services that refer patients with head and cervical spine injuries to our department. The patients are either admitted to OUH for treatment, or nonsurgical treatment is carried out locally after consultation with the Department of Neurosurgery at OUH.

This is a retrospective study based on a prospective database of all type II OFx patients diagnosed with cervical CT in Southeast Norway in the 8-year period from 2009 to 2011 and 2013 to 2017. The year 2012 has been omitted due to incomplete registration this year. Only patients with a unique 11-digit Norwegian Social Security Number living within Southeast Norway are included. The following patients were excluded: (1) patients with pathological fracture, and (2) patients with delayed diagnosis not having started primary treatment within 90 days of trauma.

The present study was based on data extracted from our quality database for acute CSF_x. The following data were extracted: date of injury, date of diagnosis, gender, age at time of injury, injury mechanism, living status at time of injury (home – self-reliant, home – with assistance or institutionalized), preinjury American Society of Anesthesiologists (ASA) score [15], type of OF_x according to Anderson and D’Alonzo’s [3] classification supplied by Grauer’s et al. [4] subclassification, measurements of translation, angulation and diastasis of the odontoid fragment (direction and magnitude) [16,17], other cervical fractures, Head Injury Severity Score [18], concomitant thoracolumbar fracture (yes/no), SCI (yes/no), primary treatment (external immobilization with stiff collar alone, open surgical fixation, or no treatment), length of collar treatment, fusion at end of primary treatment (bony fusion, fibrous union, and pseudarthrosis), crossover from primary external immobilization to surgery, reasons for crossover, surgical failures, and revision surgeries.

Bony fusion at the end of primary treatment was defined as either bone trabecula traversing the fracture line on cervical CT and/or posterior fusion in the graft after surgery.

We used the following criteria to define *fibrous union* at the end of primary treatment. If criteria 1–4 were fulfilled, we concluded that fibrous union had occurred, and flexion/extension x-ray was not performed. If the patient failed on criteria 2, 3, or 4, a flexion/extension x-ray was performed. If movement of the odontoid fragment in the anterior-posterior direction between flexion and extension x-ray was ≤ 2 mm, we concluded that fibrous union had occurred.

1. Lack of bone trabecula traversing the fracture line on cervical CT.
2. No change in the position of the odontoid fragment on cervical CT at the end of primary treatment.
3. Neck pain ≤ 3 on a Visual Analog Scale (VAS) and no new-onset myelopathy at the end of primary treatment and before collar removal.
4. No increase in neck pain after collar removal.
5. No pathological movement of the odontoid fragment (≤ 2 mm) at the flexion/extension x-ray performed at 12 to 16 weeks.

Pseudarthrosis at the end of primary treatment (conservative or surgical fixation) was defined as lack of bony fusion and >2 mm movement of the odontoid fragment in the anterior-posterior direction at the flexion/extension x-ray study [9]. This definition of pseudarthrosis deviates slightly from the most used definition, as we use the phrase before 6 months has elapsed from start of treatment.

In each case, the choice of primary treatment was determined by the treating surgeon. The surgical techniques used were anterior odontoid screw fixation, posterior fixation with screws or wire, or occipitocervical fixation [19–22]. All patients treated with surgical fixation had a rigid collar for 6 to 12 weeks. Patients treated with a rigid cervical collar alone

had the collar for at least 12 weeks. Our standard follow-up during primary treatment, for both conservatively and surgically treated patients with OF_x, was outpatient visits 1-, 4-, and 12 weeks after injury and included cervical-CT and clinical examination. If the CT scan at 12 weeks did not show bony fusion, the need for flexion/extension x-ray was evaluated with the criteria described earlier. Follow-up beyond 12 weeks was only done in selected cases. For this study an additional long-term follow-up was done.

Long-term clinical follow-up

Long-term follow-up evaluations were performed during 2018–2019 (clinical examination, cervical CT and flexion/extension x-ray study if indicated (done in 43/87 patients without bony fusion)). The following outcome variables were recorded: time from injury to clinical follow-up (months), ASIA impairment scale [23], self-reported neck stiffness (none/mild/severe), neck pain using VAS [24], living status at time of follow-up (home – self-reliant, home – with assistance or institution), hoarseness (yes/no) and swallowing difficulties (yes/no), bony fusion of odontoid fragment (yes/no), posterior bony fusion (yes/no), fracture in implanted devices (yes/no), changed position of graft (yes/no), fibrous union of odontoid fragment (same criteria as used at end of primary treatment), and pseudarthrosis (same criteria as used at end of primary treatment). The last registered vital status (dead or alive) and time of death were obtained from the Norwegian Population Registry (Folkeregisteret) on September 1, 2019.

Ethics

The study was approved by the data protection official (DPO) at Oslo University Hospital (OUH - DPO approval no 2016/7495) and the Regional Ethical Committee (approval no 2018/1887). Data were extracted from our hospital-approved quality database for acute CSF_x (OUH - DPO approval no 2014/12304). The database was developed in Medinsight and maintained by the Department of Neurosurgery. Written informed consent was obtained from all patients at follow-up.

Database and statistical analysis

Data are described by counts, percentages, medians, means, ranges and standard deviations where appropriate. Overall survival analyses were performed using Kaplan-Meier curves, which measured survival from the time of surgery to the time of death. In non-normally distributed data, we used the Mann-Whitney *U* test between two independent samples, whereas the paired Wilcoxon signed-rank test was used for paired data. In cases of normally distributed data, *t*-tests were performed. A *p* value $< .05$ was considered statistically significant. The statistical analyses were performed using SPSS v25.0 (SPSS Inc., Chicago, IL, USA).

Table 1
Patient characteristics of 282 consecutive patients with type II OFx

		N (%)
Sex	Male	153 (54.3)
	Female	129 (45.7)
Preinjury ASA	Normal healthy patient	27 (9.6)
	Patient with mild systemic disease	66 (23.4)
	Patient with severe systemic disease	172 (61.0)
	Patient with severe systemic disease that is a constant threat to life	17 (6.0)
Living status	Home – self-reliant	191 (67.7)
	Home – with assistance	45 (16.0)
	Institution	46 (16.3)
Injury mechanism	Fall	243 (86.2)
	Road traffic accident	31 (11.0)
	Other	8 (2.8)
Other spine fractures	C0 (occipital condyles) fracture	7 (2.5)
	C1 (atlas) fracture	77 (27.3)
	Subaxial cervical fracture	25 (8.9)
	Thoracolumbar fracture	18 (6.4)
SCI odontoid fracture	A ASIA impairment scale	2 (0.7)
	B ASIA impairment scale	0 (0.0)
	C ASIA impairment scale	3 (1.1)
	D ASIA impairment scale	10 (3.5)
	E ASIA impairment scale	259 (91.8)
	Missing due to severe TBI/sedation	8 (2.8)
SCI subaxial fracture		6 (2.1)
SCI thoracolumbar fracture		0 (0.0)
HISS	None	69 (24.5)
	Minimal	145 (51.4)
	Mild	50 (17.7)
	Moderate	8 (2.8)
	Severe	10 (3.5)
Primary treatment	No treatment	2 (0.7)
	Primary external immobilization	193 (68.4)
	Primary surgical fixation	87 (30.9)

OFx, odontoid fracture; ASA, American Society of Anesthesiologists; SCI, spinal cord injury; HISS, Head Injury Severity Scale.

Results

Patient characteristics

Patient characteristics are given in Table 1 and Fig. 1. A total of 282 consecutive patients with type II OFx were treated at Oslo University Hospital in the eight-year study

Fig. 1. Age groups and gender.

period. There were 153 (54.3%) males, patient age ranged from 15 to 101 years, the mean age was 76.8 years (range 15–101 years), 84.0% of the patients were above 65 years (WHO definition of elderly) and 51.4% were above 80 years. The injury mechanism was falls in 86.2%.

Comorbidity

As measures for comorbidity, we used the preinjury ASA score and preinjury living status (Fig. 2 top and bottom). Severe comorbidity, measured as ASA score ≥ 3 , was seen in 189 of 282 patients (67.0%), whereas nonindependent living (home with assistance or institutionalized) was registered in 91 of 282 patients (32.3%). Severe comorbidity and nonindependent living were significantly associated with increasing age ($p < .001$).

Fracture morphology

The OFx was classified according to Anderson and D'Alonzo's classification and subclassified according to Grauer into type IIA in 19 patients (6.8%), type IIB in 255 patients (90.4%) and type IIC in 8 patients (2.8%). We defined major translation of the odontoid fragment as

Fig. 2. (Top) Preinjury ASA score in different age groups. (Bottom) Preinjury living status in different age groups. ASA, American Society of Anesthesiologists.

≥ 5 mm dislocation anterior or ≥ 3 mm dislocation posterior, major angulation as $\geq 11^\circ$ in either the anterior or posterior direction, and major fracture diastasis as ≥ 3 mm in the sagittal plane (Fig. 3 and Table 2). Major translation was seen in 85 of 282 patients (30.1%), major angulation in 123 of 282 patients (43.6%), and major fracture diastasis in 65 of 282 patients (23.0%). Some patients had major displacement of the odontoid fragment in more than one orientation. Major displacement in any orientation was registered in 153 patients, whereas 129 patients had no or minor displacement. For concomitant spine fractures, see Table 1.

SCI

At the time of primary diagnosis, 15 of 282 patients (5.3%) had spinal cord injury (ASIA A-D) caused by dislocation of the odontoid fragment (Table 1 and Fig. 3). The median age of patients with SCI related to the OFx was

significantly lower than the median age of patients without SCI (70 years versus 80 years, $p=.015$). Another 6 patients (2.1%) had SCI due to a concomitant subaxial cervical spine fracture, and none had SCI due to concomitant thoracolumbar spine fracture.

Primary treatment

Primary treatment of the odontoid fracture was external immobilization alone in 193 patients (68.4%) and open surgical fixation in 87 patients (30.9%). Two severely injured patients (0.7%) died during the hospital stay and were not treated (Fig. 4). Of the 15 patients with SCI secondary to the OFx, 11 were treated with surgical fixation, and 4 multi-traumatized old patients with severe comorbidity were treated conservatively with a rigid collar. The surgical techniques used in primary surgical fixation were anterior fixation with one odontoid screw in 62 patients, posterior

Fig. 3. Examples of patients with major anterior translation (A), major posterior translation (B), major anterior angulation (C), major fracture diastasis and posterior angulation (D), and SCI injury secondary to posterior translation and angulation of odontoid fragments (E and F – same patient). SCI, spinal cord injury.

Table 2
Proportions of major translation, angulation, and diastases of odontoid fragments on primary cervical CT according to treatment group

	Primary external immobilization N=193 (100%)	Primary surgical fixation N=87 (100%)	No treatment N=2 (100%)
Major translation	34 (17.6%)	50 (57.5%)	1 (50%)
Major angulation	72 (37.3%)	50 (57.5%)	1 (50%)
Major fracture diastasis	36 (18.7%)	28 (32.2%)	1 (50%)

Fig. 4. Primary treatment strategy in different age groups.

Fig. 5. Surgical techniques for fixation of type II odontoid fractures. (A) Anterior odontoid screw. (B) Posterior screw fixation. (C) Posterior wire fixation. (D) Occipitocervical fixation.

fixation with screws/wires in 21 patients, occipitocervical fixation in 2 patients, and combined anterior and posterior fixation in 2 patients (Fig. 5).

When comparing patients treated with primary surgical fixation to patients treated with primary external immobilization alone, the surgery patients were younger (median 74.0 years, IQR [interquartile range] [65–80] vs. median 84.0 years, IQR [74–89]; $p < .001$) (Fig. 4), had a lower comorbidity ASA score (mean 2.40 ± 0.08 vs. mean 2.73 ± 0.05 ; $p < .001$), had greater fracture translation (median 3.5 mm, IQR [1.6–6.8] vs. median 0.0 mm, IQR [0.0–2.4]; $p < .001$), had greater fracture angulation (median 12.0° , IQR [0.0–24.8] vs. median 5.4° , IQR [0.0–20.0]; $p = .001$), and had greater fracture diastasis (median 2.0 mm, IQR [1.0–3.4] vs. median 1.4 mm, IQR [1.0–2.2]; $p = .002$). There was no significant difference between the primary surgical fixation group and the primary external immobilization group with respect to Grauer classification ($p = .058$). The presence of SCI was significantly higher in the primary surgical fixation group than in the primary conservative treatment group, 11 of 87 (12.6%) versus 4 of 193 (2.1%) ($p = .033$).

Failure of primary external immobilization was defined as crossover to surgery within 16 weeks of trauma and was

registered in 16 of 193 (8.3%) patients. Reasons for converting to surgery were increased dislocation/angulation in 15 patients and pseudarthrosis at the end of primary treatment in one patient. There was statistically insignificant difference between major displacement and failure of primary external immobilization (Wilcoxon signed-rank test, $p = .059$). New-onset SCI was not seen within the first 16 weeks of trauma.

Failure of primary surgical fixation was defined as the need for a revision surgery within 16 weeks of trauma and was performed in 4 of 87 (4.6%) patients. Revision surgery was performed due to secondary displacement of the odontoid fragment. The primary surgical fixation techniques in these patients were anterior odontoid screws in three patients and posterior wiring in one patient. None of the patients had new-onset SCI within the first 16 weeks of trauma.

Long-term follow-up

At the time of long-term follow-up, 125 patients had died, 9 patients declined the invitation to follow-up, and 5 patients did not respond. Thus, 143 patients were available for follow-up with a median follow-up time of 39 months (range 5–115 months). When grouping the long-term

Table 3

Fusion status at long-term follow-up according to primary intention to treat (N=143)

	Primary external immobilization N=82 (100%)	Primary surgical fixation N=61 (100%)
Bony fusion	24 (29.3%)	32 (52.5%)
Fibrous union	55 (67.1%)	27 (44.3%)
Pseudarthrosis	3 (3.7%)	2 (3.3%)

follow-up patients according to primary intention to treat, 82 belonged to the primary external immobilization group and 61 to the primary surgical fixation group.

After the primary treatment was finalized, 5 of 82 (6.1%) patients in the primary conservative group had surgical fixation due to radiological evident pseudarthrosis (including one patient diagnosed at the time of follow-up), and 3 of 61 (4.9%) patients in the primary surgical fixation group had revision surgery due to radiological evident pseudarthrosis ($p=.762$). Pseudarthrosis in the surgical group was seen in two patients after anterior odontoid screw fixation and in one patient after posterior wiring fixation. No patients in either group had new-onset SCI presenting after ending primary treatment.

Fusion status

At long-term follow-up, the fusion status was bony fusion in 56 of 143 (39.2%), fibrous union in 82 of 143 (57.3%), and pseudarthrosis in 5 of 143 (3.5%) patients. The proportion of bony fusion was significantly higher after primary surgical fixation than after primary conservative treatment, 32 of 61 (52.5%) versus 24 of 82 (29.3%) ($p=.005$; Table 3). Within the surgery group, the proportion of bony fusion was significantly higher after posterior screw/wire fixation than after anterior screw fixation, 10 of 14 (71.4%) versus 20 of 45 (44.4%) ($p=.032$). Only one of

the five patients with radiologically evident pseudarthrosis had movement-related neck pain and was referred to surgery at follow-up. Of the 5 patients with radiologically evident pseudarthrosis at the time of follow-up, 3 belonged to the primary external immobilization group and 2 to the primary surgical group. The median age of patients with bony fusion, fibrous union, and pseudarthrosis were 70 years, 78 years, and 74 years, respectively.

Neck pain (VAS score)

For neck pain, the median VAS score at long-term follow-up was 0 (range 0–10), with a mean score of 1.26. The VAS score was ≤ 3 in 120 of 143 (83.9%), between 4 and 6 in 19 of 143 (13.3%), and ≥ 7 in 4 of 143 (2.8%) patients. There was no significant difference in the long-term follow-up VAS score between the primary surgical fixation and primary external immobilization groups (mean 1.26 ± 0.28 vs. mean 1.26 ± 0.23 [$p=.986$]) or between patients with bony fusion and non-bony fusion (mean 1.61 ± 0.31 vs. mean 1.03 ± 0.21 [$p=.117$]).

Patients not available for long-term follow-up

At the time of long-term follow-up, 139 patients were unavailable due to either death, that they rejected control or failed to respond. Chart review of these patients revealed that one patient treated with primary external immobilization underwent surgical fixation after ending primary treatment. None of the patients treated with primary surgical fixation underwent revision surgery after finalized primary treatment. We did not receive reports of new-onset SCI for any of these patients in the period after primary treatment.

Survival

The 30-day, 6-month, and 12-month survival rates were 84.4%, 78.4%, and 73.5%, respectively (Fig. 6). The mean age of patients who succumbed within 30 days of trauma

Fig. 6. Kaplan-Meier curve showing overall survival.

was 84.4 years (range 57–99), and 76.3% of these patients had a preinjury ASA score ≥ 3 .

Discussion

In this population-based observational cohort study of 282 consecutive patients with type II OFx, 84.0% of the patients were above 65 years, and 67.0% had severe comorbidities. Primary treatment was external immobilization alone in 68.4% of the patients and open surgical fixation in 30.9% of the patients. The proportion of crossover from primary external immobilization to surgery was 14.4% (8.3% within 14 weeks of trauma and 6.1% later), whereas the proportion of revision surgery in the primary surgical group was 9.5% (4.6% within 14 weeks of trauma and 4.9% later). None of the patients developed new-onset SCI after initiation of treatment. At the time of follow-up, 84% reported no/minimal neck pain.

Patients suffering a type II OFx represent a challenge with respect to the treatment decision. The majority of patients are elderly with a high proportion of severe comorbidities [8,25,26]. Older age and a high burden of disease are associated with an increased risk of complications and mortality after trauma, more often related to the patients' comorbidities than the injury itself [8]. Our patient cohort corroborates this, with 84% of the patients older than 65 and more than half of them older than 80 years of age. In addition, 2 of 3 patients had severe comorbidities, and 1 of 3 was in need of help with daily living, either in their own home or at an institution.

The medical complexity of OFx patients is probably one of the reasons why we lack Class I evidence supporting treatment decisions [7]. There are, however, ongoing studies which we hope will provide increased knowledge [27,28]. Because a large fraction of these patients are too old and frail to tolerate general anesthesia and open surgery within acceptable risk, randomized controlled trials to compare surgical versus conservative treatment would be biased by the need to exclude a major portion of the patients in question. For this reason, a large population-based cohort series including all patients is important to provide insight into outcomes following different treatment modalities, even though this will not provide Class I evidence.

The treatment recommendation for type II OFx in patient's ≥ 50 years of age has been to consider surgical fixation in all patients, irrespective of alignment [7]. The main basis for this recommendation was the superior bony fusion rates after surgery compared with external immobilization [6,7].

If we had adhered to the treatment recommendation, 95% of our patients should have been treated with surgical fixation. However, the proportion of surgical fixation in our cohort was only 30.9%. This discrepancy has been attributed to high-surgical risk due to older age and high comorbidity [14]. We will discuss if this is a good practice based on this population-based follow-up study. It is well-known

that external immobilization alone compared with surgical fixation results in a much lower bony fusion rate and a higher rate of fibrous union at end of primary treatment. Refraining from primary surgical fixation can be acceptable in old patients with comorbidities if fibrous union also gives long-term stability. Surrogate measures for long-term stability are rate of new-onset SCI, rate of conversion from conservative treatment to surgery, and the intensity of neck pain at follow-up. Fibrous union can be regarded as sufficiently stable if treatment-related new-onset SCI is close to zero, severe neck pain at long-term follow-up is not higher than in the surgery group, and the rate of conversion from conservative treatment to surgery is low.

Recent reports have challenged the recommendation of surgical fixation of almost all type II OFx and indicated that fibrous/nonbony fusion can be a satisfactory outcome in frail elderly patients [8,9,14,29]. Among our patients available for long-term follow-up, 39% had bony fusion, 57% had fibrous union, and only 4% had pseudarthrosis. The proportion of bony fusion was higher after surgery than after external immobilization. Within the surgical group, the proportion of fusion was higher after posterior fixation than after anterior odontoid screw fixation. This is in accordance with other reports [8].

The most feared complication of OFx is SCI. The initial rate of SCI in our cohort of type II OFx was 5.3%. Others have reported the rate of SCI in OFx patients to be in the range of 2% to 7.5% [30–32]. Some previous publications have argued against accepting fibrous union as an acceptable outcome due to a potentially high risk of late SCI [33,34]. No patients in our large cohort developed secondary SCI, either during treatment or later. Thus, in this study conservative treatment of type II OFx is not associated with an increased risk of late SCI.

In addition to SCI, chronic severe neck pain (defined as VAS ≥ 7) secondary to pseudarthrosis is the other main long-term sequela of concern. In our cohort, only 3% reported severe neck pain at the time of follow-up, and 84% reported no/minor neck pain. There was no statistically significant difference with respect to neck pain between the surgical and conservative groups. Thus, in this study conservative treatment of type II OFx is not associated with an increased risk of severe neck pain.

The proportion of crossover from primary external immobilization to surgery was 14.4% (8.3% within 14 weeks of trauma and 6.1% later), whereas the proportion of revision surgery in the primary surgical group was 9.5% (4.6% within 14 weeks of trauma and 4.9% later). In our opinion, a conversion rate to surgery of 14.4% is acceptable, especially in light of the rather high revision rate in the surgical group. This means that $>85\%$ of frail elderly patients were well treated without primary external immobilization alone.

Fibrous union after conservative treatment of type II OFx is associated with very low risk of new-onset SCI, low rate of later surgical fixation, and no more long-term neck

pain than after surgical fixation. Thus, conservative treatment of selected OFx in old patients with severe comorbidities appears to be safe. In younger patients with less comorbidity, we still believe that surgical fixation should be considered.

Limitations of this study

The patients received treatment based on the best judgment of the treating neurosurgeon, both in terms of surgical versus nonsurgical treatment and regarding choice of surgical technique. There will always be room for divergent judgment between physicians. A large fraction of patients died between the time of injury and planned follow-up, leading to missing data at follow-up.

Strengths

This is a large patient cohort from a defined total population, providing us data on essentially all patients with type II OFx within this population in the defined timeframe without bias.

Conclusions

In this population-based observational cohort study of 282 consecutive patients suffering a type II OFx, 84% of patients were ≥ 65 years of age, and 67% had severe comorbidities. Primary treatment was external immobilization alone in 69% and open surgical fixation in 31% of the patients. The proportion of crossover from primary external immobilization to surgery was 14.4%, whereas the proportion of revision surgery in the primary surgical group was 9.5%. None of the patients developed new-onset SCI after initiation of treatment, and only 3% reported severe neck pain at the time of follow-up. Primary conservative treatment for elderly comorbid patients with type II OFx appears to be safe and should be regarded as good clinical practice.

Data availability

The research data is confidential because it contains clinical and personnel information about our patients which can lead to identification of the patients. According to the organization restrictions and regulations the data cannot be made public available. Data are however available from the authors upon reasonable request and with permission of the Data Protection Officer at OUH.

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Clinical Study

Favorable prognosis with nonsurgical management of type III acute odontoid fractures: a consecutive series of 212 patients

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Abstract

BACKGROUND CONTEXT: The recommended primary treatment for type III odontoid fractures (OFx) is external immobilization, except for patients having major displacement of the odontoid fragment. The bony fusion rate of type III OFx has been reported to be >85%. High compliance to treatment recommendations is favorable only if the treatment leads to a good outcome.

PURPOSE: The primary aim of this study was to determine the long-term outcome after conservative and surgical treatment of type III OFx and to reaffirm that primary external immobilization is the best treatment for most type III fractures.

STUDY DESIGN/SETTING: Retrospective study based on a prospective database.

PATIENT SAMPLE: Two hundred twelve consecutive patients with type III OFx treated at Oslo University Hospital over an 8-year period (2009–2017).

OUTCOME MEASURES: Long-term rates of bony fusion, crossover from primary conservative treatment to surgical fixation, new onset spinal cord injury (SCI), severe persistent neck pain (visual analogue scale - VAS), and persistent disability measured with Neck Disability index (NDI).

METHODS: The present study was based on data extracted from our quality control database for acute cervical spine fractures from a general population. During the years 2018 to 2019 long-term follow-up of alive patients was performed (median follow-up time was 38.0 months; range 3.0–108.0 months). The follow-up included neurological examination, radiological examination and scoring of bony fusion status, crossover from primary conservative treatment to surgical fixation, new onset SCI, neck pain, and Neck Disability Index (NDI score).

RESULTS: In this consecutive series of 212 patients with type III acute OFx, median patient age was 72 years, 56% had severe preinjury comorbidities (ASA score ≥ 3) and 22% lived dependently. Severe comorbidities and dependent living were significantly associated with increasing age ($p < .001$). The trauma mechanism was fall injury in 82%. The median age of patients injured by falls was significantly higher than in patients with a nonfall injury ($p < .001$). At the time of diagnosis, 4% had an OFx related SCI. Primary treatment was external immobilization alone in 95.3% and open surgical fixation in 4.7%. Patients treated with primary external immobilization alone

Abbreviations: ADL, Activities of daily living; ASA, American Society of Anesthesiologists; ASIA, American Spinal Injury Association; CSF, cervical spine fracture; IQR, interquartile range; HISS, Head Injury Severity Scale; NDI, Neck disability index; OFx, odontoid fracture; OUH, Oslo University Hospital; SCI, Spinal cord injury; VAS, Visual Analog Scale
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presented with significantly less translation of the odontoid fragment ($p<.001$) and less angulation of the odontoid fragment ($p=.025$) than patients treated with primary surgery. Subsequent crossover to surgical fixation was performed in 5.4%. At long-term follow-up, 95.7% of patients had bony fusion of the OFx, 80.5% had minimal/no neck pain, and none developed new onset SCI. There was no significant difference in long-term follow-up VAS ($p=.444$) or NDI ($p=.562$) between the primary external immobilization group and the primary surgical group.

CONCLUSION: This study reaffirms that nonsurgical treatment remains the preferable option in the majority of patients with type III OFx. © 2021 Elsevier Inc. All rights reserved.

Keywords: Odontoid fracture; Trauma; Collar; Surgery; Outcome; Fusion rate

Introduction

Twenty percent of traumatic cervical spine fractures (CSFx) are odontoid fractures (OFx) of the second cervical vertebra (C2) [1]. The incidence of OFx increases with age, making OFx the most common CSFx in the elderly population. OFx are subdivided into types I, II, and III, where type I is a rare and stable fracture of the tip of odontoid, while types II and III are more common and unstable fractures [2,3]. In type III fractures, the fracture line extends into the body of C2 and, by definition, into the C1/C2 joint. The incidence of type III OFx in Norway is 1.1/100,000/year [4].

The recommended primary treatment for type III OFx is external immobilization, except for patients having major displacement of the odontoid fragment. In these cases, surgical fixation is recommended [5]. Bony fusion rates after external immobilization alone are reported to be significantly higher for type III than for type II OFx. The bony fusion rate of type III odontoid fractures has been reported to be >85%, while for type II OFx, the rate is reported to be in the range of 50% to 87% [6–10]. The difference in bony fusion rates is probably due to regional variations of vascularization within the C2. The fracture line in type III fractures runs through cancellous bone with a rich blood supply, while the fracture line in type II fractures runs through noncancellous bone with poor vascular supply [11].

We recently reported a high compliance rate (86%) with treatment recommendations for type III OFx and that 95% of patients were treated with primary external immobilization [4]. High compliance to treatment recommendations is favorable only if the treatment leads to a good outcome. In this prospective population based observational cohort study of 212 consecutive patients treated for type III OFx, we investigated the bony fusion rate after primary treatment, the rate of conversion from primary external immobilization to open surgical fixation, and long-term clinical outcome. The primary aim of this study was to reaffirm that primary external immobilization is the best treatment for most type III fractures.

Materials and methods

Oslo University Hospital (OUH) is a level 1 trauma center situated in Oslo, Norway and is the only major trauma-care facility in the Southeastern Norway Regional Health

Authority (Norwegian: Helse Sør-Øst RHF), with 3.0 million inhabitants (2018). OUH is the only hospital in this region with neurosurgical services, and it performs >95% of trauma-related neurosurgical procedures in this population, including all surgeries for cervical spine injuries.

This is a retrospective population-based cohort study of type III OFx based on a prospective database. Inclusion criteria were as follows:

- All patients having type III OFx diagnosed with cervical spine CT within 90 days of trauma.
- Patients from the Southeast region of Norway.
- Time period: 2009 to 2017.
- Patients with a unique 11-digit Norwegian Social Security Number.

Exclusion criteria were as follows:

- Pathological type III OFx (C2 lysis/fracture secondary to malignant tumor, benign tumor or infection).
- First radiological examination >90 days after trauma.
- Data from the year 2012 were excluded due to incomplete registration.

Data were prospectively entered into the hospital approved quality database for acute cervical spine fractures (OUH - DPO approval no 2014/12304). This database was developed in MedInsight and is maintained by the Department of Neurosurgery.

For the present study, the following data were extracted from the database for acute cervical spine fractures: date of injury and diagnosis, sex, age at time of injury, injury mechanism, living status at time of injury (home – self-reliant, home – with assistance, or institution), preinjury American Society of Anesthesiologists (ASA) score [12], type III odontoid fracture according to Anderson and D'Alonzo's [2] classification supplied by Grauer [3], three measures for major displacement of the odontoid fragment were applied (major translation of the odontoid fragment was defined as ≥ 5 mm anterior or ≥ 3 mm posterior, major angulation as $\geq 11^\circ$ in either anterior or posterior direction, and major fracture diastasis as ≥ 3 mm in the sagittal plane) [7,8], other cervical fractures, Head Injury Severity Score (HISS) [13], concomitant thoracolumbar fracture (yes/no), spinal cord injury (SCI) (yes/no), multitrauma (yes/no),

primary treatment (external immobilization with stiff collar alone, open surgical fixation or no treatment), and crossover from primary external immobilization to surgery (yes/no).

Type III OFxs with no/minor displacement of the odontoid fragment were treated with a cervical collar (Miami J) as external immobilization for 12 weeks. Halo Vest was not used for external immobilization in these patients. The external immobilization was for 24 hours a day. The collar was only removed for hygiene or change of pads with the help of local physiotherapist, nurse or trained family member. In a few patients with persistent significant neck pain and non-bony fusion at 12 weeks follow-up, the immobilization was extended for 2 to 4 weeks (until flexion/extension X-ray was performed). Surgical fixation was considered in patients with major displacement of the odontoid fragment, and in patients with pseudarthrosis after primary external immobilization. In each case, the final choice of treatment was determined by the treating surgeon. The surgical techniques used included posterior fixation with screws or wire or anterior odontoid screw fixation [14–17].

Long-term clinical follow-up

All living patients were invited for follow-up examination (clinical and radiological) during 2018 to 2019. The following variables were recorded at follow-up: time from injury to clinical follow-up (weeks), ASIA impairment scale [18], self-reported neck stiffness (none/mild/severe), neck pain using the Visual Analog Scale (VAS) [19], the Neck Disability Index [20,21], living status at time of follow-up (home – self-reliant, home – with assistance, or institution), fusion status (bony fusion – with bone trabecula bridging the previous fracture line, fibrous union – defined as lack of bony fusion and no pathological movement of the odontoid fragment on flexion/extension X-ray studies, or pseudarthrosis) [10,22], fracture in osteosynthesis material (yes/no), changed position of implanted graft (yes/no), and instability on flexion-extension X-ray (yes/no). Last registration of vital status (dead or alive) and time of death were obtained from the Norwegian Population Registry (Folkeregisteret) on September 1, 2019. New onset SCI was defined as any kind of newly emerged myelopathy from diagnosis to follow-up with link to the traumatized region, including gradual onset myelopathy from a C1–C2 stenosis.

Ethics

This study was approved by the data protection official (DPO) at Oslo University Hospital (OUH - DPO approval no 2016/7495) and the Regional Ethical Committee (approval no 2018/1887). Written informed consent was obtained from all patients at follow-up.

Database and statistical analysis

Data are described by counts, percentages, medians, means, ranges and standard deviations where appropriate.

Overall survival (OS) analyses were performed using Kaplan-Meier curves, which measured survival from the time of surgery to the time of death. In non-normally distributed data, we used the Mann-Whitney *U*-test between two independent samples. Spearman's rank-order correlation was used to determine association between ordinal variables. A *p*-value <.05 was considered statistically significant. Statistical analyses were performed using SPSS v25.0 (SPSS Inc., Chicago, IL, USA).

Results

Patient characteristics

A total of 212 consecutive patients with type III OFx were included in this study (Table 1, Fig. 1). There were 101 (47.6%) females, and the median age was 72.0 years (IQR [5–98 years]). The proportion of patients ≥65 years of age was 70.6%. Severe comorbidity, defined as ASA score ≥3, was registered in 119 (56.1%) patients, and 46 (21.7%) patients were unable to care for themselves (dependent living; Fig. 2A and B). The median age of patients with ASA score ≥3 was significantly higher than for patients with ASA score 1-2 (median 83.0 years vs. median 66.0 years; Mann-Whitney *U* test; *p*<.001), and the median age of patients with dependent living status was significantly higher than for patients able to care for themselves (median 88.0 years vs. median 69.0 years; Mann-Whitney *U* test; *p*<.001).

Injury

The injury mechanism was falls in 173 patients (81.6%) and road traffic accidents in 31 patients (14.6%). The median age of patients injured by falls was significantly higher than in patients with a nonfall injury (median 75.0 years vs. 62.0 years; Mann-Whitney *U* test; *p*<.001). Major translation of the odontoid fragment was observed in 32 patients (15.1%), major angulation in 38 patients (17.9%) and major fracture diastasis in 17 patients (8.0%). In total, 61 patients (28.8%) exhibited major displacement of the odontoid fragment in one or more directions. Concomitant CSFx elsewhere were registered in 47/212 (22.2%), 8 of which had fractures in the occipital condyle (C0), 25 had fractures in the atlas (C1), and 23 had fractures in a subaxial level. Concomitant thoracolumbar fractures were observed in 20 patients (9.4%).

SCI related to the OFx and present at time of diagnosis was seen in eight patients (3.8%), two with complete SCI and six with incomplete SCI (Table 1). Three other patients had SCI secondary to a spinal fracture below C2, one cervical and two thoracolumbar.

Multitrauma was registered in 66/212 patients (31.1%), and moderate or severe head injury (according to HISS) were seen in 12/212 patients (5.7%).

Table 1
Patient characteristics

		N (%)
Sex	Male	111 (52.4)
	Female	101 (47.6)
Preinjury ASA	1. A normal healthy patient	34 (16.0)
	2. A patient with mild systemic disease	59 (27.8)
	3. A patient with severe systemic disease	110 (51.9)
	4. A patient with life-threatening disease	9 (4.2)
Living status	Home – self-reliant	166 (78.3)
	Home – with assistance	26 (12.3)
	Institution	20 (9.4)
Injury mechanism	Fall	173 (81.6)
	Road traffic accident	31 (14.6)
	Others	8 (3.8)
Other spine fractures	C0 fracture*	8 (3.8)
	C1 (atlas) fracture	25 (11.8)
	Subaxial cervical fracture	23 (10.8)
	Thoracolumbar fracture	20 (9.4)
SCI odontoid fracture	ASIA impairment scale A	2 (0.9)
	ASIA impairment scale B	0 (0.0)
	ASIA impairment scale C	1 (0.5)
	ASIA impairment scale D	5 (2.4)
	ASIA impairment scale E	199 (93.9)
	Missing due to severe TBI/sedation	5 (2.4)
SCI subaxial fracture		1 (0.5)
SCI TL fracture [†]		2 (0.9)
HISS	None	48 (22.6)
	Minimal	114 (53.8)
	Mild	38 (17.9)
	Moderate	5 (2.4)
	Severe	7 (3.3)
Primary Treatment	None	1 (0.5) [‡]
	External immobilization	201 (94.8)
	Surgery	10 (4.7)

* C0 fracture = occipital condyle fracture.

[†] SCI TL fracture = Spinal cord injury secondary to thoracolumbar fracture.

[‡] Patient died at admission due to multitrauma.

Fig. 1. Age groups and sex.

Primary treatment

Primary treatment was external immobilization alone in 201 patients (94.8%), open surgical fixation in 10 patients (4.7%), and no treatment in 1 patient (0.5%; Table 1 and Fig. 3). The patient who was not treated died soon after admission due to multitrauma. Surgical techniques used in primary surgery included posterior fixation with wiring in seven patients and anterior fixation with one odontoid screw in three patients.

Patients treated with primary external immobilization alone presented with significantly less translation of the odontoid fragment than patients treated with primary surgery (median 1.4 mm vs. median 5.6 mm; Mann-Whitney *U* test: $p < .001$) and less angulation of the odontoid fragment (median 0.0° vs. median 9.2° ; Mann-Whitney *U* test: $p = .025$) but no difference in diastasis of the odontoid fragment (median 0.0 mm vs. median 0.3 mm, Mann-Whitney *U* test: $p = .588$).

(A)

Fig. 2A. Preinjury ASA score in different age groups.

Primary external immobilization failure was defined as crossover to surgery within 16 weeks of trauma and occurred in 9/201 (4.5%) patients due to increased displacement (translation, angulation, and/or diastasis) of the odontoid fragment. None of these nine patients suffered neurological deterioration. The surgical procedures used were posterior C1–C2 screw fixation (Harms fixation) in six, posterior fixation with wiring in two, and anterior fixation with odontoid screw in one. Two more patients had surgery after 16 weeks due to pseudarthrosis, 1 with posterior wiring 134 days after injury and one posterior C1–C2 screw fixation 124 days after injury. Therefore, a total of 11/201 (5.4%) patients in the primary conservative group were at some point redirected to surgical fixation. None of these patients experienced neurological deterioration.

Primary surgical fixation failure was defined as revision surgery within 16 weeks of trauma. None of the primary surgically treated patients required revision surgery within this time frame.

Major displacement of the odontoid fragment, especially translation in the anterior-posterior plane (≥ 5 mm anterior or ≥ 3 mm posterior), is a criterion for considering surgical fixation. Major translation of the odontoid fragment was registered in 32 patients (15.1%), but only 8 patients were

(B)

Fig. 2B. Preinjury living status in different age groups.

Fig. 3. Primary treatment strategy in different age groups.

primarily treated surgically. Chart review revealed the following reasons for not choosing surgery in 21 patients with major translation of the odontoid fragment (Table 2): degree of translation within 1 mm of the preset range for nonmajor translation and after overall assessment accepted for external immobilization (8 patients), surgical risk considered too high due to high age and severe comorbidities (11 patients), and nonsurvivable injury due to high complete SCI (2 patients). Additionally, the chart review did not provide a clear answer as to why three patients with major translation aged 60 to 71 years with preinjury ASA 3 were treated with external immobilization alone without surgical fixation.

Long-term follow-up

Of the 212 patients, 72/212 (34%) were dead and 140/212 (66%) were alive at the time of follow-up in 2018–2019. Five declined invitations to follow-up, and seven did not respond. Thus, 128 patients were included in the follow-up part of the study. The median follow-up time for these was 38.0 months (range 3.0–108.0 months). Three patients with short (3 months) follow-up time had all achieved bony fusion, and all had cognitive impairment not compatible with further examinations.

Bony fusion at time of follow-up

Cervical spine CT was performed in 116/128 patients (90.6%) patients at time of follow-up. Twelve patients rejected a new cervical spine CT. The reason for rejection was a lack of neck symptoms in 9 patients (patients felt an additional CT was unnecessary) and poor general function in three institutionalized patients. Bony fusion of the odontoid fragment with trabecular bone crossing the fracture line was seen in 111/116 (95.7%) patients undergoing cervical spine CT at the time of follow-up. Fibrous union was observed in 4/116 (3.4%; all in the primary external immobilization group), and 1/116 (0.8%) presented with radiologically evident pseudarthrosis at flexion/extension X-ray but no symptoms.

Table 2

Patients with major displacement of the odontoid fragment accepted for primary conservative treatment

Age	Sex	ASAScore	ADL	AIS score	Translation (direction)	Translation (mm)	30-day mortality	Why not surgery?
94	Male	3	Dependent	E	Posterior	4	-	Age/Comorbidity
76	Male	3	Independent	E	Posterior	3	-	Translation accepted
63	Male	2	Independent	E	Posterior	3	-	Translation accepted
64	Female	3	Independent	E	Posterior	3	-	Translation accepted
70	Male	3	Independent	E	Anterior	5	-	Translation accepted
54	Female	3	Independent	E	Anterior	5	-	Translation accepted
77	Female	2	Independent	E	Anterior	5	-	Translation accepted
71	Female	3	Independent	E	Anterior	5	-	Translation accepted
79	Female	3	Independent	E	Posterior	3	No	Translation accepted
38	Male	2	Independent	A	Posterior	14	Yes	Lethal trauma
84	Female	2	Independent	A	Posterior	3	Yes	Lethal trauma
82	Male	3	Dependent	E	Posterior	3	Yes	Age/Comorbidity
90	Male	3	Dependent	E	Posterior	3	Yes	Age/Comorbidity
83	Male	3	Dependent	E	Posterior	4	Yes	Age/Comorbidity
95	Male	4	Dependent	E	Posterior	3	Yes	Age/Comorbidity
83	Female	3	Dependent	E	Posterior	7	Yes	Age/Comorbidity
95	Male	2	Independent	E	Posterior	4	No	Age/Comorbidity
85	Female	3	Independent	E	Posterior	4	No	Age/Comorbidity
88	Male	3	Independent	E	Posterior	3	No	Age/Comorbidity
87	Male	3	Dependent	E	Anterior	5	Yes	Age/Comorbidity
87	Female	3	Independent	E	Anterior	6	Yes	Age/Comorbidity
67	Male	3	Independent	E	Anterior	6	No	Unknown
71	Male	3	Independent	D	Anterior	7	No	Unknown
60	Female	3	Independent	E	Posterior	5	No	Unknown

Living status at time of follow-up

Thirteen of 128 patients living independently before the injury experienced a decrease in their ADL (Activities of daily living) status to dependent living at the time of follow-up. No patients demonstrated an improvement in living status. Thus, at time of follow-up, 28/128 (21.9%) patients had a dependent living status.

Neck pain at time of follow-up

Median and mean neck pain VAS was 0 and 1.48, respectively. Among all patients, 103/128 (80.5%) reported a VAS score ≤ 3 , 18/128 (14.0%) reported a VAS score of 4 to 6, and 7/128 (5.5%) patients reported VAS score of ≥ 7 . There was no significant difference in long-term follow-up VAS with respect to primary treatment (conservative group VAS mean 1.47 vs. surgery group VAS mean 1.71; Mann-Whitney *U* test: $p=.444$). Of the patients reporting severe neck pain, all had bony fusion (not eligible for statistical analysis).

Neck disability index (NDI)

NDI was scored in 117/128 patients (nine patients could not fill out the questionnaire due to cognitive impairment, one patient because of decreased functionality and one patient refused). Of the 117 patients with NDI scores, 62 patients (53.0%) did not demonstrate any disability (NDI score 0–4), 23 patients (19.7%) presented with mild disability (NDI score 5–14), 21 patients (17.9%) exhibited

moderate disability (NDI score 15–24), 6 patients (5.1%) presented with severe disability (NDI score 25–34) and 5 patients (4.3%) had complete disability status (NDI score 35–50). There was no significant difference in long-term follow-up NDI with respect to type of primary treatment (conservative group NDI median 8.7 vs. surgery group NDI median 7.7; Mann-Whitney *U* test: $p=.562$). All 11 patients reporting severe/complete disability on NDI were in the primary conservative group, and all had bony fusion at time of follow-up. No significant association between age and NDI was found (*Spearman's rank-order correlation*; $r_s=-0.064$, $p=.495$).

Cervical spinal cord injury at follow-up

At time of primary diagnosis, eight patients had SCI related to their OFx. The two patients with complete SCI (ASIA A) died in the early course. Of the 128 patients available for follow-up, 127/128 had ASIA impairment score E (no symptoms or signs of SCI) at the time of follow-up. The only patient with persisting symptoms and signs of cervical SCI at time of follow-up was scored to ASIA C at the time of primary admission, underwent primary surgical stabilization and had improved to ASIA D at the time of follow-up. Two patients with ASIA D at the time of injury recovered at follow-up to ASIA E. None of the 128 patients experienced new onset SCI after the start of primary treatment.

Fig. 4A. Kaplan-Meier curve showing overall survival.

Fig. 4B. Kaplan Meier curve separated by age groups.

Survival

The 30-day, 6-month, and 12-month survival rates were 86.3%, 81.6%, and 80.6%, respectively (Fig. 4A). Increasing age was associated with reduced survival (log-rank test $p < .001$; Fig. 4B).

Discussion

In this consecutive series of 212 patients with type III acute odontoid fractures (OFx), median patient age was 72 years, 56% had pre-injury severe comorbidities (ASA score ≥ 3) and 22% lived dependently. The trauma mechanism was fall injury in 82%, and 4% had SCI related to the OFx at the time of diagnosis. Primary treatment was external immobilization alone in 95.3% and open surgical fixation in 4.7%. Subsequent crossover to surgical fixation was performed in 5.4%. At follow-up, 95.7% of patients exhibited bony fusion, 80.5% had minimal or no neck pain, and no one had developed new onset SCI.

In our study, the typical patient with a traumatic type III OFx was an elderly man or woman with major comorbidities who had suffered a fall. These observations are in line with previous studies [23,24]. One must expect an increase in OFx as the population is aging. The World Health Organization has defined risk factors for falls, including

polypharmacy, comorbidities, age >80 years, impaired cognition (especially attention and executive dysfunction), impaired vision, and environmental factors [25,26]. Thus, the implementation of fall preventive measures is needed [27].

In our cohort, primary treatment was external immobilization alone in 95.3% and open surgical fixation in 4.7%. Our low rate of surgery is in line with other studies reporting a rate of 0% to 5% [7,9,28]. Two recent reports recommend that all type III OFx should be treated conservatively with close monitoring during patient recovery [9,29]. Our data can be considered as support to this recommendation.

Major translation of the odontoid fragment was registered in 32 patients (15.1%), but only 8 of these received surgery as a primary treatment. A reasonable explanation for deviation from treatment recommendations was found in the large majority of patients, including high surgical risk, nonsurvivable injury, and the degree of translation within 1 mm of the preset range for nonmajor translation. In three cases, the reason for refraining from surgery was obscure. Despite refraining from surgical fixation in 3/4 of patients with major translation, only 5.4% of all patients treated with primary immobilization required conversion to secondary surgery. The proportion of crossover from primary external immobilization to surgery corresponds with other studies reporting rates between 0% and 7% [9,24]. Niemeier et al. have recently published a series of type III OFx, where they conclude that a subset of these fractures, called complex, high-energy fractures, have a higher crossover rate to surgery [29]. The reason for secondary surgery in our patient cohort was increasing displacement in all cases. Of the 11 patients who were redirected to secondary surgery, 7 (64%) had no initial displacement. This emphasizes that, even though the majority of patients with type III OFx can be treated nonsurgically, conservatively treated patients should be followed with close monitoring during recovery. In our institution, we followed these patients with a cervical spine CT and clinical examination 1, 4, and 12 weeks after diagnosis.

Achieving stability is the primary goal when treating OFx, and bony fusion is considered the gold standard. We observed bony fusion of the fracture in 95.7% of our patients at long-term follow-up. This very high bony fusion rate is in line with previous reports [7–9]. Stability is considered crucial for avoiding secondary SCI. None of our patients developed secondary SCI after primary treatment. Patients with an OFx and complete SCI do not usually survive their injury [30]. The two patients in our cohort with primary SCI classified as ASIA A died during their primary hospital stay. All patients with initial SCI, who were available for long-term follow-up, experienced improvement or total recovery of their SCI. The rate of SCI at time of primary diagnosis of traumatic OFx type III is by others reported in the range 3.5% to 13%, in line with our observations [9,24,31]. Previous studies have also noted improvement of SCI over time in surviving OFx patients [9,24,31].

Even though the primary treatment goal is to achieve stability and thereby avoid secondary SCI, another important aim is a good clinical outcome, regarding both pain and general function. At the time of follow-up, 80.5% of patients had no or minimal neck pain. There was no significant difference in long-term follow-up neck pain between the primary conservative and primary surgery groups. Severe neck pain was reported by seven patients, all with bony fusion of the fracture at follow-up. It seems reasonable to conclude that severe persistent neck pain was quite rare after treatment of type III OFx in our patient cohort.

NDI is often used as an additional measure of functional long-term outcome in patients suffering an OFx. The majority of patients in our cohort reported a favorable outcome, with 90.6% having none to moderate disability, with the largest fraction having none. A proportion of 9.4% of patients reported severe or complete disability according to NDI. All patients with this unfavorable functional outcome had achieved bony fusion at the time of follow-up. As with neck pain, it is probably unavoidable that a minority of patients experience neck-related disability after an OFx, either as a direct sequela after the fracture or coinciding soft tissue injury, or as a result of or in combination with predisposing conditions.

There are few publications on isolated type III OFx from general populations, and thereby sparse data reporting long-term neck pain using VAS scale or NDI. Our data on neck pain VAS and NDI are in line with the previous reports we have identified [32–34].

Thirteen of 128 patients living independently before the injury had a reduction in their ADL status to dependent living at the time of follow-up. In addition to the OFx, further multitrauma was registered in 1/3 of patients, with moderate/severe head injury being observed in 6%. These other injuries might also have influenced the self-care ability of the patients. When considering that 70% of patients were elderly (≥ 65 years of age), we find this fraction of a 10% decrease in ADL status rather low.

The 30-day survival in this series was 86.3%. Increasing age and high comorbidities were correlated with increased risk of death after suffering from OFx, which is in line with previous studies [23,35,36]. A very small proportion dies because of the OFx itself, primarily patients with concomitant complete SCI. The largest proportion of mortality is likely due to old age, comorbidities and frailty, leading to complications in an acute trauma setting [23,30,35,37].

In our cohort of patients with type III OFx, we treated the majority of patients with external immobilization alone. Patients with significant fracture displacement have routinely been considered for surgery, but due to old age and comorbidities, the majority in our series received conservative treatment. In summary, our study shows a low rate of crossover from external immobilization to surgery, very high long-term bony fusion rate, low rate of long-term severe neck pain, and no cases of new onset SCI. Altogether, our results support that

primary external immobilization is the treatment of choice for the majority of patients with type III OFx. A few of these patients will be redirected to surgery due to increasing dislocation of the odontoid fragment during the external immobilization period, emphasizing the need for close follow-up with cervical spine CT during the primary treatment period.

Limitations of this study

Patients received treatment based on the best judgment of the treating neurosurgeon, both in terms of surgical versus nonsurgical treatment and regarding choice of surgical technique. There will always be room for divergent judgment between physicians. High age is closely linked to both risk of death and cognitive impairment. Thus, our follow-up group was to some extent biased by the fact that many very old people died before the follow-up part of the study and by cognitive impairment in some of the patients at time of follow-up. This study was performed in Norway, a country with free and equal access to health care (treatment and rehabilitation). Therefore, the generalizability of this study is to some extent limited to countries with the same organization of health care.

Strengths

This is a large patient cohort from a defined total population, providing data on essentially all patients with type III OFx within this population during the defined timeframe without bias.

Conclusion

In this population-based observational cohort study of 212 consecutive patients with traumatic type III OFx, primary treatment was external immobilization alone in ~95%. The proportion of crossover from primary external immobilization to surgery was 5.4%. This management strategy resulted in very good long-term outcomes with a high bony fusion rate, a low rate of chronic neck pain and no patients with new onset SCI, reaffirming that nonsurgical treatment is still the preferable option in the majority of patients with type III OFx.

Data availability

The research data is confidential because it contains clinical and personnel information about our patients which can lead to identification of the patients. According to the organization restrictions and regulations the data cannot be made public available. Data are however available from the authors upon reasonable request and with permission of the Data Protection Officer at OUH.

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Conflict of interest

The authors have no conflicts of interest to declare

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