

Top 50 most-cited articles on craniocervical junction surgery

ABSTRACT

Background: Craniocervical junction is a complex anatomical location posing unique challenges to the surgical management of its pathologies. We aimed to identify the fifty most-cited articles that are dedicated to this field.

Methods: A keyword search using the Thomson Reuters Web of Knowledge was conducted to identify articles relevant to the field of craniocervical junction surgery. The articles were reviewed based on title, abstract, and methods, if necessary, and then ranked based on the total number of citations to identify the fifty most-cited articles. Characteristics of the articles were determined and analyzed.

Results: The earliest top-cited article was published in 1948. When stratified by decade, 1990s was the most productive with 16 articles. The most-cited article was by Anderson and Dalonzo on a classification of odontoid fractures. By citation rate, the most-cited article was by Herms and Melcher who described Goel's technique of atlantoaxial fixation using C1 lateral mass screws and C2 pedicle screws with rod fixation. Atlantoaxial fixation was the most common topic. The United States, Barrow Neurological Institute, and VH Sonntag were the most represented country, institute, and author, respectively. The significant majority of articles were designed as case series providing level IV evidence.

Conclusion: Using citation analysis, we have provided a list of the most-cited articles representing important contributions of various authors from many institutions across the world to the field of craniocervical junction surgery.

Key words: Bibliometrics; citation; craniocervical.

Introduction

Surgical approach to the craniocervical junction requires intimate knowledge of the skeletal, ligamentous, neural and vascular anatomy, and the natural history of its pathologies. Our knowledge of this unique anatomical location has undergone advancements through the work of many authors.

Citation analysis is a bibliometric tool that can be utilized to quantitatively evaluate the influence of an article on a given field. The goal of this study was to select the fifty most-cited articles pertaining to the surgical management of craniocervical junction pathologies published between 1900 and 2015.

Methods

Inclusion criteria

Following the initial search process, studies were selected for inclusion in the final list of fifty based on several inclusion

criteria. Eligible studies were required to have focused primarily on the study of pathologies or interventions involving the craniocervical junction. Studies involving nonhuman subjects and studies published in languages other than English were excluded from the final list. Studies that discussed other related conditions, such as cervical spine pathologies, were included as long as patients with


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craniovertebral pathologies constituted the majority of the patient population in the study.

Eligible articles were selected from all journals and databases indexed on the Thomson Reuters Web of Science at the time of this analysis.

Data collection

A two-step query of the Thomson Reuters Web of Science was conducted to assemble the final list of fifty articles.

The first stage consisted of a topic search for the term “craniovertebral.” This search yielded 2190 results, which were subsequently sorted from the most-cited articles to the least-cited articles. The top 100 relevant studies in the list were analyzed to compile a list of keywords to be used in the subsequent search phase.

Seventy-six keywords were chosen from the aforementioned articles [Table 1] based on the following four categories: Location, approach, pathology, and therapy. These keywords were then used to search the database a second time using a compiled search term [Table 2]. This phase of the search yielded 31,965 papers, which were similarly sorted in order from most to least citations. We eliminated self-citations by conducting a “cited reference search” which provides all citing articles, followed by an “author search.” Results of the latter search, which yielded all articles published by authors of the article of interest, were then subtracted from the “cited reference search.”

The fifty most-cited papers in this list were selected out of the first 298 results for final inclusion in the list presented in this report.

The following information was extracted from each article selected for the final list: Article title, year of publication, total number of citations, citation rate, article topic, study type, and level of evidence. Citation rate was defined as the number of citations per year since the year of publication. Article topic categories included atlantoaxial fixation, atlantoaxial instability, occipitocervical fusion, trauma, anterior approach to craniovertebral junction, mixed, and others. Study type pertains to whether a study is nonclinical or clinical in which case the study design, potentially ranging from randomized controlled trial to case report, is determined. Level of evidence is determined for clinical studies, potentially ranging I–V.

Results

Table 3 provides information on the articles including their citations’ count, citation rate, article topic, article summary, article type, and level of evidence. Our final list consisted of articles published between 1948 and 2004. Publications peaked in 1985 with four articles [Figure 1];^[20,31,49,40] however, the most productive decade was the 1990s with 16 articles [Table 4].^[18,22,33,15,30,51,6,48,9,11,10,7,42,12,46,8]

The top journal was the Journal of Bone and Joint Surgery: American Volume which produced 12 out of the fifty articles.

Table 1: Keywords, in 4 categories, determined based on the first query

Location	Approach	Pathology	Therapy
Cranial	Dorsolateral	Rheumatoid	Fix*
Cervical	Suboccipital	Ankylosing	Fus*
Cranio-cervical	Transcondylar	Down syndrome	Plat*
Occipitocervical	Transoral	Chiropract*	Screw*
Atlanto-occipital	Transpharyngeal	Trisomy 21	Rod*
Atlantoaxial	Retropharyngeal	Trauma*	Cabl*
Occipito-atlanto-axial	Transarticular	Jefferson*	Instrument*
Atlantal	Intralaminar	Hangman*	Arthro*
Atlas	Endoscopic*	Injur*	Distract*
Axial		Fractur*	Stabiliz*
Axis		Disloc*	Mobiliz*
Condyl*		Sublux*	Reduc*
Dens		Burst*	Decompress*
Odontoid*		Rota*	Biomechanic*
Clivus		Rupture*	Galle
Clival		Congenital*	Halo
C1		Anomal*	
C2		Invag*	
Basilar		Impress*	
Transverse ligament*		Migrat*	
Alar ligament*		Settl*	
Atlantal ligament*		Degen*	
Vertebrobasilar		Instab*	
		Unstab*	
		Obstruct*	
		Fistul*	
		Myelopath*	
		Radiculopath*	

This was followed by the Journal of Neurosurgery and Spine, with nine and seven articles, respectively [Figure 2]. The authors with the most top 50 publications included VKH Sonntag^[15,30,48,35,40,34,42,12,46] (9), CA Dickman^[15,30,48,35,42,12] (6), and MN Hadley^[30,48,40,35,34] (5).

From Figure 3, it can be observed that atlantoaxial fixations (14) was the most common topic among the articles in the final list.

Articles in the final list originated from 13 different countries, with the majority having been based in the United States (26 articles). Table 5 displays the top ten institutions affiliated with articles on the final list. The most productive institutions were Barrows Neurological Institute (six articles) and St. Luke's Hospital (three articles).

The most-cited article pertaining to the craniovertebral junction was the 1974 study by Anderson and D'Alonzo on odontoid fractures.^[11] The article with the highest citation rate was Harms and Melcher's report on the use of C1 lateral mass screws and C2 pedicle screws with rod fixation for atlantoaxial fixation.^[2]

Discussion

We used citation analysis to identify the most-cited articles on the topic of craniovertebral junction surgery. This list represents the authors, institutions, and countries, which have been instrumental in the advancement of the field. We characterized the most-cited research topics and the study design utilized by the authors to investigate it, providing a perspective on the trends within the field and the level of evidence available for the surgical management of this complex anatomical location.

The years of publication ranged from 1948 to 2004. The article from 1948, ranked 19th overall and authored by

McGregor, provides an alternative to Chamberlain's line for the diagnosis of basilar impression. This line, which later known as McGregor line, is a line that connects the posterior edge of the hard palate to the most caudal end of the occipital bone's curve. If the tip of the odontoid process is 4.5 mm rostral to this line, the diagnosis of basilar impression is made.^[19] The article in 2004, ranked 16th overall and authored by Wright,^[16] is the first description of the use of bilateral crossing C2 laminar screws in rigid constructs that include

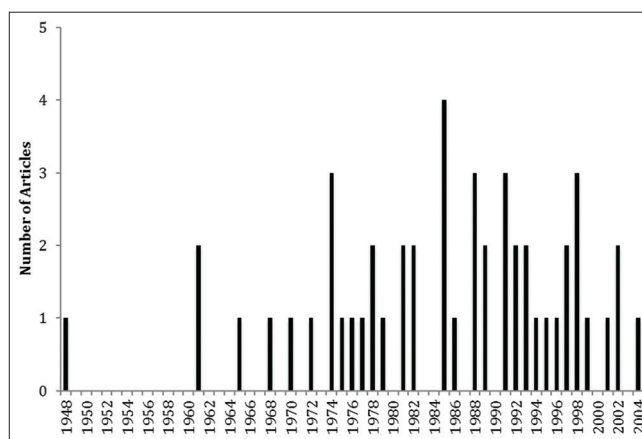


Figure 1: The number of top 50 articles published per year

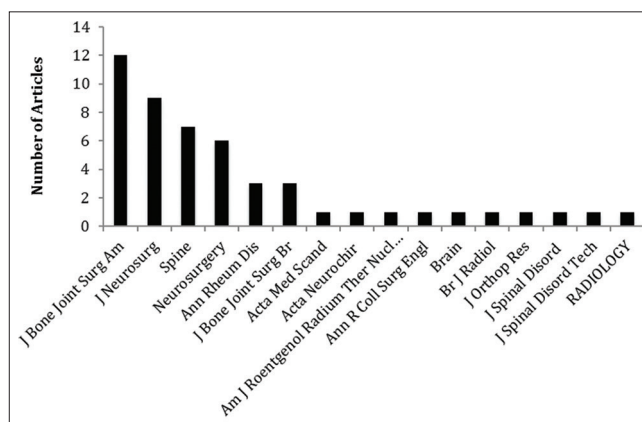


Figure 2: Number of top 50 articles published per journal

Table 2: Finalized search terms used in the second query

Search terms
(cranial OR cervical OR craniocervical OR occipitocervical OR atlantooccipital OR atlantoaxial OR occipito-atlanto-axial OR atlantal OR atlas OR axial OR axis OR condyl* OR dens OR odontoid* OR clivus OR clival OR C1 OR C2 OR basilar OR "transverse ligament*" OR "alar ligament*" OR "atlantal ligament*" OR vertebrobasilar) AND (dorsolateral OR suboccipital OR transcondylar OR transoral OR transpharyngeal OR retropharyngeal OR transarticular OR intralaminar OR endoscopic* OR rheumatoid OR ankylosing OR "down syndrome" OR "trisomy 21" OR chiropract* OR trauma* OR Jefferson* OR hangman* OR injur* OR fracture* OR disloc* OR sublux* OR burst* OR rota* OR rupture* OR congenital* OR anomal* OR invag* OR impress* OR migrat* OR settl* OR degen* OR instab* OR unstab* OR obstruct* OR fistul* OR myelopath* OR radiculopath* OR fix* OR fus* OR plat* OR screw* OR rod* OR cabl* OR instrument* OR arthro* OR distract* OR mobiliz* OR stabiliz* OR reduc* OR decompress* OR biomechanic* OR galle OR halo)

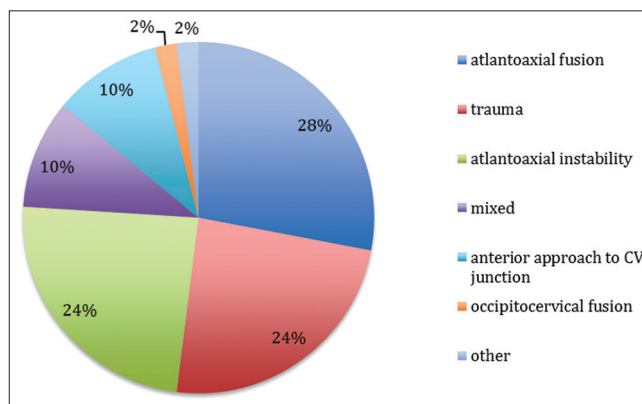


Figure 3: Frequency of article topics on the final list

Table 3: List of top 50 most-cited articles on craniovertebral surgery

Rank	Article	Article topic	Article summary	Study type	Level of evidence	Total citations	Citation rate
1	Anderson and D'Alonzo, 1974 ^[1]	Trauma- odontoid fracture	Outcome of 49 odontoid fractures stratified by three types of fracture patterns	Case series	IV	526	12.5 (4 th)
2	Harms and Melcher 2001 ^[2]	Atlantoaxial fixation-surgical technique	First description of the technique and outcome of 37 patients who underwent atlantoaxial fixation using C1 lateral mass screws and C2 pedicle screws with rod fixation	Case series	IV	493	32.9 (1 st)
3	Brooks and Jenkins 1978 ^[3]	Atlantoaxial fixation- surgical technique	First description of the technique and outcome of 15 patients who underwent atlantoaxial fusion by wedge compression technique	Case series	IV	411	10.8 (8 th)
4	Ranawat et al., 1979 ^[4]	Mixed (rheumatoid arthritis, atlantoaxial fusion, OC fusion)	Outcome of 35 patients with rheumatoid arthritis and cervical instability, of whom 13 underwent atlantoaxial Gallie fusion and 12 underwent occipitovertebral fusion	Case series	IV	330	8.9 (13 th)
5	Fielding and Hawkins 1977 ^[5]	Atlantoaxial instability-outcome	Outcome of 17 patients with atlantoaxial rotatory subluxation, of whom 11 underwent atlantoaxial Gallie fusion	Case series	IV	286	7.3 (17 th)
6	Goel and Laheri 1994 ^[6]	Mixed (atlantoaxial fixation and OC fusion)	First description of technique and outcome of 30 patients with atlantoaxial subluxation who underwent atlantoaxial fusion with C1 and C2 lateral mass screws, or OC fusion with C2 lateral mass screws connected with plate	Case series	IV	271	12.3 (5 th)
7	Madawi et al., 1997 ^[7]	Atlantoaxial fixation-outcome	Outcomes and complications of 61 patients who underwent atlantoaxial transarticular fusion with discussion of optimal screw trajectories	Case series	IV	262	13.8 (3 rd)
8	Wright and Laurysen 1998 ^[8]	Atlantoaxial fixation-surgical technique	Risk of vertebral artery injury during atlantoaxial transarticular screw fixation based on survey of 847 neurosurgeons	Case series	IV	222	12.3 (6 th)
9	Grob et al., 1992 ^[9]	Atlantoaxial fixation-biomechanics	<i>In vitro</i> biomechanical evaluation of four methods of atlantoaxial fixation: Gallie's, Brooks', Magerl's, and Halifax's techniques	Case-control	III	220	9.2 (11 th)
10	Jeanneret and Magerl 1992 ^[10]	Atlantoaxial fixation-outcome	Outcome of 12 patients with odontoid fractures who were managed by transarticular atlantoaxial fusion	Case Series	IV	214	8.9 (14 th)
11	Grob et al., 1991 ^[11]	Atlantoaxial fixation-outcome	The outcome of 38 patients who underwent transarticular atlantoaxial fusion due to atlantoaxial instability	Case series	IV	196	9.8 (10 th)
12	Paramore et al., 1996 ^[12]	Atlantoaxial fixation-surgical technique	Evaluation of the atlantoaxial anatomy, mainly the location of transverse foramen of C2 on unenhanced cervical CT, in 94 patients with cervical trauma to determine suitability for atlantoaxial transarticular fusion	Case series	IV	196	7.8 (15 th)

Contd...

Table 3: Contd...

Rank	Article	Article topic	Article summary	Study type	Level of evidence	Total citations	Citation rate
13	Sharp and Purser 1961 ^[13]	Atlantoaxial instability-rheumatoid arthritis, ankylosing spondylitis	Report of atlantoaxial dislocation in 12 patients with ankylosing spondylitis and 24 patients with rheumatoid arthritis	Case series	IV	187	3.4 (40 th)
14	Menezes and VanGilder 1988 ^[14]	Anterior approach to CV junction-outcome	Outcome of transoral transpharyngeal approach to the anterior CV junction in 72 patients, with more than half of the patients presenting with basilar invagination	Case series	IV	186	6.6 (21 st)
15	Dickman and Sonntag 1998 ^[15]	Atlantoaxial fixation-outcome	Outcome of 121 patients who underwent atlantoaxial transarticular fusion	Case series	IV	182	15.2 (2 nd)
16	Wright 2004 ^[16]	Mixed (atlantoaxial fixation, OC fusion)	First description of the technique of using C2 laminar screws during atlantoaxial, OC, or subaxial fusion	Case series	IV	182	10.1 (9 th)
17	Fielding <i>et al.</i> , 1974 ^[17]	Trauma-ligamentous injury	Biomechanical evaluation of atlantoaxial ligaments in anterior subluxation of atlas on axis based on cadaveric studies with clinical correlation to 11 patients	Case series	IV	181	4.3 (32 nd)
18	Bertalanffy and Seeger 1991 ^[18]	Anterior approach to CV junction-surgical technique	Description of technique for dorsolateral approach to the anterior aspect of CV junction in 6 patients with intradural mass	Case series	IV	179	7.2 (19 th)
19	McGregor 1948 ^[19]	Other	Diagnosis of basilar impression based on specific measurements of the skull, including modified Chamberlain's line and skull base angle	Case series	IV	178	5.7 (24 th)
20	Clark and White 1985 ^[20]	Trauma-odontoid fracture	Survey of the members of the Cervical Spine Research Society on management of the fractures of the dens	Case series	IV	178	2.6 (49 th)
21	Pellicci <i>et al.</i> , 1981 ^[21]	Atlantoaxial instability-rheumatoid arthritis	Progression of cervical spine disease over an average of 6.1 years in 106 patients with rheumatoid arthritis, 81% of which included atlantoaxial subluxation	Case series	IV	171	4.9 (26 th)
22	Boden <i>et al.</i> , 1993 ^[22]	Atlantoaxial instability-rheumatoid arthritis	Description of neurological deficit and its predictors in 73 patients with rheumatoid arthritis, of whom 61 patients had atlantoaxial subluxation, over 20-year study period	Case series	IV	169	7.3 (18 th)
23	Smith <i>et al.</i> , 1972 ^[23]	Atlantoaxial instability-rheumatoid arthritis	Natural history of cervical subluxation in rheumatoid arthritis based on 962 patients with the disease, of whom 150 developed cervical subluxation, with 91 patients at C1–C2	Case series	IV	167	3.8 (36 th)
24	Martel 1961 ^[24]	Atlantoaxial instability-rheumatoid arthritis, ankylosing spondylitis	Radiographic evaluation of occipito-atlantoaxial joint complex based on lateral flexion-extension cervical X-ray of 34 patients with rheumatoid arthritis and 32 patients with ankylosing spondylitis	Case series	IV	161	2.9 (44 th)

Contd...

Table 3: Contd...

Rank	Article	Article topic	Article summary	Study type	Level of evidence	Total citations	Citation rate
25	Goel <i>et al.</i> , 2002 ^[25]	Atlantoaxial fixation-surgical outcome	Outcome of atlantoaxial fusion using plate and screw method based on 160 patients over a 14-year period	Case series	IV	154	11.0 (7 th)
26	Effendi <i>et al.</i> , 1981 ^[26]	Trauma-axial fracture	Classification of type of fractures of the ring of C2, based on displacement of anterior fragment, flexion of body of C2, and involvement of C2–C3 facet joints	Case series	IV	151	4.3 (33 rd)
27	Schneider <i>et al.</i> , 1965 ^[27]	Trauma-Hangman's fracture	First description of Hangman's fracture based on the author's experience in 8 cases	Case series	IV	149	2.9 (45 th)
28	Böhler 1982 ^[28]	Anterior approach to CV junction-outcome	Outcome of 12 patients with dens fractures who underwent combined anterior cervical approach for impaction of bone into the body of C2 in addition to posterior fusion	Case series	IV	148	4.4 (31 st)
29	Greenberg 1968 ^[29]	Atlantoaxial instability-classification	Categorization of types of atlantoaxial dislocations with review of anatomy, embryology, and radiological measurements of atlantoaxial complex	Case series	IV	147	3.1 (43 rd)
30	Dickman <i>et al.</i> , 1991 ^[30]	Atlantoaxial fixation- surgical technique	First description of atlantoaxial interspinous fusion and outcome of 36 patients	Case series	IV	143	5.7 (25 th)
31	Levine and Edwards 1985 ^[31]	Trauma-Hangman's fracture	Outcome of 52 patients with Hangman's fracture requiring conservative or surgical management	Case series	IV	140	4.5 (30 th)
32	Anderson and Montesano 1988 ^[32]	Trauma-occipital condyle fracture	Description of three different types of occipital condyle fractures and their outcomes based on 6 patients	Case series	IV	136	4.9 (27 th)
33	Coyne <i>et al.</i> , 1995 ^[33]	Atlantoaxial fixation-outcome	Comparison of long-term outcome of atlantoaxial fusion using different techniques based on 32 patients	Case series	IV	134	6.4 (22 th)
34	Hadley <i>et al.</i> , 1989 ^[34]	Anterior approach to CV junction- outcome	Outcome transoral approach for management of anterior compression of brainstem and/or cervical cord in 53 patients, 44 with odontoid pathology and 9 with extradural tumors	Case series	IV	132	4.9 (28 th)
35	Hadley <i>et al.</i> , 1989 ^[35]	Trauma-axial fractures	Management and outcome of 229 patients with fractures of the C2 vertebra	Case series	IV	131	4.9 (29 th)
36	Abumi <i>et al.</i> , 1999 ^[36]	OC fusion-surgical technique	First description of OC fusion using pedicle screws and OC rod systems and clinical outcome of 26 patients	Case series	IV	130	7.6 (16 th)
37	Apuzzo <i>et al.</i> , 1978 ^[37]	Trauma-odontoid fractures	Management and outcome of 45 patients with fractures of odontoid process	Case series	IV	129	3.4 (41 st)
38	Melcher <i>et al.</i> , 2002 ^[38]	Atlantoaxial fixation-biomechanics	<i>In vitro</i> biomechanical comparison of the stability of atlantoaxial fusion constructs between transarticular-wiring technique versus screw-rod system	Nonclinical	N/A	128	9.1 (12 th)

Contd...

Table 3: Contd...

Rank	Article	Article topic	Article summary	Study type	Level of evidence	Total citations	Citation rate
39	Weissman <i>et al.</i> , 1982 ^[39]	Atlantoaxial instability-rheumatoid arthritis	Clinical and radiological findings of 194 patients with rheumatoid arthritis who developed atlantoaxial subluxation	Case series	IV	128	3.8 (37 th)
40	Hadley <i>et al.</i> , 1985 ^[40]	Trauma-axial fractures	Management and outcome of 107 patients with fractures of C2 categorized into odontoid fractures, traumatic spondylolisthesis, and miscellaneous fractures	Case series	IV	122	3.9 (35 th)
41	Fielding <i>et al.</i> , 1976 ^[41]	Mixed (atlantoaxial fixation, OC fusion, atlantoaxial instability)	Outcome of 57 patients with atlantoaxial instability who underwent fusion including 46 atlantoaxial fusions and 11 OC fusions	Case series	IV	121	2.9 (46 th)
42	Naderi <i>et al.</i> , 1998 ^[42]	Atlantoaxial instability- biomechanics	Biomechanical investigation of C1–C2 motion after posterior fixation in four combination of cable, graft, and transarticular screw	Case series	IV	120	6.7 (20 th)
43	Mikulowski <i>et al.</i> , 1975 ^[43]	Atlantoaxial instability-rheumatoid arthritis	Case report and review of literature for sudden death due to atlantoaxial instability secondary to rheumatoid arthritis	Case series	IV	120	6.3 (23 rd)
44	Mathews 1974 ^[44]	Atlantoaxial instability-rheumatoid arthritis	5-year natural history of atlantoaxial instability in 76 consecutive patients with rheumatoid arthritis	Case series	IV	120	3.2 (42 nd)
45	Spence <i>et al.</i> , 1970 ^[45]	Trauma-atlantal fractures	Case report of burst of the atlas, associated with rupture of transverse ligament indicated by lateral mass displacement of more than 6.9 mm, which is later known in the literature as "rule of Spence"	Case report	IV	117	4.2 (34 th)
46	Stillerman <i>et al.</i> , 1993 ^[46]	Atlantoaxial fixation-surgical technique	Description of a modification of atlantoaxial transarticular fusion with screw fixation and bony fusion without wiring, and outcome of 22 patients	Case series	IV	117	3.8 (38 th)
47	Dvorak <i>et al.</i> , 1988 ^[47]	Atlantoaxial instability-biomechanics	Biomechanical properties of alar and transverse ligaments in stability of CV junction	Nonclinical	N/A	116	2.9 (47 th)
48	Greene <i>et al.</i> , 1997 ^[48]	Trauma-axial fractures	Management and outcome of 340 fractures of C2 divided into odontoid fracture, traumatic spondylolisthesis of axis and miscellaneous fractures	Case series	IV	113	3.8 (39 th)
49	Crockard 1985 ^[49]	Anterior approach to CV junction-surgical technique	Description of the technique of transoral approach to the CV junction	Review	V	109	2.7 (48 th)
50	Crockard <i>et al.</i> , 1986 ^[50]	Mixed - (atlantoaxial instability, anterior approach to CV junction, OC fusion)	Outcome of 14 patients with rheumatoid arthritis with atlantoaxial instability who underwent transoral decompression followed by OC fusion	Case series	IV	108	2.6 (50 th)

CV - Craniovertebral; CT - Computed tomography; N/A - Not available; OC - Occipitocervical

Table 4: Frequency of articles per decade

Decade	Number of articles	Top-cited article
1940s	1	McGreger, 1948 ^[9]
1950s	0	N/A
1960s	4	Sharp and Purser, 1961 ^[13]
1970s	11	Anderson and D'Alonzo, 1974 ^[1]
1980s	14	Menezes and VanGilder, 1988 ^[14]
1990s	16	Goel and Laheri, 1994 ^[6]
2000s	4	Harms and Melcher, 2001 ^[2]

N/A - Not available

C2 in occipitocervical, atlantoaxial, and subaxial fusion. The author discusses the advantage of this previously unreported technique, including the low risk of vertebral artery injury.

The distribution of the year of publication of the top 50 articles reveals interesting trends. Our search criteria began in 1900 and ended in 2015. There were a total of five articles in the first 70 years of the 20th century, with no articles in the 1950s on our list. In the 1970s, the number of articles increased to 11, followed by another increase to 14 articles in the 1980s, peaking in the 1990s with 16 articles. This was followed by a stark decrease in the 2000s to four articles. There were no articles from the 2010s that qualified for the top 50 list.

We identified the most-cited articles stratified by the decade of publication. In the 1940s, the most-cited article, and also the only article from this decade in our list, was McGregor's study, which was discussed earlier. In the 1960s, the most-cited article was a case series by Sharp and Purser^[13] who reported the incidence and the diagnostic criteria of atlantoaxial subluxation in patients with rheumatoid arthritis and ankylosing spondylitis. In the 1970s, the most-cited article was by Anderson and D'Alonzo.^[1] This article is also the most-cited article in our top 50 list. The authors provide their well-known classification of the dens fracture into type I, fracture of the tip of dens, type II fracture at the base of dens, and type III fracture of the dens extending to the lateral masses of the axis.^[1] All the above articles are concerned primarily with the radiologic diagnosis of pathology concerning the craniovertebral junction.

The most-cited articles in the subsequent decades (1980s–2000s) are focused on surgical management of the pathologies that involve the craniovertebral junction. In 1980s, Menezes and VanGilder described their 10-year experience in using transoral approach to the craniovertebral junction in 72 patients with various pathologies.^[14] Although this article is not the first to describe the anterior approach to this anatomical location, it may be considered the most-cited article that promoted this surgical technique, its efficacy and safety.^[14] This article was ranked 14th overall.

In the 1990s, the most-cited article, ranked 6th overall, was by Goel and Laheri who described for the first time the technique of using lateral mass screws of C1 and C2 with plates in atlantoaxial or occipitocervical fusion constructs. In the 2000s, the most-cited article was by Harms and Melcher who described the incorporation of rods, instead of plates, in connecting C1 lateral mass and C2 pedicle screws in atlantoaxial fixation. This article is ranked 2nd overall. Of note, the Harms' paper unfortunately did not cite the Goel's paper.^[52]

Ranking based on citation rate revealed that the aforementioned article by Harms and Melcher was the 1st. The second-ranked article was by Dickman and Sonntag, from 1998, whereby the authors described the outcome of patients undergoing atlantoaxial transarticular fixation.^[15] This article was not the first to describe the technique of transarticular atlantoaxial fixation which is attributed to Magerl.^[53] This article was published in German, thus not meeting our inclusion criteria (due to the language of publication). The Dickman and Sonntag study was not the first to describe the outcome and complications of this technique either, which is credited to Grob *et al.*'s^[11] study from 1991, ranked 11th overall and 10th based on citation rate. It should be noted that Dickman and Sonntag's study included 121 patients compared to the 38 patients in Grob *et al.*'s study. The 3rd ranked article based on citation rate was by Madawi *et al.* in 1997,^[7] which, interestingly, also described the outcome of transarticular fusion of C1 and C2 in 61 patients. Thus, the top three ranked articles based on citation rate are all related to atlantoaxial fixation.

In fact, article topics were predominantly concerned with atlantoaxial fixation comprising 28% of the studies, with six of the top ten articles dedicated to this topic. Trauma and atlantoaxial instability were the second most common topics with 24% each. Among the articles on trauma, nine articles were concerned with fractures of C2. Of the 12 articles on atlantoaxial instability, eight were dedicated to patients with rheumatoid arthritis. Mixed topic articles were 10% of the top 50 cited articles in the field. All five of the mixed articles included the topic of occipitocervical fusion. Among all the fifty studies, only one was dedicated solely to this surgery as described by Abumi *et al.*^[36] The authors described for the first time the technique of occipitocervical fusion using cervical pedicle screws and occipitocervical rod system.^[36] This article was ranked 36th overall.

The most productive country, institution, and author in our list of top 50 most-cited articles were the United States of

America, Barrow Neurological Institute, and Dr. Sonntag. However, as demonstrated in Figure 4 and Table 5, the advancement of the field has been a multinational and multi-institutional effort involving centers in North America, Europe, and Asia.

Absence of high level of evidence among the top 50 cited articles was unambiguous. There are 46 clinical studies, all of which provide a class IV evidence with the predominant majority designed as case series. This could be attributed to the complexity, diverse, and rare pathologies affecting the craniovertebral junction, which have proved the design of higher quality studies difficult. The other four articles are *in vitro* biomechanical studies, to which the designation of level of evidence does not apply.

This study has limitations. Citation analysis is biased. Citation does not necessarily imply the impact of an article on the study that is citing it. Authors often provide extensive background information in the introduction section of their articles citing various previous related articles or they may cite an article without fully reading it. Another important bias of citation analysis is the issue of self-citation, whereby

authors refer to their own work.^[54] Although it is seldom the intention of the authors, self-citation inflates the number of citations of a given article which may be misinterpreted as the extent of its influence in the field. To eliminate this bias, we removed self-citation. On average, the total number of citations was reduced by an average of 11 citations per article. Another bias arises from the fact that the total number of citations for an article may increase merely based on how old a publication is: An older study would have a higher chance of accumulating citations than a newer study. To circumvent this bias, we also provide citation rate, the total number of citations divided by the number of years since publication. This is an attempt to take into consideration the date of publication. A review of the top ten articles in our list reflects this phenomenon, whereby four articles are from 1970s, five articles from 1990s, and only one article from 2000s. However, citation rate is not flawless either. The older the study, the higher the denominator of the equation to determine citation rate. This, in essence, “dilutes” the total number of citations of a given article. This is reflected, at least partially, in the fact that based on citation rate, the top 3 articles are from 2001, 1998, and 1997, respectively. Therefore, we believe that both the total number of citations and citation rate, when considered together, provide a more comprehensive perspective of which articles in the field of craniovertebral junction surgery are the most cited. Finally, implicit citations is another bias of citation analysis, whereby an article whose contribution to the field has been absorbed to the body of knowledge becomes cited less and less over time. As described above, we have made every attempt to consider and account for the inherent biases of citation analysis. Importantly, the flaws of citation analysis is a reminder that citation does not imply influence. Therefore, we have deliberately avoided referring to the articles in our top 50 list as “most influential.”

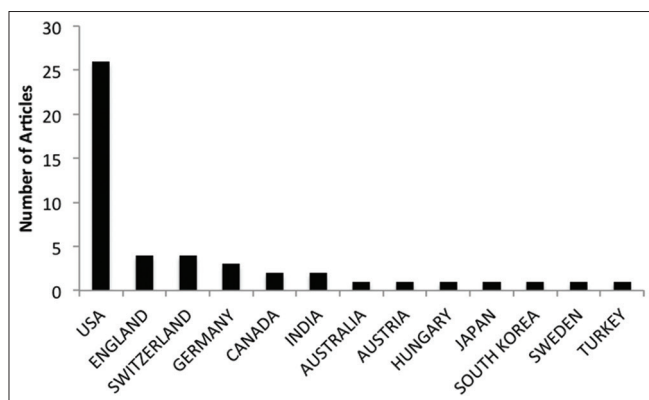


Figure 4: Country of origin of articles on the final list

Table 5: Top 10 institutions responsible for articles on the final list

Rank	Institution	Country	Number of articles
1	Barrow Neurological Institute	USA	6
2	St. Luke’s Hospital Center	USA	3
3	Kantonsspital	Switzerland	2
4	Klinikum Karlsbad Langensteinbach	Germany	2
5	Mercy Healthcare Arizona	USA	2
6	National Hospital	USA	2
7	Seth Gordhandas Sunderdas Medical College	India	2
8	University College Hospital, London	England	2
9	University of Southern California	USA	2
10	Washington University	USA	2

Conclusion

We identified the fifty most-cited articles related to the craniovertebral junction pathologies. This field has attracted the attention of various centers from various countries. Although until the 1970s, the most-cited articles were primarily focused on the diagnostic evaluation of the pathologies of this complex anatomical location, the most-cited articles thereafter are concerned with surgical management of these pathologies, with the advent of multiple new techniques, the majority of which are posterior approaches. The omnipresence of level IV evidence through case series in this list underlines the paucity of high-level evidence and the necessity to design appropriate studies toward developing such evidence.

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Conflicts of interest

There are no conflicts of interest.

References

- Anderson LD, D'Alonzo RT. Fractures of the odontoid process of the axis. *J Bone Joint Surg Am* 1974;56:1663-74.
- Harms J, Melcher RP. Posterior C1-C2 fusion with polyaxial screw and rod fixation. *Spine (Phila Pa 1976)* 2001;26:2467-71.
- Brooks AL, Jenkins EB. Atlanto-axial arthrodesis by the wedge compression method. *J Bone Joint Surg Am* 1978;60:279-84.
- Ranawat CS, O'Leary P, Pellicci P, Tsairis P, Marchisello P, Dorr L. Cervical spine fusion in rheumatoid arthritis. *J Bone Joint Surg Am* 1979;61:1003-10.
- Fielding JW, Hawkins RJ. Atlanto-axial rotatory fixation. Fixed rotatory subluxation of the atlanto-axial joint. *J Bone Joint Surg Am* 1977;59:37-44.
- Goel A, Laheri V. Plate and screw fixation for atlanto-axial subluxation. *Acta Neurochir (Wien)* 1994;129:47-53.
- Madawi AA, Casey AT, Solanki GA, Tuite G, Veres R, Crockard HA. Radiological and anatomical evaluation of the atlantoaxial transarticular screw fixation technique. *J Neurosurg* 1997;86:961-8.
- Wright NM, Lauryssen C. Vertebral artery injury in C1-2 transarticular screw fixation: Results of a survey of the AANS/CNS section on disorders of the spine and peripheral nerves. *J Neurosurg* 1998;88:634-40.
- Grob D, Crisco JJ 3rd, Panjabi MM, Wang P, Dvorak J. Biomechanical evaluation of four different posterior atlantoaxial fixation techniques. *Spine (Phila Pa 1976)* 1992;17:480-90.
- Jeanneret B, Magerl F. Primary posterior fusion C1/2 in odontoid fractures: Indications, technique, and results of transarticular screw fixation. *J Spinal Disord* 1992;5:464-75.
- Grob D, Jeanneret B, Aebi M, Markwalder TM. Atlanto-axial fusion with transarticular screw fixation. *J Bone Joint Surg Br* 1991;73:972-6.
- Paramore CG, Dickman CA, Sonntag VK. The anatomical suitability of the C1-2 complex for transarticular screw fixation. *J Neurosurg* 1996;85:221-4.
- Sharp J, Purser DW. Spontaneous atlanto-axial dislocation in ankylosing spondylitis and rheumatoid arthritis. *Ann Rheum Dis* 1961;20:47-77.
- Menezes AH, VanGilder JC. Transoral-transpharyngeal approach to the anterior craniocervical junction. Ten-year experience with 72 patients. *J Neurosurg* 1988;69:895-903.
- Dickman CA, Sonntag VK. Posterior C1-C2 transarticular screw fixation for atlantoaxial arthrodesis. *Neurosurgery* 1998;43:275-80.
- Wright NM. Posterior C2 fixation using bilateral, crossing C2 laminar screws: Case series and technical note. *J Spinal Disord Tech* 2004;17:158-62.
- Fielding JW, Cochran GV, Lawsing JF 3rd, Hohl M. Tears of the transverse ligament of the atlas. A clinical and biomechanical study. *J Bone Joint Surg Am* 1974;56:1683-91.
- Bertalanffy H, Seeger W. The dorsolateral, suboccipital, transcondylar approach to the lower clivus and anterior portion of the craniocervical junction. *Neurosurgery* 1991;29:815-21.
- McGregor M. The significance of certain measurements of the skull in the diagnosis of basilar impression. *Br J Radiol* 1948;21:171-81.
- Clark CR, White AA 3rd. Fractures of the dens. A multicenter study. *J Bone Joint Surg Am* 1985;67:1340-8.
- Pellicci PM, Ranawat CS, Tsairis P, Bryan WJ. A prospective study of the progression of rheumatoid arthritis of the cervical spine. *J Bone Joint Surg Am* 1981;63:342-50.
- Boden SD, Dodge LD, Bohlman HH, Rehtine GR. Rheumatoid arthritis of the cervical spine. A long-term analysis with predictors of paralysis and recovery. *J Bone Joint Surg Am* 1993;75:1282-97.
- Smith PH, Benn RT, Sharp J. Natural history of rheumatoid cervical luxations. *Ann Rheum Dis* 1972;31:431-9.
- Martel W. The occipito-atlanto-axial joints in rheumatoid arthritis and ankylosing spondylitis. *Am J Roentgenol Radium Ther Nucl Med* 1961;86:223-40.
- Goel A, Desai KI, Muzumdar DP. Atlantoaxial fixation using plate and screw method: A report of 160 treated patients. *Neurosurgery* 2002;51:1351-6.
- Effendi B, Roy D, Cornish B, Dussault RG, Laurin CA. Fractures of the ring of the axis. A classification based on the analysis of 131 cases. *J Bone Joint Surg Br* 1981;63:319-27.
- Schneider RC, Livingston KE, Cave AJ, Hamilton G. "Hangman's fracture" of the cervical spine. *J Neurosurg* 1965;22:141-54.
- Böhler J. Anterior stabilization for acute fractures and non-unions of the dens. *J Bone Joint Surg Am* 1982;64:18-27.
- Greenberg AD. Atlanto-axial dislocations. *Brain* 1968;91:655-84.
- Dickman CA, Sonntag VK, Papadopoulos SM, Hadley MN. The interspinous method of posterior atlantoaxial arthrodesis. *J Neurosurg* 1991;74:190-8.
- Levine AM, Edwards CC. The management of traumatic spondylolisthesis of the axis. *J Bone Joint Surg Am* 1985;67:217-26.
- Anderson PA, Montesano PX. Morphology and treatment of occipital condyle fractures. *Spine (Phila Pa 1976)* 1988;13:731-6.
- Coyne TJ, Fehlings MG, Wallace MC, Bernstein M, Tator CH. C1-C2 posterior cervical fusion: Long-term evaluation of results and efficacy. *Neurosurgery* 1995;37:688-92.
- Hadley MN, Spetzler RF, Sonntag VK. The transoral approach to the superior cervical spine. A review of 53 cases of extradural cervicomedullary compression. *J Neurosurg* 1989;71:16-23.
- Hadley MN, Dickman CA, Browner CM, Sonntag VK. Acute axis fractures: A review of 229 cases. *J Neurosurg* 1989;71(5 Pt 1):642-7.
- Abumi K, Takada T, Shono Y, Kaneda K, Fujiya M. Posterior occipitocervical reconstruction using cervical pedicle screws and plate-rod systems. *Spine (Phila Pa 1976)* 1999;24:1425-34.
- Apuzzo ML, Heiden JS, Weiss MH, Ackerson TT, Harvey JP, Kurze T. Acute fractures of the odontoid process. An analysis of 45 cases. *J Neurosurg* 1978;48:85-91.
- Melcher RP, Puttlitz CM, Kleinstueck FS, Lotz JC, Harms J, Bradford DS. Biomechanical testing of posterior atlantoaxial fixation techniques. *Spine (Phila Pa 1976)* 2002;27:2435-40.
- Weissman BN, Aliabadi P, Weinfeld MS, Thomas WH, Sosman JL. Prognostic features of atlantoaxial subluxation in rheumatoid arthritis patients. *Radiology* 1982;144:745-51.
- Hadley MN, Browner C, Sonntag VK. Axis fractures: A comprehensive review of management and treatment in 107 cases. *Neurosurgery* 1985;17:281-90.
- Fielding JW, Hawkins RJ, Ratzan SA. Spine fusion for atlanto-axial instability. *J Bone Joint Surg Am* 1976;58:400-7.
- Naderi S, Crawford NR, Song GS, Sonntag VK, Dickman CA. Biomechanical comparison of C1-C2 posterior fixations. Cable, graft, and screw combinations. *Spine (Phila Pa 1976)* 1998;23:1946-55.
- Mikulowski P, Wollheim FA, Rotmil P, Olsen I. Sudden death in rheumatoid arthritis with atlanto-axial dislocation. *Acta Med Scand* 1975;198:445-51.
- Mathews JA. Atlanto-axial subluxation in rheumatoid arthritis. A 5-year follow-up study. *Ann Rheum Dis* 1974;33:526-31.
- Spence KF Jr., Decker S, Sell KW. Bursting atlantal fracture associated with rupture of the transverse ligament. *J Bone Joint Surg Am* 1970;52:543-9.
- Stillerman CB, Wilson JA, Sonntag VK, Cooper PR. Atlanto-axial stabilization with posterior transarticular screw fixation: Technical description and report of 22 cases. *Neurosurgery* 1993;32:948-54.
- Dvorak J, Schneider E, Saldinger P, Rahn B. Biomechanics of the

- craniocervical region: The alar and transverse ligaments. *J Orthop Res* 1988;6:452-61.
48. Greene KA, Dickman CA, Marciano FF, Drabier JB, Hadley MN, Sonntag VK. Acute axis fractures. Analysis of management and outcome in 340 consecutive cases. *Spine (Phila Pa 1976)* 1997;22:1843-52.
 49. Crockard HA. The transoral approach to the base of the brain and upper cervical cord. *Ann R Coll Surg Engl* 1985;67:321-5.
 50. Crockard HA, Pozo JL, Ransford AO, Stevens JM, Kendall BE, Essigman WK. Transoral decompression and posterior fusion for rheumatoid atlantoaxial subluxation. *J Bone Joint Surg Br* 1986;68:350-6.
 51. Goel A, Bhatjiwale M, Desai K. Basilar invagination: A study based on 190 surgically treated patients. *J Neurosurg* 1998;88:962-8.
 52. Goel A, Laheri V. Re: Harms J, Melcher P. Posterior C1-C2 fusion with polyaxial screw and rod fixation. *Spine (Phila Pa 1976)* 2002;27:1589-90.
 53. Magerl F. Spondylodesis of the upper cervical spine. *Acta Chir Austriaca* 1982;43 [Suppl]:69.
 54. Ioannidis JP. A generalized view of self-citation: Direct, co-author, collaborative, and coercive induced self-citation. *J Psychosom Res* 2015;78:7-11.