Pain Medicine, 2024, **25**, 203–210
https://doi.org/10.1093/pm/pnad153
Advance access publication 20 November 2023
Original Research Article

OXFORD

INTERVENTIONAL PAIN & SPINE MEDICINE SECTION

Athrodesis of the lateral atlanto-axial joint for the relief of neck pain and cervicogenic headache

Richard D. Ferch, MBBS, FRACS[1], Tyson Zhang, MD[1], Nikolai Bogduk, MD, PhD, DSc[2,*]

[1]Department of Neurosurgery, John Hunter Hospital, Newcastle, NSW 2305, Australia
[2]School of Medicine and Public Health, The University of Newcastle, Newcastle, NSW 2308, Australia

**Corresponding author:* School of Medicine and Public Health, The University of Newcastle, PO Box 431, East Maitland, NSW 2323, Australia.
Email: nbogduk@bigpond.net.au

Abstract

Background: Osteoarthrosis of the lateral atlanto-axial joint (LAAJ) may be a cause of upper neck pain and headache. Intra-articular injection of steroids may provide only short-lasting relief. For intractable pain, arthrodesis of the joint might be considered.

Objective: To determine the success rates of arthrodesis of the lateral atlanto-axial joint for relieving neck pain and disability.

Design: Practice audit.

Setting: Private practice of senior author.

Subjects: Prospective series of 23 consecutive patients.

Methods: Outcomes were measured using a numerical rating scale for neck pain, and the Neck Disability Index for disability. Success rates were calculated for various degrees of improvement of neck pain at long-term follow-up (8–40 months), and for achieving various combinations of improvement of both neck pain and disability.

Results: Complete relief of pain was achieved in 40% of patients, with a further 40% achieving at least 50% relief. At long-term follow-up, 30% of patients had no neck pain and no disability, and a further 25% had only minimal pain, minimal disability, or both.

Conclusions: The present study did not corroborate earlier studies that claimed outstanding outcomes for arthrodesis of the LAAJ, but its outcomes are consonant with more recent studies that provided transparent outcome data. These studies provide Pain Physicians with empirical data on success rates and outcomes, upon which they can base their consideration of referral for arthrodesis.

Introduction

Pain from the lateral atlanto-axial joint (LAAJ) is one of several causes of cervicogenic headache.[1,2] The pain is perceived in the upper neck and can be referred to the occiput, ear, vertex, and forehead.[3] It is typically associated with suboccipital tenderness and aggravation by head rotation. However, none of these features, alone or in combination, is diagnostic of the source of pain[1,2]; and LAAJ pain can be misinterpreted as occipital neuralgia or migraine.[4,5]

Pain physicians may be accustomed to treating LAAJ pain with intra-articular injections of steroids[6,7] or perhaps pulsed radiofrequency[8]; but these interventions may be only partially effective, effective in only some patients, or effective for only a short time. For intractable pain, arthrodesis of the joint becomes an option that might be considered.[1]

In the surgery literature, osteoarthritis has been invoked as one of the possible causes of LAAJ pain.[4,9,10] The prevalence of osteoarthritis of the LAAJ, as seen on radiographs, ranges from 5% in the sixth decade to 18% by the ninth decade,[11] but it is not always symptomatic. Nevertheless, surgeons have been satisfied that, in patients with upper neck pain, the presence of osteoarthritis in a LAAJ is sufficient to establish that the affected joint is the source of pain.[4,9,10] Diagnostic tests such as intra-articular blocks of the joint have not been embraced by surgeons, in any of the published literature on C1-2 arthrodesis.[4,9–31]

Although there is now a substantial body of literature on arthrodesis for LAAJ pain, most of it consists of case reports of one[12–15] or fewer than 10[4,16–19] patients. Similar numbers have been reported in studies in which osteoarthritis was not the only indication for arthrodesis.[20–23] Otherwise, several case series, covering between 9 and 79 patients, have promoted arthrodesis as an effective treatment.[24–31]

The case reports [12–23] and an early case series [24] reported that virtually all of their patients obtained long-lasting, complete relief of their pain after arthrodesis. Later case series were all supportive of the treatment but differed in their criteria for success. Some relied on patient satisfaction[27,31] or the numbers of patients who became "pain-free or markedly improved"[26] who "improved significantly,"[25] or who obtained "substantial benefit."[28] Most of the case series[27,28,30,31] measured neck pain or neck disability, but reported only group data.

Although group data might indicate that a treatment is effective on average, they do not show how often the treatment is effective, or to what degree it is effective. That requires categorical data on success rates for various definitions of success.[32,33] In the context of arthrodesis for LAAJ pain, this distinction is illustrated by the study of Fung et al.[29]

Received: 27 July 2023. **Revised:** 7 September 2023. **Accepted:** 9 November 2023

These authors reported impressive changes in mean group scores. Pain improved from 9.4 to 2.9, and neck disability improved from 72 to 18.9. However, these authors also reported raw data on individual patients, from which categorical data can be calculated. These showed that only 26% of their patients obtained complete relief of pain, while 52% achieved only between 40% and 60% relief. So, improvements were not uniformly distributed.

Other studies have not been as transparent when reporting their outcomes. So it is difficult to determine from the literature what the representative success rate of arthrodesis is for the treatment of painful osteoarthritis of the LAAJ.

When pain physicians encounter patients with LAAJ pain for whom their interventions do not provide lasting relief; they might be drawn to consider arthrodesis of the joint as a definitive treatment; but the surgery literature does not provide them with a clear picture of the effectiveness of arthrodesis. Therefore, the present study was undertaken to help clarify how often and how effective arthrodesis might be.

Methods

The study was conducted in the private practice of the senior author (R.F.). Data were collected prospectively on a series of 23 consecutive patients treated by a single surgeon (R.F.) between 2007 and 2022. The Ethics Committee of the Hunter New England Health District certified that the study did not require ethics approval because it was a personal audit.

Included in the study were patients >18 years of age, with suboccipital neck pain, longer than 6 months in duration, resistant to conservative therapy, and associated with osteoarthrosis of the ipsilateral LAAJ, manifest on computerised tomography scans of the upper cervical spine. The cardinal features for the diagnosis of osteoarthritis of the joint were loss of cartilage and joint space, subchondral sclerosis, and marginal osteophytes. Exclusion criteria for the study were instability, cancer, trauma, congenital malformations, or previous atlanto-axial surgery.

All of the patients had previously attended a pain clinic where they underwent intra-articular injection of local anaesthetic and steroid, with various degrees of benefit. Instead of repeating conservative therapy, they elected to undergo surgery. Response to intra-articular steroids was not used as an indication for surgery, but it was noted for later, post hoc, analysis.

Using a posterior approach, the target joint was opened and curetted to allow packing with autologous bone graft, harvested from the C2 spinous process. The C2 nerve roots were preserved during the dissection. In the earliest patient treated, transarticular screws and posterior wiring were used to achieve fixation. In all subsequent patients, fixation was achieved using a polyaxial screw and rod construct (Figure 1). Screws were placed into the lateral mass of C1, and into the pars interarticularis of C2. In one patient a laminar screw was used because the pars interarticularis could not accommodate a screw.

After treatment, technical aspects of the surgery were monitored. Recorded were complications, adverse effects, need for revision, and if fusion was achieved. Radiographic evidence of fusion was evaluated on CT at least 6 months after surgery and was defined as bridging bone across the C1-2 joint (Figure 2).

Prior to surgery patients completed a Numerical Rating Scale (NRS) for pain.[34,35] Disability was assessed using the Neck Disability Index (NDI).[36] The latter was supplemented by an additional, ad hoc device, because the NDI relied on several items, such as driving, that might not be appropriate for the elderly population in the present study. The Roland-Morris Disability Questionnaire [37] was adapted by replacing "back pain" with "neck pain" in all items.

The NRS was graduated from 0 to 10, with higher scores representing more intense pain. The NDI is a patient-reported questionnaire that consists of 10 sections that evaluate aspects of neck function. Each section is rated out of 5 points. The scores are aggregated to produce a total score of 50, which can be converted to a percentage. Summary scores can be interpreted as: 0–8%, no disability; 10–28%, mild disability; 30–48%, moderate disability; 50–68% severe disability; 70–100%, complete disability. The Roland-Morris Disability Questionnaire generates scores that range form 0 to 24, with higher scores representing greater disability.

These same assessments were repeated at long-term follow-up. They were administered by the treating surgeon (R.F.) but completed independently by each patient. Patients were also asked if they would undergo the same surgery again in the same circumstances.

Group scores for neck pain and disability were determined by calculating the median value and interquartile range of each outcome measure before treatment and at long-term follow-up. These were compared using a Mann-Whitney test, because the data were not normal in distribution. The calculations were performed using Minitab [https://minitab.com]. For each patient, the percentage improvement of pain was calculated as (change in NRS)/(original NRS) × 100%. These improvements were tallied to show the proportions of patient who achieved various degrees of improvement from 0 to 100%.

Success rates were calculated in two ways. For relief of neck pain, success rates were inferred from the proportions of patients who achieved various degrees of success, ranging in 10% increments from 0% to 100%. For composite outcomes, an innovative device was used. A matrix was constructed, in which the 11 rows represented pain scores at follow-up, ranging from 0 to 10; and the columns represented the 5 grades of disability on the NDI: no disability, mild disability, moderate disability, severe disability, and complete disability. Into the cells of this matrix were entered the numbers of patients who simultaneously achieved the final pain score and final disability score represented by each cell. From these numbers, success rates could be calculated for achieving given combinations of pain and disability.

Results

Arthrodesis was successfully completed in 23 patients. No revision surgery was required. Fusion was achieved in all cases.

Complete data on outcomes were available for 20 of these patients (Table 1). They were 7 males and 13 females, with a median age of 71 years. Five of these patients were followed for between 6 months and 10 months, and 15 were followed for longer than 15 months, for a median value of 27 months with an interquartile range of 8–40 months.

Of the 3 other patients, one was lost to follow-up, and one died, of causes unrelated to the surgery, before a follow-up could be conducted. For the third patient, inception data could not be found, but she provided follow-up data. For lack of baseline data this patient was not included in the

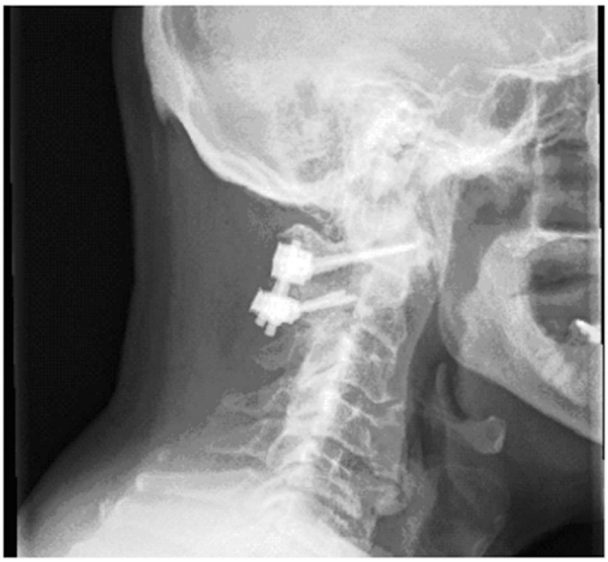

Figure 1. Lateral radiograph of cervical spine showing the polyaxial screw and rod construct used for arthrodesis of the lateral atlanto-axial joint.

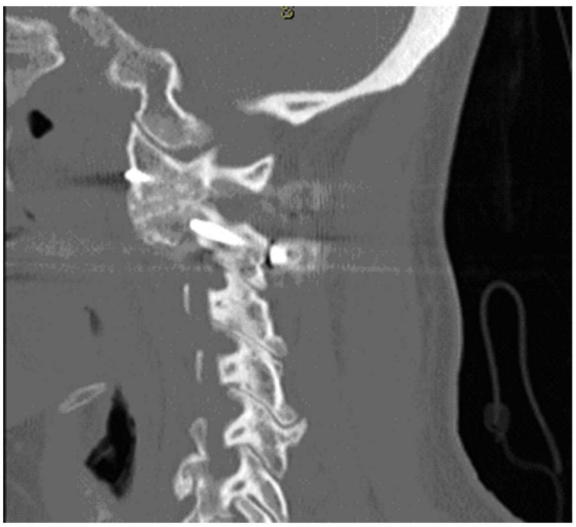

Figure 2. Lateral computerized tomography scan of cervical spine showing bridging of bone across the lateral atlanto-axial joint after arthrodesis.

calculation of group data and changes in outcome, but, along with the other patients lost to follow-up, she was later included in the calculation of success rates. Her follow-up data showed that she had not benefitted from the treatment.

The patients with complete data showed large improvements in scores for neck pain, neck disability index, and Roland Morris Disability Questionnaire (Table 2 and Figure 3). The effect-size for the change in neck pain was 2.2. For NDI it was 1.6, and for RMDQ it was 0.96.

At inception, neck pain and NDI were not significantly correlated ($R = 0.404$, $P = .78$) but after treatment, improvement of disability was strongly correlated with relief of neck pain ($R = 0.856$, $P = .000$). Both before and after treatment, NDI and RMDQ were strongly correlated ($R = 0.756$, $P = .000$ before, and $R = 0.889$, $P = .000$ after).

Improvements in neck pain, however, were not uniformly distributed between patients (Table 3). Only 40% of patients obtained complete relief of pain, but a further 40% obtained at least 50% relief of pain. For a worst-case analysis, these success rates for relief of pain should be discounted by 2% each, for the three patients for whom data were missing or who did not complete follow-up.

Table 4 summarises the data on composite outcomes. Thirty percent of patients had no pain and no disability at follow-up. A further 25% had only minimal or no pain and minimal or no disability. This Table also shows that complete or near complete relief of pain ensures minimal or no disability, but not vice versa. Of the 9 patients with mild disability at follow-up, 6 still had pain at intensities between 2 and 5.

Deeper insights can be gained by including into the format of Table 4 the scores for pain and disability at inception. Doing so allows the histories of individual patients to be followed. Figure 4 shows that 55% of patients had impressive improvements, meaning that they achieved minimal or no pain, along with minimal or no disability. A further 25% of patients showed substantial improvements, meaning that they achieved 50% reduction in pain scores or disability scores, or both. Only 15% had minimal improvements, and one patient was worse.

Five patients suffered complications. One patient suffered a myocardial infarction during surgery. She was transferred directly to an angiography suite, where she was revascularised. After a prolonged stay in hospital, she recovered and had no lasting effects attributable to the surgery.

A second patient developed a posterior reversible encephalopathy syndrome. Although she recovered from this, it emerged that she had paraesthesiae in the occiput. A third patient also developed paraesthesiae in the occiput. A fourth patient reported worsening of their original pain, and the onset of a new, neuralgic pain in the occiput. These latter three cases imply injury to the C2 spinal nerve or one of its branches. A fifth patient incurred a laceration of the temple when being moved on the operation table and was left with dysaesthesia as a result of this.

Patients with apparent C2 nerve injury were investigated for complications such as adversely placed screws, but no such features were found; and surgical exploration was neither indicated nor undertaken. The exact cause of the apparent nerve injury remains unknown, and symptoms have persisted in all affected patients.

Eighteen (90%) of the patients recorded that they would undergo the treatment again, which included the 2 patients with occipital dysaesthesia. Only the patient with the temporal laceration and the one who developed new neuralgic pain said that they would not undergo the treatment again.

When compared with outcomes from surgery, no significant relationship was found with prior responses to intra-articular steroids. The χ^2 analysis could not be conducted because there were too many small numbers in the contingency table (Table 5). Although there was a trend for success rates to be higher in patients who previously responded to intra-articular steroids, half the patients who did not respond to intra-articular steroids nevertheless also had successful outcomes from surgery.

Table 1. Demographic features and outcome measures of all patients who underwent arthrodesis of a lateral atlanto-axial joint.

Patient	Gender	Age	Relief from IA steroids?	Neck Pain inception	Neck Pain follow-up	NDI inception	NDIf follow-up	RMDQ inception	RMDQ follow-up	Follow-up (months)	Again?	Complications
1	M	76	Yes	7	5	46	38	10	8	6	Yes	
2	F	72	No	10	0	70	0	19	0	10	Yes	Yes
3	M	67	No	8	2	38	16	5	4	8	Yes	Yes
4	F	69	Yes	8	0	46	0	5	0	6	Yes	
5	M	76	Yes	6	3	18	10	3	1	7	Yes	
6	F	61	Yes	9	0	72	12	21	1	15	Yes	
7	M	71	Yes	9	1	36	0	6	0	30	Yes	
8	F	68	No	6	0	34	2	12	0	25	Yes	
9	F	71	Yes	7	0	28	2	3	0	23	Yes	
10	F	76	No	10	1	38	0	7	0	34	Yes	
11	F	73	Yes	8	5	20	20	7	0	38	Yes	
12	F	74	Yes	8	0	22	2	3	0	37	Yes	
13	F	75	Yes	5	0	38	10	11	8	33	No	Yes
14	F	79	Yes	6	0	26	8	9	1	41	Yes	
15	F	71	Yes	8	1	40	11	5	1	84	Yes	
16	M	50	Yes	5	9	56	64	12	16	185	No	Yes
17	M	81	Yes	9	4	78	46	23	16	50	Yes	
18	M	67	No	8	5	50	27	12	8	25	Yes	
19	F	64	No	10	5	44	12	8	7	69	Yes	
20	F	59	Yes	9	3	54	22	15	10	8	Yes	
21	F	75	Yes		7				10	35	Yes	
22	F	88	Yes	8		54		19		Lost to follow-up		
23	M	83	Yes	7		28		10		Died		Yes

For 20 patients, complete data were available.
Complications. Patient 2: Encephalopathy resolved but posterior scalp dysesthesia. Patient 3: Posterior scalp dysesthesia. Patient 13: Scalp injury, temporal dysesthesia. Patient 16: Original pain worse with new occipital neuralgia. Patient 23: Myocardial infarction.

Table 2. Outcome measures for neck pain, Neck Disability Index (NDI), and Roland Morris Disability Questionnaire, of patients 20 patients with osteoarthrosis of the lateral atlanto-axial joint, treated by arthrodesis.

Outcome Measure		Inception	Follow-up	*P*-value
Neck pain	Median	8	1	.0000
(0–10)	IQR	6–9	0–5	
NDI	Median	39	10	.0000
(0–100)	IQR	30–53	2–22	
RMDQ	Median	8	1	.0026
(0–24)	IQR	5–32	0–8	

Discussion

Painful osteoarthrosis of the lateral atlanto-axial joint is either not a common condition or is one not commonly referred to neurosurgeons. It is therefore difficult to collect large case series, which is why the present study—like most of the published case series—had a small sample.

Small studies can be compromised if too many patients are lost to follow-up, but this can be accommodated by undertaking a worst-case analysis. In the present study, the missing patients discount the observed success rates only by

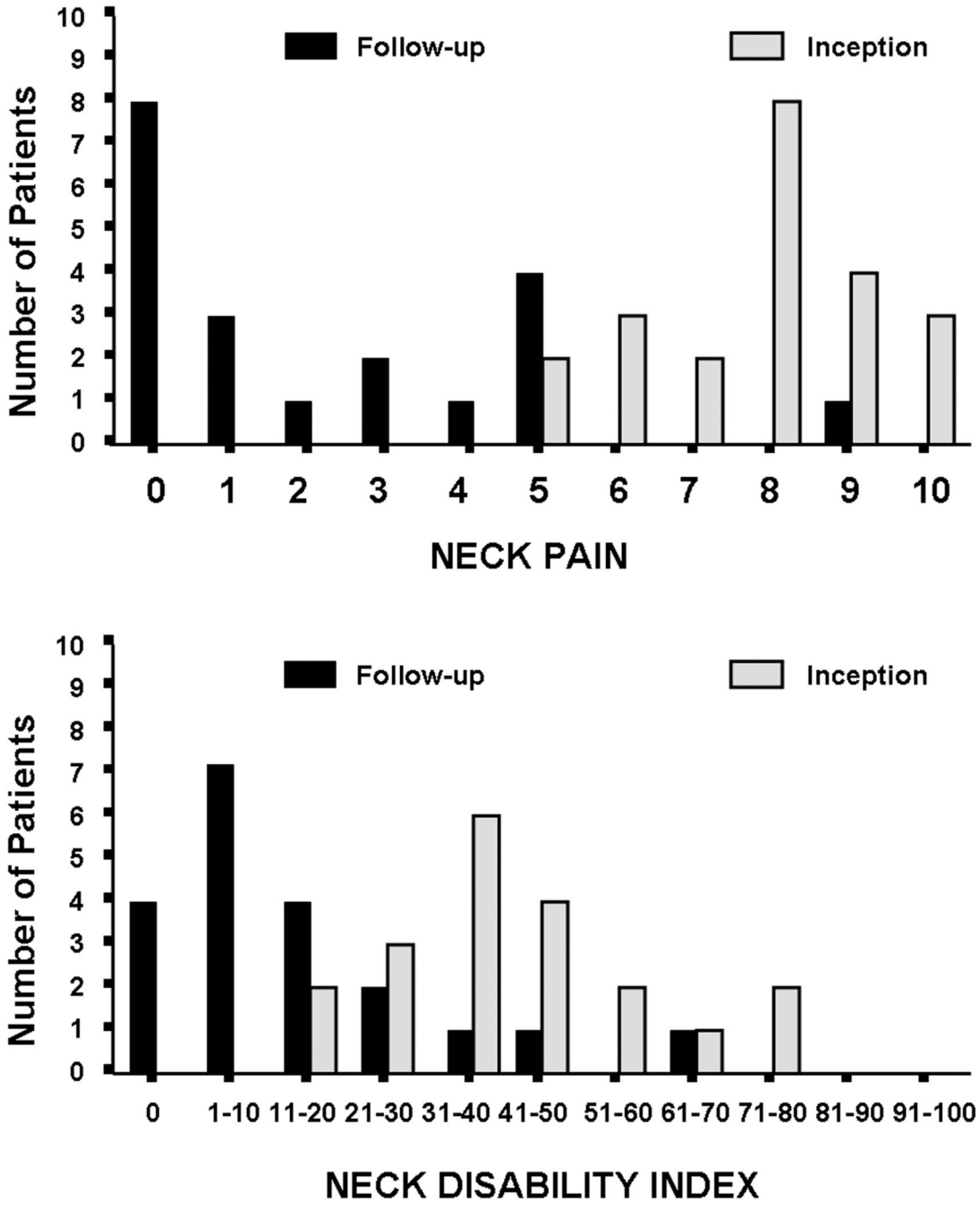

Figure 3. Histograms of the scores for neck pain and neck disability at inception and at follow-up, of 20 patients treated by arthrodesis of the lateral atlanto-axial joint.

2% each, which is well within the 95% confidence intervals of the observed success rates.

The results of the present study did not corroborate the 90% - 100% success rates reported in case reports and some case series. The present results are also difficult to compare with the results of other case series. Studies that relied on patient satisfaction claimed high success rates, such as 91% and 96%.[27,31] This was echoed by a high satisfaction rate of 90% in the present study; but the present study showed that despite satisfaction, several patients were not rendered free of pain or disability. Other studies reported good outcomes on the basis of reduced group scores for NDI; but as shown in the present study, improvement in NDI alone is not necessarily associated with reduction in pain, let alone its elimination.

The results of the present study closely resemble those of Fung et al.,[29] which is the only other study to provide transparent, detailed data on multiple outcomes. Table 6 shows the concordance between the outcomes of the present study and those of Fung et al.,[29] and a summary of the combined data. Because of the detailed data of these 2 studies we suggest that collectively they represent the best approximation of the true effectiveness of arthrodesis for painful osteoarthrosis of the LAAJ. They indicate to pain physicians what they can realistically expect if they refer their patients for this treatment.

Table 3. Numbers, proportions, and cumulative proportions of patients who achieved various percentage improvements in scores for neck pain, after arthrodesis of a lateral atlanto-axial joint.

Change in Pain (%)	Number	Proportion	Cumulative Proportion
100	8	0.40	0.40
90	1	0.05	0.45
80	2	0.10	0.55
70	1	0.05	0.60
60	1	0.05	0.65
50	3	0.15	0.80
40		0.00	0.80
30	2	0.10	0.90
20	1	0.05	0.95
10			
0			
Worse	1	0.05	0.05

The cumulative proportion indicates the proportion of patients who achieved either the improvement indicated in the corresponding row, or greater improvements.

Arthrodesis is not a panacea for painful LAAJ. Surgery does not offer the ultimate "fix" for all patients; but as shown in Figure 4, the majority of patients can expect an impressive improvement of both neck pain and disability. A smaller proportion can expect substantial but incomplete improvement.

Osteoarthrosis of the LAAJ is a condition for which there is no proven conservative therapy, and no other surgical alternative. Therefore, arthrodesis is worthy of consideration for patients with intractable pain. However, as with other surgical procedures for pain, a minority of patients may not benefit, or can be rendered worse.

Another serious consideration is that of complications or adverse events. Arthrodesis of the LAAJ carries general risks of surgery and specific risks of the procedure itself. General risks are those of having a general anaesthetic, haemorrhage, paralytic ileus, urinary tract infection, impaired wound healing, and cardiovascular or cerebrovascular events. For arthrodesis of the LAAJ, the risks of cardiac and cerebrovascular complications are greater than average because so many patients are elderly. Complications of a generic nature were encountered in the present study and have been reported by others.[4,30,31]

Specific risks are misplacement of screws, non-union and pseudarthrosis, injury to the dura mater or vertebral artery, new pain, and injury to the C2 nerve, which runs behind the target joint. Dural tear, pseudarthrosis, and failure of fusion have been reported by others[24,30,31] but were not encountered by others. Onset of new pain and injury to the C2 nerve occurred in the present study, and have been reported by others.[17,29,31]

The specific nature of injury to the C2 nerve could not be determined in the present study; nor was it determined in previous studies that encountered it. The C2 dorsal root ganglion, the C2 spinal nerve, the C2 ventral ramus, and the C2 dorsal ramus all lie behind the LAAJ, and near to it. The greater occipital nerve is also behind the joint but more superficially. Any of these nerves can be injured when accessing the joint, for example by retraction or when stemming hemorrhage from the venous plexus that accompanies these nerves. If arthrodesis of the LAAJ becomes more popular, perhaps surgeons might be more mindful of C2 nerve

Table 4. A matrix that shows the proportions of patients who, at follow-up, achieved the score for neck pain and also the score for disability that define each cell.

		Neck Disability Index				
		0–8% No Disability	10–28% Mild Disability	30–48% Moderate Disability	50–68% Severe Disability	70–100% Complete Disability
Neck Pain	0	0.30	0.10			
	1	0.10	0.05			
	2		0.05			
	3		0.10			
	4			0.05		
	5		0.15	0.05		
	6					
	7					
	8					
	9				0.05	
	10					

The bold lines demarcate the cell for perfect outcome, and the cells for near perfect outcome.

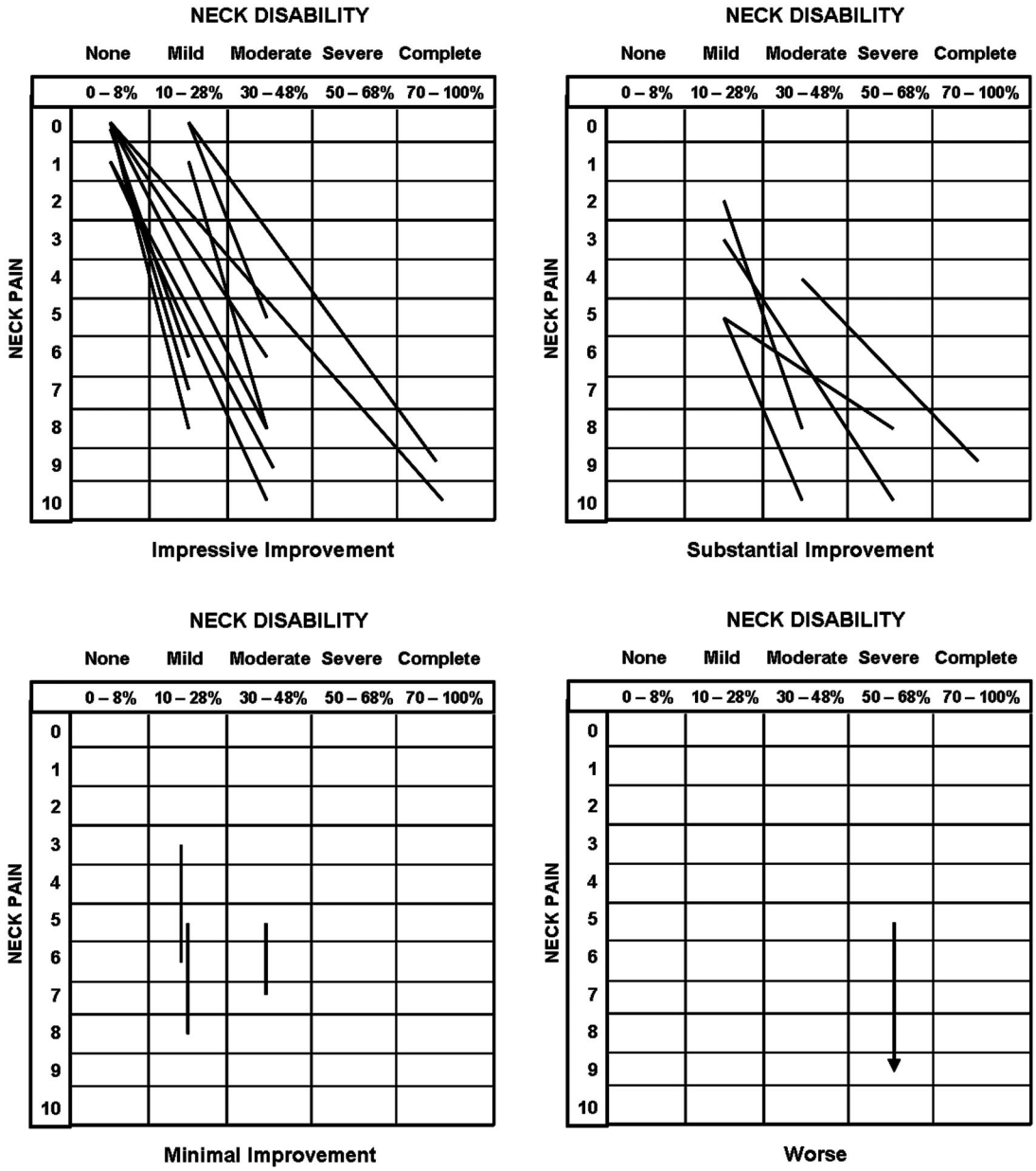

Figure 4. The histories of individual patients treated by arthrodesis of the lateral atlanto-axial joint. Each line represents a patient. Each line starts in the cell that represents the combined scores of that patient for neck pain and neck disability and ends in the cell that represents their final combined scores. For clarity of display, the patients have been depicted separately in 4 groups: Those with impressive improvements, those with substantial improvements, those with minor improvements, and the one patient who became worse.

Table 5. The association between response to intra-articular (IA) steroids and outcomes of Surgery.

Response to IA steroids	Outcome of Surgery			
	Impressive	Substantial	Minor	Worse
Relief	9	2	2	1
No relief	3	1	2	0

injury as a risk and develop methods by which to be more protective of the nerve.

With respect to the predictive value of intra-articular injection of steroids, the present study was too small to reveal meaningful associations. However, the data reported might serve to guide planning the much larger study that would be needed to explore the predictive validity of either intra-articular injections of steroids, or controlled blocks using local anesthetic agents.

Funding

No funds were obtained or used for this study.

Conflicts of interest: The authors have no conflict of interests over any material raised in this manuscript.

Table 6. Comparison of the worst-case success rates for relief of neck pain of the present study with those of Fung et al[29].

Study	*N*	Outcomes for Percentage Relief of Neck Pain					
		Unknown	Worse	0–50%	50%	60–90%	100%
Fung et al	23		0.00	0.17	0.09	0.48	0.26
Present	23	0.13	0.04	0.13	0.13	0.22	0.35
Combined	46	0.07	0.02	0.15	0.11	0.35	0.30
95% CI		0.00–0.14	0.00–0.06	0.05–0.25	0.02–0.20	0.21–0.49	0.17–0.47

References

1. Bogduk N, Govind J. Cervicogenic headache: an assessment of the evidence on clinical diagnosis, invasive tests, and treatment. Lancet Neurol. 2009; 8 (10):959-968.
2. Govind J, Bogduk N. Sources of cervicogenic headache among the upper cervical synovial joints. Pain Med. 2022; 23 (6):1059-1065.
3. Cooper G, Bailey B, Bogduk N. Cervical zygapophysial joint pain maps. Pain Med. 2007; 8 (4):344-353.
4. Star MJ, Curd JG, Thorne RP. Atlantoaxial lateral mass osteoarthritis. A frequently overlooked cause of severe occipitocervical pain. Spine. 1992; 17 (suppl 6):S71-S76.
5. Halla JT, Hardin JG. Atlantoaxial (C1-C2) facet joint osteoarthritis: a distinctive clinical syndrome. Arthritis Rheum. 1987; 30 (5):577-582.
6. Aprill C, Axinn M, Bogduk N. Occipital headaches stemming from the lateral atlanto-axial (C1–2) joint. Cephalalgia. 2002; 22 (1):15-22.
7. Narouze SN, Casanova J, Mekhail N. The longitudinal effectiveness of lateral atlantoaxial intra-articular steroid injection in the treatment of cervicogenic headache. Pain Med. 2007; 8 (2):184-188.
8. Halim W, Chua NH, Vissers KC. Long-term pain relief in patients with cervicogenic headaches after pulsed radiofrequency application into the lateral atlantoaxial (C1-2) joint using an anterolateral approach. Pain Pract. 2010; 10 (4):267-271.
9. Elliott RE, Tanweer O, Smith ML, Frempong-Boadu A. Outcomes of fusion for lateral atlantoaxial osteoarthritis: meta-analysis and review of literature. World Neurosurg. 2013; 80 (6):e337-e346.
10. Yin M, Ding X, Liu S, Ma J, Mo W. Research progress of atlantoaxial osteoarthritis: a narrative literature review. World Neurosurg. 2022; 160 :e573-e578.
11. Zapletal J, de Valois JC. Radiologic prevalence of advanced lateral C1-C2 osteoarthritis. Spine (Phila Pa 1976). 1997; 22 (21):2511-2513.
12. Fuentes S, Bouillot P, Palombi O, Manera L, Desgeorges M. [Atlanto-axial lateral mass osteoarthritis. Three case reports and review of the literature.]. Neurochirurgie. 2001; 47 (1):51-54.
13. Käfer W, Cakir B, Richter M. Osteoarthritis—a rare indication for atlantoaxial fusion. Acta Orthop Belg. 2004; 70 (4):380-385.
14. Guha D, Mohanty C, Tator CH, Shamji MF. Occipital neuralgia secondary to unilateral atlantoaxial osteoarthritis: Case report and review of the literature. Surg Neurol Int. 2015; 6 :186.
15. Neal MT, Gibbs W, Lyons MK. Atlantoaxial osteoarthritis: a well-established entity that remains frequently overlooked. Turk Neurosurg. 2022; 32 :336-340.
16. Joseph B, Kumar B. Gallie's fusion for atlantoaxial arthrosis with occipital neuralgia. Spine (Phila Pa 1976). 1994; 19 (4):454-455.
17. Schaeren S, Jeanneret B. Atlantoaxial osteoarthritis: case series and review of the literature. Eur Spine J. 2005; 14 (5):501-506.
18. Holly LT, Batzdorf U, Foley KT. Treatment of severe retromastoid pain to C1-2 arthrosis by using cervical fusion. J Neurosurg. 2000; 92 (suppl 2):162-168.
19. Pakzaban P. Transarticular screw fixation of C1-2 for the treatment of arthropathy-associated occipital neuralgia. J Neurosurg Spine. 2011; 14 (2):209-214.
20. Harata S, Tohno S, Kawagishi T. Osteoarthritis of the atlantoaxial joint. Int Orthop. 1981; 5 (4):277-282.
21. Stulik J, Vyskocil T, Sebesta P, Kryl J. Atlantoaxial fixation using the polyaxial screw-rod system. Eur Spine J. 2007; 16 (4):479-484.
22. Finn M, Fassett DR, Apfelbaum RI. Surgical treatment of nonrheumatoid atlantoaxial degenerative arthritis producing pain and myelopathy. Spine (Phila Pa 1976). 2007; 32 (26): 3067-3073.
23. Payer M, Luzi M, Tessitore E. Posterior atlantoaxial fixation with polyaxial C1 lateral mass screws and C2 pars screws. Acta Neurochir (Wien). 2009; 151 (3):223-229; discussion 229.
24. Ghanayem AJ, Leventhal M, Bohlman HH. Osteoarthrosis of the atlanto-axial joints. Long-term follow-up after treatment with arthrodesis. J Bone Joint Surg Am. 1996; 78 (9):1300-1307.
25. Kuklo TR, Riew KD, Orchowski JR, Won DS, Schroeder TM, Gilula LA. Management of recalcitrant osteoarthritis of the atlanto-axial joint. Orthopedics. 2006; 29 (7):633-638.
26. Grob D, Bremerich FH, Dvorak J, Mannion AF. Transarticular screw fixation for osteoarthritis of the atlanto axial segment. Eur Spine J. 2006; 15 (3):283-291.
27. Grob D, Luca A, Mannion AF. An observational study of patient-rated outcome after atlantoaxial fusion in patients with rheumatoid arthritis and osteoarthritis. Clin Orthop Relat Res. 2011; 469 (3):702-707.
28. Kang DG, Lehman RA, Jr, Wagner SC, Peters C, Riew KD. Outcomes following arthrodesis for atlanto-axial osteoarthritis. Spine (Phila Pa 1976). 2017; 42 (5):E294-E303.
29. Fung M, Frydenberg E, Barnsley L, Chaganti J, Steel T. Clinical and radiological outcomes of image guided posterior C1-C2 fixation for atlantoaxial osteoarthritis (AAOA). J Spine Surg. 2018; 4 (4):725-735.
30. Adogwa O, Buchowski JM, Sielatycki JA, et al. Improvements in neck pain and disability following C1-C2 posterior cervical instrumentation and fusion for atlanto-axial osteoarthritis. World Neurosurg. 2020; 139 :139e496-139e500.
31. Kleinstück FS, Fekete TF, Loibl M, et al. Patient-rated outcome after atlantoaxial (C1-C2) fusion: More than a decade of evaluation of 2-year outcomes in 126 patients. Eur Spine J. 2021; 30 (12):3620-3630.
32. Bogduk N, Stojanovic M. Group data or categorical data for outcomes of pain treatment. Pain Med. 2020; 21 (10):2046-2052.
33. Bogduk N. Criteria for determining if a treatment for pain works. Int Pain Med. 2022; 1 :100125.
34. Strong J, Ashton R, Chant D. Pain intensity measurement in chronic low back pain. Clin J Pain. 1991; 7 (3):209-218.
35. Thong ISK, Jensen MP, Miró J, Tan G. The validity of pain intensity measures: what do the NRS, VAS, VRS, and FPS-R mean? Scand J Pain. 2018; 18 (1):99-107.
36. Vernon H, Mior S. The neck disability index: a study of reliability and validity. J Manip Physiol Ther. 1991; 14 :409-415.
37. Roland MO, Morris RW. A study of the natural history of back pain. Part 1: development of a reliable and sensitive measure of disability in low back pain. Spine. 1983; 8 (1):141-144.