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Functional outcome of elderly patients treated for odontoid fracture. A multicenter study.

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Reviewers' comments:

Reviewer #1: Abstract:
More data has to be included: Please ad how many patients have been treated by surgery (and by which technique) compared to conservative treatment.
We have integrated the abstract according to your suggestion.

Materials and methods:
"Type III odontoid fractures were considered unstable whenever a shallow-type, an antero-posterior displacement of more than 5mm and an odontoid angulation of more than 11°was noted."
Did you consider all type 2 fractures as unstable?
Thank you for your question. All type II fractures have been considered potentially unstable and, since those ones revealing an antero-posterior displacement over 5mm should be considered severely unstable, we have included this value in the multivariate analysis, in order to establish if "severely unstable" fractures may have a different outcome. Therefore, all the patients included in the study had an unstable odontoid fracture, because of the radiological evidence of a type II or alternatively of a type III shallow-type/A-P dislocated >5mm/angulated>11°. Manuscript has been modified accordingly

Treatment modalities:
Basically, patients with stable fractures have been treated non-operatively (cervical collar or halo vest), and all other patients have been treated by one of three different operative techniques. If this is how patients have been treated you should emphasize this (in abstract and text). I would strongly recommend that you provide data with exact numbers of patients treated by halo vs cervical collar for a stable fracture (how many non-fusions, how many cross - overs, functional outcome) and of patients treated by the three operative techniques for instable fractures and compare the outcome of these techniques.
Thank you for your comment. Since all type II odontoid fractures have been considered as unstable, the choice of treatment (conservative Vs surgical) appeared influenced only by the antero-posterior displacement (< or >5mm) or by the surgeon decision: in fact, in some cases, despite a higher antero-posterior displacement, the surgeon decided to treat patients with collar or halo, due to patient clinical conditions that would have increased the risk of surgery unacceptably. In order to correct this selection bias, we performed a multivariate analysis including Comorbidity indexes (Charlson, ASA, Modified Rankin Scale). Other radiological fracture characteristics had no role in setting treatment strategy. As suggested, we've modified abstract and manuscript in order to emphasize this concept. According to your recommendation, but respecting the aforementioned assumption of instability for type II fractures, we've integrated the manuscript with the most significant data regarding functional outcome and cross-over for all the treatments adopted (conservative and surgical), comparing them in the discussion. Since all the 25 "cross-over" patients needed for a second step treatment because of a mobile non-fusion at the dynamic cervical spine imaging, non-fusion data should be discussed including this subgroup of patients, which has been excluded from the analysis from the beginning in order to avoid confusion. According to the previous revision requested, cross-over has been considered as an outcome parameter, preserving the main purpose of our study which is the analysis of functional outcome. Functional outcome for patients with crossover cannot be evaluated properly because it is impossible to establish if outcome is more related to initial treatment or second treatment or both. For this reason, like in all studies analyzing outcome, the subgroup of patients with treatment crossover was not included in the analysis of functional outcome. These patients would deserve a detailed method, another stat, results, tables and discussion rather than a paragraph in this manuscript, which would risk to generate confusion in the reader considering the topic of this study.

The advantage of your investigation is that you obtained clinical outcome parameters for a large number of patients. The results of your investigation show what is already known: Stable fractures do have a better outcome than unstable fractures. Anterior screw fixation in elderly patients shows higher rates of re-operation.
Thank you for your comment. As you noted cross-over regarded even patients who underwent surgery and more specifically 3/25 patients needed for a second step C1-C2 posterior arthrodesis as a rescue procedure after mechanical failure of anterior odontoid screw fixation. The manuscript has been integrated with this data.

Functional outcome of elderly patients treated for odontoid fracture. A multicenter study.

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on behalf of the "DENSER group"

*these authors equally contributed to the paper

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ABSTRACT

Study Design: Retrospective multicenter study.

Objective: Analysis of impact of conservative and surgical treatments on functional outcome of geriatric odontoid fractures.

Summary of Background Data: Treatment of odontoid fractures in aged population is still debatable.

Methods: 147 consecutive odontoid fractures in elderly patients were classified according to Anderson-D'Alonzo and Roy-Camille classifications. Philadelphia type collar was always positioned and kept as a treatment whenever acceptable. Halo-vest, anterior screw fixation, C1-C2 posterior arthrodesis and occipito-cervical fixation were the other treatments adopted. Conservative or surgical treatment strategy were more significantly influenced by antero-posterior displacement (< or >5 mm) and by surgeon decision. On admission ASA, modified Rankin scale (mRS-pre) and Charlson Comorbidity Index (CCI) were assessed. Modified Rankin scale (mRS-post), Neck Disability Index (NDI) and Smiley Webster Pain Scale (SWPS) were administered 12-15 months after treatment to estimate functional outcome in terms of general disability, neck-related disability and ability to return to work/former activity. Risk of treatment crossover was calculated considering factors affecting outcome. Fracture healing process in terms of fusion-stability, no fusion-stability, no fusion-no stability was evaluated at 12 months through a cervical CT scan. Dynamic cervical spine x-rays were obtained whether necessary. No fusion-stability was considered an adequate treatment goal in our geriatric population. Chi square/Fisher exact test and logistic regression were performed for statistical analysis.

Results: Overall 67 patients were treated conservatively whereas 80 underwent surgery. Collar was adopted in 45 patients, while anterior odontoid fixation and C1-C2 posterior arthrodesis were preferred for 30 patients each. 79.8% of patients showed good outcomes according to NDI. No significant differences were observed between patients of 65-79 years and ≥80 years ($p=0.81$). CCI greatly correlated with mRS-post, with higher indexes in 68.8% of cases characterized by good outcomes ($p=0.05$). mRS-pre correlated with NDI ($p<0.000001$) and mRS-post ($p=0.04$). CCI, mRS-pre and surgery were associated with worse NDI, while both C1-C2 posterior arthrodesis and occipito-cervical stabilization were associated with worse mRS-post, respectively in 40% and 30% of cases. Younger patients had a higher risk of treatment crossover.

Conclusions: mRS-pre and CCI provided two independent predictive values respectively for functional outcome and post-treatment disability. Compared to conservative immobilizations**,** surgery revealed no advantages in the elderly in terms of functional outcome.

Keywords: C2, odontoid, fracture, comorbidity, disability, elderly, ultra-elderly, functional outcome, stability, healing, treatment, fusion, surgery, conservative, crossover

Abbreviations: mRS-pre = pre-treatment modified Rankin scale; mRS-post = post-treatment modified Rankin scale; CCI = Charlson Comorbidity Index; NDI = Neck Disability Index; SWPS = Smiley Webster Pain Scale; MPR = multiplanar reconstruction;

Level of Evidence: 3

Keypoints

- Outcome of odontoid fractures should not be measured with fusion rate, but with functional outcome scoring systems;
- Pre-treatment higher comorbidity rate (Charlson Comorbidity Index) and higher disability (Modified Rankin Scale) are associated with worse functional outcome in geriatric type II odontoid fractures regardless of treatment;
- Surgery is related to higher risk of worse functional outcome in patients aged 65 or over compared with external immobilization with collar or halo.

Mini Abstract

Functional outcome of elderly patients treated for odontoid fracture is strictly related to their pre-injury level of function and comorbidity. Compared to conservative external immobilizations, surgery revealed no advantages in the elderly in terms of functional outcome.

INTRODUCTION

Odontoid fractures represent the most common cervical spine fractures among elderly and the most frequent vertebral fractures among patients over 80 years. Their rate in this old patient group is increasing, growing faster than the ageing population[1].

Despite recent advances in internal fixation techniques, controversy remains regarding whether operative or non-operative management is the best treatment approach for elderly patients[2-11]. Non-operative treatment options include hard cervical collar and halo-vest orthosis, while operative strategies comprehend anterior odontoid osteosynthesis, C1-C2 posterior arthrodesis and occipito-cervical stabilization. Treatments with cervical immobilization avoid the risks of surgery but they are associated with higher non-union rates, whereas surgical fixations put patients at risk for post-operative complications but leading to significantly better union rates[1]. The outcomes for those patients showing nor fusion nor signs of fracture healing process remain unclear and morbidity of odontoid pseudoarthrosis in aged population is also not well defined[12,13]. Many factors have to be taken into account to find the right balance between support of fracture consolidation and risk of treatment complications. Based on these considerations, the decision for either conservative or surgical therapy is made[11,14]. In this particular subset of patients, most studies focus on radiological outcome and survival, without considering how different treatment modalities may have an impact on daily life[3,5,12,14-19]. The aim of this study was to assess the functional outcome of elderly patients with unstable odontoid fractures in relation to the different treatment modalities, focusing on the impact of external

immobilizations, surgical fixations and comorbidities in such a fragile population.

MATERIALS AND METHODS

Study population and radiological classification

From January 2012 through December 2016, 210 consecutive patients treated for unstable odontoid fractures in four different trauma centres were included in this retrospective analysis. Three different causes of injury were identified: vehicle accidents (including any kind of means of transport, or as a pedestrian); falls with low energy impact (less than 2 meters); falls with high energy impact (more than 2 meters). Nine patients died, two were lost at follow-up and those ones under 65 years or with missing/incomplete data were excluded from the study. Six patients with spinal cord injury were also excluded because their functional outcome would have been affected by their neurological impairment. Among the remaining 172 patients, 25 were excluded because of treatment crossover. All the 147 enrolled patients underwent a baseline cervical spine CT evaluation at the hospital admission and at 1, 6 and 12 months after surgery as part of a standardized radiological follow-up.

CT scans of the cervical spine were performed using a clinical multidetector scanner. Images always contained multiplanar reconstructions (MPR), which were systematically reviewed to classify each fracture according to the Anderson and D'Alonzo (type II or III) and the Roy-Camille classifications (anterior oblique, posterior oblique and horizontal) respectively describing fracture localization and direction of fracture line. All type II odontoid fractures have been considered potentially unstable and those ones, among them, revealing an antero-posterior displacement over 5 mm, have been considered potentially severely unstable. Type III odontoid

fractures were considered unstable whenever a shallow-type, an antero-posterior displacement of more than 5 mm and an odontoid angulation of more than 11°was noted.

Treatment modalities

All the patients had a Philadelphia® type cervical collar (Center for Prostethics Orthotics, Inc., Seattle, WA, USA) positioned soon after the spine trauma and worn as an acceptable treatment or as a temporary immobilization before surgery, depending on the decisions taken by the physicians after the imaging of the cervical spine. No protocols were applied to drive the choice of the most appropriate strategy and patients were managed conservatively or surgically according to knowledge and experience of dedicated neurosurgeons/orthopedics and their surgical armamentarium. However, all the treating physicians preferred surgery whenever a fracture gap of more than 2 mm, an antero-posterior displacement of more than 5 mm and an odontoid angulation of more than 11° occurred. Conservative or surgical treatment strategy were more significantly influenced by antero-posterior displacement (< or >5 mm) and by surgeon decision. More specifically, despite an antero-posterior displacement over 5 mm, in some cases surgeon decided to treat patients with external immobilization, due to patient clinical conditions that would have unacceptably increased the risk of surgery. Other radiological fracture characteristics played no role in setting treatment strategy. Five different treatments were reported: hard cervical collar (Philadelphia® [Center for Prostethics Orthotics, Inc., Seattle, WA, USA], Aspen® or Vista® [Aspen Medical Products, Irvine, CA, USA] type) and halo vest (PMT® Corporation, Chanhassen, MN, USA) among those ones conservatives; anterior odontoid screw fixation, C1-C2 posterior arthrodesis (Harms technique) and occipito-cervical stabilization among the surgical options. Risk of treatment crossover was calculated for all the factors affecting outcome, but those patients who needed for such a second step surgery were excluded from the analysis due to the impossibility to establish the role of first,

second or both treatments in determining the final functional outcome.

Functional and radiological assessment

On admission, each patient was clinically assessed adopting ASA score, modified Rankin scale (mRS-pre) and Charlson Comorbidity Index (CCI) respectively for estimating general physical status, degree of disability and mortality risk according to comorbidities (*table 1*).

From 12 to 15 months after treatment, functional evaluations were performed employing a second modified Rankin scale (mRS-post) together with the Neck Disability Index (NDI) and the Smiley Webster Pain Scale (SWPS), investigating respectively general disability, neck-related disability and ability to return to work/former activity. Both NDI and SWPS were delivered as phone interview questionnaires by two different operators whether necessary.

The radiological outcome was evaluated through CT scans of the cervical spine with MPR 12 months after treatment. In cases with doubtful fracture healing attitude, dynamic cervical spine x-rays were obtained to rule out atlantoaxial instability. According to the evidences of both CT scan and dynamic x-rays, three different conditions were identified: fusion-stability, no fusion-stability, no fusion-no stability.

Fusion was defined by the evidence of bone trabeculae crossing the fracture line in absence of sclerotic borders/bone resorption of fracture's fragments. Fracture stability was determined by the absence of secondary displacement of the odontoid process. This latter condition was considered an adequate treatment goal in our geriatric population, even without radiological evidences of bony fusion (no fusion-stability).

All the surgical consents included paragraphs regarding patient agreement to elaborate and share disease-related information for scientific purposes. A similar agreement form, included

in a paper with indications for management of external immobilization, was signed at first follow-up appointment by those patients non-operatively treated.

Statistical analysis

The statistical analyses were performed with the Statistical Package for the Social Sciences software for Windows (SPSS Inc. Released 2008. SPSS Statistics for Windows, Version 17.0. Chicago, IL, USA). Univariate analysis included impact of age (65-79 vs 80 and over), Charlson Comorbidity Index (2-5 vs 6-8), ASA score (1-2 vs 3 vs 4), mRS-pre (0-3 vs 4-5), Anderson-D'Alonzo classification (odontoid fracture type II vs III vs II-III plus other cervical fractures), fragment dislocation (more or less than 5 mm) and treatment (collar vs halo vs anterior odontoid screw vs C1-C2 posterior arthrodesis vs occipito-cervical stabilization) on outcome.

Outcome variables were analyzed: complications (yes vs no), radiological outcome (fusion, no fusion-stable, no fusion-unstable), NDI (0-28% vs 30-48% vs 50-100%), mRS-post (0-3 vs 4-5), SWPS (excellent or good vs fair or poor) and crossover (yes vs no).

Chi square/Fisher exact test were adopted to compare variables. Logistic regression analysis investigated the impact of the aforementioned variables on dichotomous outcome variables, including NDI 1-48% vs 50-100%. Results presenting $p < 0.05$ were considered statistically significant.

Source of funding

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper. No funds or grants have been received for this study.

RESULTS

Among all the 147 patients (73 male, 74 female) included in this multicenter study, 51.7% were aged 80 or over. In 71.4% of the cases the odontoid fracture derived from a fall with low energy impact, while in 19% occurred for a vehicle accident. Type II fractures were recorded in 58.6% of the cases, while in 27.9% type II or type III fractures were associated with other lesions of the craniocervical junction. Only 8% of the patients had an odontoid process dislocation ≥ 5 mm.

Treatment

Most patients treated conservatively (45.6% of total), received a Philadelphia type hard cervical collar, while patients who underwent surgery (54.4% of total) were treated as follows: anterior odontoid screw fixation (20.4%), C1-C2 posterior arthrodesis (20.4%), and occipito-cervical stabilization (13.6%). Overall treatment-related complications were 5.3% over 80 years and 7% between 65 and 79 years (Pearson's Chi Square 2-sided, $p=0.65$). Correlating the different treatment modalities with NDI, a good outcome (NDI 0-48%) was recorded in: 100% of hard cervical collar, 95.5% of halo vest, 90% of occipito-cervical stabilization, 47.6% of anterior odontoid screw fixations and 45.5% of C1-C2 posterior arthrodesis (Pearson chi squared 2 sided, $p<0.0001$). Similarly, a positive outcome, in terms of SWPS excellent or good, was reported in 88.9%, 81.8% and 75% of patients respectively treated with collar, halo vest and occipito-cervical stabilization, and only in 47.6% and 59.1% of those who respectively underwent anterior odontoid screw fixation and C1-C2 posterior arthrodesis (Pearson's Chi

Square 2-sided, *p<0.0001*).

Radiological outcome

At 12-month follow up, 54% of patients obtained a complete fracture healing process while 36.5% didn't reach the fusion although revealing stable at dynamic x-rays. No significant differences were observed in the rate of fusion between patients over 80 and those ones between 65 and 79 years (Pearson's Chi Square 2-sided, *p=0.74*)

Functional outcome

According with NDI, 79.8% of patients had a good outcome (range 0-48%). No differences were observed between younger (65-79 years) and older (≥80 years) patients (Pearson's Chi Square 2-sided, *p=0.81*).

Accordingly, the outcome based on SWPS showed a 48.5% of good and 23.8% of excellent outcome in terms of return to work/former activities with a post-treatment level of satisfaction equally outstanding in both age subgroups (Fisher's exact test 2-sided, *p=0.56*).

A CCI from 2 to 5 and an ASA score of 3 were recorded respectively in 66% and 63.9% of patients, and most of them needed no assistance neither before or after treatment with mRS-pre and mRS-post ranging from 0 to 3 respectively in 70.1% and 76.2% of cases.

As expected, CCI significantly correlated with mRS-post, with higher indexes (6-8) reported in 68.8% of cases characterized by worse outcomes (Fisher's exact test 2-sided, *p=0.05*).

Pre-treatment mRS strongly correlated with NDI (92% of patients with pre-treatment mRS 0-3 had a NDI between 0% and 48%-Fisher's exact test. 2-sided, *p<0.0001*) and with post-treatment mRS (83.3% of patients with pre-treatment mRS 0-3 had a post-treatment mRS 0-3, Fisher's exact test 2-sided, *p=0.04*).

Patient's satisfaction was reported as excellent or good (SWPS) in 83.2% of patients with mRS-

pre 0-3, but only in 41.4% of patients with mRS-pre 4-5 (Fisher's Exact test 2-sided, *p<0.0001*). No correlation between mRS-pre and radiological outcome was observed.

Factors affecting functional outcome

When correcting for confounding variables at logistic regression analysis, we found that high values of CCI and mRS-pre, together with all surgical procedures (anterior odontoid screw fixation, C1-C2 posterior arthrodesis and occipito-cervical stabilization) were associated with worse NDI (*Figure 1, table 2*). Likewise, high scores of mRS-pre and surgery were associated with worse SWPS (*table 3*). Multivariate analysis also showed that C1-C2 posterior arthrodesis and occipito-cervical stabilization were associated with worse mRS-post, respectively in 40% and 30 % of cases (*table 4*), while C1-C2 posterior arthrodesis and ultra-elderly patients were associated with a lower risk of crossover (*table 5*). Among the 25 patients who needed a treatment crossover, thus not included in our outcome analysis, 13 were wearing a halo vest and 9 a Philadelphia type collar. The remaining 3 patients underwent C1-C2 posterior arthrodesis as rescue surgery for loosening of the anterior odontoid screw.

DISCUSSION

To date, this multicenter study represents one of the largest investigations on odontoid fractures and the largest study on functional outcome in the elderly.

The main limitations of this study lie in its retrospective nature, in the number of dead patients and in the presence of patients needing a treatment crossover. Nonetheless, the percentage of patients with missing data or lost at follow-up (15 out of 204-7.3%) and the percentage of patients with treatment crossover (25 out of 172-14.5%) is relatively low.

Discordance between radiological and functional outcome can be explained with the particular fragility of this subset of patients expressed by the poor post-surgery level of function: sharp dissection of paraspinal muscles and ligaments together with the fixation itself have both an influence on outcome much more than fracture union. On the other hand, such geriatric population shows an age-related cervical spondylosis, which represents a pre-existent limitation likely not overloading any eventual odontoid fibrous union, because of the reduced range of motion of head and neck usually associated to this degenerative spine condition.

Interestingly, according to the scales used for the assessment of functional outcome, patients aged 80 years or over had no worse results than those between 65 and 79 years-old, with these latters revealing even a higher risk of crossing over from conservative to surgical treatment.

Indipendently from the age group, multivariate analysis showed that greater numbers of comorbidities, thus higher CCIs, were related to more severe degrees of disability.

The mRS-pre represented a strong independent predictive value for functional outcome.

As expected, independently from the conservative/surgical strategy, patients needing assistance before treatment (i.e. with higher mRS-pre values) didn't improve their post-treatment score, therefore indicating a marginal role of surgery whenever a severe disability already exists. On this line, patients with mRS-pre 4 or 5 revealed a favourable NDI (0-48%) and an excellent or good SWPS only in 37.9% and 41.4% of cases, respectively. Patients with a low mRS-pre (0-3), instead, had a favourable NDI (0-48%) and an excellent or good SWPS in 92% and 83.2% of cases, respectively.

Such deep difference expressed in percentages demonstrated both the effectiveness and reliability of mRS-pre in estimating the functional outcome, confirming what assumed by Vaccaro et al. [11] about the pre-injury level of function and its relevant impact on outcome regardless the treatment type.

Logistic regression analysis showed that CCI, mRS-pre and all the surgical procedures were associated with worse NDI while both C1-C2 posterior arthrodesis and occipito-cervical stabilization were associated with worse mRS-post. Differently from Joestl et al. [6], who observed better functional results among patients who underwent anterior odontoid screw fixation compared with those ones treated with halo, we noticed a homogeneously worse functional outcome after any kind of surgical procedure, but an expectable lower risk of crossover after C1-C2 posterior arthrodesis. The risk (OR) of having a worse NDI after surgery was 769-fold increased with anterior screw fixation, 3412-fold increased with C1-C2 posterior arthrodesis and 162-fold increased with occipito-cervical stabilization, compared with collar alone. The risk of having a worse mRS post-treatment was 11-fold increased with C1-C2 posterior arthrodesis and 15-fold increased with occipito-cervical stabilization, compared with cervical collar. Similarly, the probability of having a worse outcome measured with the SWPS increased 7 to 11-fold for patients treated with anterior screw, C1-C2 arthrodesis and occipito-cervical stabilization. Anterior odontoid screw and C1-C2 arthrodesis demonstrated identical rates (53.4%) of negative NDI (range 50-100%), and similar percentages of unsatisfactory SWPS (fair-poor), being the two treatments associated to the worst results adopting these parameters of functional outcome, although with the bias related to the crossover of those 3 patients who underwent a second step C1-C2 arthrodesis after an anterior screw mechanical failure. Occipito-cervical stabilization revealed instead unexpected positive outcomes in terms of NDI, mRS-post and SWPS respectively in 90%, 70% and 75% of cases. These data likely biased by the limited number of this subgroup of patients (n=20), all octogenarians and all died because of their severe age-related comorbidities, could be deeply influenced even by the relatively short follow-up for this subset of patients and their pre-treatment compromised general clinical status, which led these ultra-elderlies to be more accustomed to tolerate pain and to accept discomfort and functional limitations. In terms of

pre-injury level of function, higher comorbidity rates were associated with 10-fold increased risk of worse NDI, while severe pre-treatment disabilities were associated with 14-fold increased risk of worse SWPS.

Although some authors encourage the anterior odontoid screw fixation as the technique of choice for surgical treatment of type II odontoid fractures without any substantial limitation [5,6], some others, in line with our findings recognize that morbidity, mortality and functional outcome are influenced by patient's age [8,20] and age-related comorbidities [11]. Due to their youthful appearance in terms of general clinical status, 11 among our ultra-elderly patients underwent anterior odontoid screw fixation. Despite the absence of major comorbidities, this subset of patients showed a surprisingly negative functional outcome with a 18.2% of mechanical failure, which led to a second step C1-C2 posterior arthrodesis.

Therefore, differently from Henaux et al [4] and Hou et al [5], we wouldn't recommend an anterior odontoid screw fixation in the elderly [4,5] whatever the fracture type, since functional outcome appeared worse than conservative treatments, but similar to other surgical treatment modalities (and with a theoretical lower percentage of radiological stability compared with C1-C2 and occipito-cervical arthrodesis). Moreover, a high probability of anterior screw loosening in these osteoporotic patients may expose both to the risk of a revision surgery (crossover) with additional posterior fixation and to further risks in terms of morbidity and mortality [20].

In line with these trends we found a SWPS fair or poor in 53.4% of patients who underwent anterior screw fixation, while no substantial differences in outcome were observed between the two conservative treatments with cervical collar and halo vest, which distinguished for excellent or good SWPS respectively in the 88.8% and 81.80% of the cases.

Joestl et al [16] emphasize the excellent or good outcome obtained in the elderly with Harms technique up to five years after surgery. Our data, instead, showed that all surgical techniques

(anterior odontoid screw fixation, posterior arthrodesis C1-C2 with Harms technique, and occipito-cervical fixation) and high mRS-pre were associated with worse results in terms of Smiley Webster Pain Scale. Therefore, differently from Vaccaro et al [11], we didn't find any favor of surgical management in elderly patients in terms of functional outcome, but we agree with them that patients and their families should be aware that treatment might not restore the average patient to his/her pre-injury level of function.

CONCLUSION

Based on data validated by multiple measures of functional outcome, our study may provide useful guidance for surgeons and clinicians in advising elderly/ultra-elderly patients and their families about treatment for unstable odontoid fractures.

The comparison between homogenous groups of patients managed with the most adopted conservative and surgical treatments provides a unique and comprehensive view about the impact of each different technique on functional outcome of the most fragile patients.

Prospective multicenter studies evaluating clinico-radiological aspects of odontoid fractures focused on specific types of treatment with setup based on age groups should be favoured.

Future studies should include measures for evaluating the level of function: radiological outcome (fusion) should not represent the only aim of C2 fracture treatment in the elderly, since quality of life is influenced by several factors, and a treatment modality that impairs daily disability may have a tremendous impact also on survival of these fragile patients.

Therefore, the decision for the best treatment should be tailored taking into consideration and balancing the probability of fusion and stability with the probability of impairing functional outcome, the latter being negatively influenced by comorbidities (CCI), fragility (mRS) and surgery. An analysis of these factors could lead the basis for designing algorithms able to

customize the treatment strategy. Further investigations, involving a larger patient sample, may elucidate if the surprising advantage evidenced with conservative immobilizations, especially with hard cervical collars, comes from the absence of true minimally invasive procedures for odontoid fractures fixations or if materials and designs of modern cervical collars can really make enough difference to represent the best treatment compromise in the elderly.

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Table 1: Pre-treatment patients' characteristics

	Collar	Halo	Anterior screw	C1-C2 posterior arthrodesis	Occipito-cervical fixation	Total
Age: 65-79	10 (22%)	12 (54%)	19 (63%)	17 (57%)	13 (65%)	71 (48%)
Age: ≥ 80	35 (78%)	10 (46%)	11 (37%)	13 (43%)	7 (35%)	76 (52%)
ASA: 1-2	10 (23%)	9 (41%)	10 (33%)	8 (27%)	8 (40%)	45 (31%)
ASA: 3	33 (75%)	13 (59%)	18 (60%)	20 (67%)	10 (50%)	94 (64%)
ASA: 4	1 (2%)	0	2 (7%)	2 (6%)	2 (10%)	7 (5%)
CCI: 2-5	28 (62%)	14 (64%)	22 (73%)	23 (77%)	10 (50%)	97 (66%)
CCI: 6-8	17 (38%)	8 (36%)	8 (27%)	7 (33%)	10 (50%)	50 (34%)
mRS-pre: 0-3	35 (78%)	21 (95%)	14 (47%)	13 (43%)	20 (100%)	103 (70%)
mRS-pre: 4-5	10 (22%)	1 (5%)	16 (43%)	17 (47%)	0	44 (30%)
Dislocation < 5 mm	44 (97%)	21 (91%)	29 (96%)	26 (87%)	14 (72%)	135 (92%)
Dislocation ≥ 5 mm	1 (3%)	1 (9%)	1 (4%)	4 (13%)	6 (28%)	12 (8%)

ASA, ASA score; CCI, Charlson Comorbidity Index; mRS-pre, pre-treatment modified Rankin Scale.

Table 2

Table 2: Analysis of factors affecting outcome in relation to NDI (0-48 Vs 50-100)

Logistic regression analysis: dichotomous NDI	p	OR	95% C.I. for OR Lower	95% C.I. for OR Upper
Gender (male Vs female)	0,330	2,375	0,417	13,524
Age ≥ 80	0,956	0,947	0,136	6,583
CCI: 6 or 7 or 8	0,039	10,260	1,127	93,384
ASA 2	0,130			
ASA 3	0,064	8,067	0,887	73,327
ASA 4	0,815	0,530	0,003	108,380
mRS-pre: 4 or 5	0,001	159,676	9,037	2821,409
Anderson D'Alonzo Classification 2	0,409			
Anderson D'Alonzo Classification 3	0,662	1,815	0,126	26,200
Anderson D'Alonzo Classification 2 + other fractures of cranio-vertebral junction	0,188	3,525	0,541	22,982
Dislocation ≥ 5mm	0,244	0,052	0,0001	7,492
Treatments: cervical collar	0,005			
halo vest	0,035	89,109	1,373	5783,955
odontoid anterior screw fixation	0,001	769,807	17,959	32997,711
posterior arthrodesis (Harms)	0,0001	3412,629	44,766	260153,092
occipito-cervical stabilization	0,013	162,042	2,899	9058,388

ASA, ASA score; CCI, Charlson Comorbidity Index; mRS-pre, pre-treatment modified Rankin Scale.

Table 3: Analysis of factors affecting outcome in relation to SWPS

Logistic regression analysis: SWPS	p	OR	95% C.I. for OR Lower	95% C.I. for OR Upper
Gender (male Vs female)	0,233	1,899	0,662	5,449
Age ≥ 80	0,959	0,968	0,277	3,378
CCI: 6 or 7 or 8	0,662	0,772	0,242	2,462
ASA 2	0,448			
ASA 3	0,206	2,106	0,664	6,674
ASA 4	0,556	2,048	0,189	22,243
mRS-pre: 4 or 5	0,0001	14,394	3,732	55,512
Anderson D'Alonzo Classification 2	0,334			
Anderson D'Alonzo Classification 3	0,336	0,432	0,078	2,390
Anderson D'Alonzo Classification 2 + other fractures of cranio-vertebral junction	0,183	0,419	0,116	1,509
Dislocation ≥ 5mm	0,329	0,342	0,040	2,946
Treatments: cervical collar	0,047			
halo vest	0,040	6,409	1,086	37,820
odontoid anterior screw fixation	0,004	11,523	2,221	59,787
posterior arthrodesis (Harms)	0,022	7,030	1,321	37,405
occipito-cervical stabilization	0,016	11,355	1,568	82,243

ASA, ASA score; CCI, Charlson Comorbidity Index; mRS-pre, pre-treatment modified Rankin Scale.

Table 4: Analysis of factors affecting outcome in relation to mRS-post

Logistic regression analysis: mRS-post	p	OR	95% C.I. for OR Lower	95% C.I. for OR Upper
Gender (male Vs female)	0,831	1,116	0,410	3,037
Age ≥ 80	0,086	2,820	0,864	9,201
CCI: 6 or 7 or 8	0,219	1,982	0,666	5,899
ASA 2	0,788			
ASA 3	0,953	0,966	0,306	3,051
ASA 4	0,521	0,479	0,050	4,551
mRS-pre: 4 or 5	0,185	2,324	0,668	8,088
Anderson D'Alonzo Classification 2	0,886			
Anderson D'Alonzo Classification 3	0,640	1,403	0,340	5,793
Anderson D'Alonzo Classification 2 + other fractures of cranio-vertebral junction	0,786	1,186	0,345	4,078
Dislocation ≥ 5mm	0,208	2,739	0,570	13,153
Treatments: cervical collar	0,023			
halo vest	0,142	4,031	0,627	25,911
odontoid anterior screw fixation	0,141	3,669	0,649	20,732
posterior arthrodesis (Harms)	0,004	11,092	2,163	56,874
occipito-cervical stabilization	0,005	15,770	2,275	109,343

ASA, ASA score; CCI, Charlson Comorbidity Index; mRS-pre, pre-treatment modified Rankin Scale.

Table 5

Table 5: Analysis of factors affecting outcome (all patients): risk of crossover

Logistic regression analysis: risk of crossover	p	OR	95% C.I. for OR Lower	95% C.I. for OR Upper
Gender (male Vs female)	0,512	0,720	0,270	1,919
Age ≥ 80	0,004	0,180	0,056	0,577
CCI: 6 or 7 or 8	0,424	0,624	0,197	1,980
ASA 2	0,542			
ASA 3	0,347	1,692	0,565	5,066
ASA 4	0,396	3,779	0,175	81,499
mRS-pre: 4 or 5	0,480	1,662	0,405	6,813
Anderson D'Alonzo Classification 2	0,478			
Anderson D'Alonzo Classification 3	0,314	0,310	0,032	3,034
Anderson D'Alonzo Classification 2 + other fractures of cranio-vertebral junction	0,610	1,327	0,447	3,938
Dislocation ≥ 5mm	0,331	0,322	0,033	3,158
Treatments: cervical collar	0,009			
halo vest	0,255	1,963	0,614	6,271
odontoid anterior screw fixation	0,056	0,225	0,049	1,041
posterior arthrodesis (Harms)	0,035	0,090	0,010	0,843
occipito-cervical stabilization	0,125	0,171	0,018	1,632

ASA, ASA score; CCI, Charlson Comorbidity Index; mRS-pre, pre-treatment modified Rankin Scale.

Figure Legend:

Figure 1: NDi distribution in the different treatments

Figure 1: NDI distribution in the different treatments