**Supplemental Digital Content 3**

**Case Reports of Perioperative Cervical Spinal Cord Injury in Patients with Cervical Spondylosis**

Material in this supplement is provided to support the following statement in the third paragraph of the Discussion in the primary manuscript, *“**…*there are more than 20 case reports describing patients with severe cervical spondylosis and who, in the absence of a difficult intubation, suffered intraoperative cervical cord injury during non-cervical spine surgery*.”*

Table S3-1 summarizes case reports of patients who had cervical spondylosis and who suffered acute perioperative cervical spinal cord injury or dysfunction (19 publications, 22 patients) in association with non-cervical spine surgery.1-19

**Table S3-1.** Case Reports of Acute Perioperative Cord Injury in Patients with Cervical Spondylosis

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Reference** | **Surgery** | **Pre-Procedure Neurologic Symptoms or Signs** | **Cervical abnormalities recognized prior to procedure** | **Description of Intubation** | **Description of cervical spine position during surgery** | **Cervical Cord Injury** | **Cervical Abnormalities** | **Cause of Injury as Ascribed by the Authors** |
| Deem et al.,19911 | T10-L5 laminectomies (prone) | Yes | Yes | “Awake oral tracheal intubation under direct visual laryngoscopy…without difficulty and with minimal cervical extension.” | While still awake, intubated, prone, and face resting in a horseshoe headrest, the patient “was encouraged to assist in positioning so that his cervical spine would be aligned in a position comfortable to him (approximately neutral).” | Worsening of pre-existing motor weakness, especially in the upper extremities | Severe cervical stenosis with cord compression C2-C3, C3-4, C4-5, C5-6 | "...subtle alternations in spinal cord blood flow or anatomy or both resulted in central cord ischemia and injury." |
| Fujioka et al., 20032 | CABG | No | No | "…without trauma." "The intubation...[was] technically easy and did not require neck extension" | "…the patient’s neck was placed in a position of extension. This position was maintained for the duration of surgery." | Quadriparesis | C4-C5 and C5-C6 canal stenosis with corresponding cord T2 hyperintensities. | “… probable … placing the neck in an extended position during surgery ... aggravated a preexisting spinal canal stenosis to produce cervical cord injury.” |
| Buchowski et al., 20053 | Total hip replacement (right lateral decubitus) | No | No | "standard ... oral endotracheal intubation under direct laryngoscopy" | No description | Central Cord Syndrome | C4-C5 and C5-C6 canal stenosis with anterior and posterior cord compression and T2 hypointensity at C3-C4 | "...likely caused by cervical spine extension during intubation and positioning in the presence of severe cervical spine spondylosis with canal narrowing." |
| Hirose et al., 20054 | CABG with IMA graft | No | No | "…easy intubation" | No description | Quadriplegia | C4-C5 and C5-C6 canal stenosis, C7-T1 disc herniation, and C5-T2 cord T2 hyperintensity | "…intubation was the only apparent stress to the cervical spine during our entire surgical course. "...severe degenerative cervical spine disease...may have [con]tributed…" |
| Naja et al., 20055 | CABG | No | No | "…easy orotracheal intubation" | "…neck was placed in extension position" | Quadriplegia | Congenital cervical stenosis C3-C6, with C6-C7 disc herniation and cord compression | Not stated outright but authors suggest "...avoid extending the neck in patients with a preoperative diagnosis of cervical spine stenosis." |
| Lewandrowski et al., 20066 | Shoulder arthroscopy (beach chair) | Yes | No | "reportedly...without difficulty or excessive cervical extension" | No description | Quadriparesis | Acute C5-C6 disc herniation, and C5-6 and C6-7 canal stenosis | "...Preexisting spinal stenosis may have played a role …" "Acute cervical disc herniation... [as a] direct injury during intubation, [or] precipitated by cervical hyperextension caused by excessive traction on the upper extremity while in the 'beach chair' position." |
| Total hip replacement | No | No | "...routine endotracheal intubation" | No description | Quadriparesis | C3-C4, C4-C5 and C5-C6 canal stenosis with anterior and posterior cord compression. | "...Preexisting spinal stenosis may have played a role …" Referring to the first patient, "…a similar mechanism is likely…" …hyperextension of the cervical spine…exacerbated the preexisting stenosis…" |
| Hwang et al., 20087 | CABG | No | Yes | "With minimal extension … and …. external laryngeal manipulation, the posterior portion of the glottis and the arytenoids were visible during direct laryngoscopy… facilitated by the use of a gum elastic bougie." | "...a 5-cm thick gel pad ... placed below and across the shoulder to elevate the chest... After placement of the gel pad, hyperextension ... was prevented by placement of a gel donut head pad … between the occiput of the patient and his pillow." | Quadriplegia | C4-C5, C5-C6, and C6-C7 disc herniation causing mild cord compression and canal stenosis at the latter 2 levels | "... postulated that his spinal canal was narrowed enough by the bulging intervertebral discs that with his head and neck placed in that posture for a prolonged duration and with fluctuations in perfusion, any tissue edema that occurred at the cervical spinal cord region was enough to result in significant cervical spinal canal stenosis and neurologic deficit.” |
| Mercieri et al., 20098 | Parathyroidectomy | Yes | No | No description | "...positioned supine with a pillow under his shoulders to facilitate neck extension. | Quadriparesis | C3-4, C4,5 and C5,6 canal stenosis with anterior and posterior cord compression. | "…acute myelopathy… as a consequence of prolonged neck extension." |
| Parathyroidectomy | No | No | No description | "…supine position, with significant neck extension." | Quadriparesis | C3-C4, C4-C5, C5-C6, C6-C7 canal stenosis with anterior and posterior cord compression. | "…acute myelopathy … as a consequence of prolonged neck extension." |
| Gorur et al., 20109 | CABG with bilateral IMA grafts | Yes | No | "...the patient’s neck was placed in an extension position, orotracheal intubation was technically easy" | No description | Quadriplegia | C5-C6 disc herniation. | Not specifically stated. |
| Watanabe et al., 201010 | Thyroidectomy | Yes | Cannot determine | “...the trachea was easily intubated with a Macintosh laryngoscope … without neck extension." | "The patient's neck was extended, and a cylindrical towel was placed under her back ... This position was maintained throughout the surgery." | Quadriplegia | C3-C4 and C4-C5 canal stenosis, without abnormal cord signal | "…placement of the neck in an extended position during surgery could have aggravated a preexisting spinal canal stenosis…" |
| Kudo et al., 201111 | Retina | Yes | No | "... easily intubated, without overextension of the neck" | "supine … without neck extension." | Quadriparesis | "C3-C4, C4-C5 disc herniation, hypertrophic ligamentum flavum C5-C6 and C6-C7 resulting in marked spinal cord compression at C5-C6 and C6-C7. | Not specifically stated. |
| L1-5 spinal fusion (prone) | No | No | "...easily intubated, without overextending the neck." | "prone … without neck extension." | Bilateral upper extremity motor weakness. (Lower extremity function not described) | Disc herniation and hypertrophic ligamentum flavum (C3-C4, C5-C6, C6-C7, T1-T2) with severe cord compression at C3-C4, C5-C6, C6-C7, and T1-T2 | Not specifically stated. |
| Chen et al., 201312 | Head and neck reconstruction | No | Yes | No description | No description | Quadriparesis | Preoperative cervical spondylosis C3-C5. Postoperative C3-C7 stenosis. | Not specifically stated |
| Li et al., 201313 | CABG with IMA graft | No | No | "...orotracheal intubation without difficulty" | "A pillow was placed under his shoulder and upper back to facilitate sternotomy and internal mammary artery harvesting. His head was in an extended position but rested on a gel donut in the occipital region." | Quadriparesis | Cervical stenosis and ossification of posterior longitudinal ligament, with cord compression from C3 to C7 | "…neck extension to facilitate surgical exposure for hours appeared to be the main factor involved in the genesis of the [spinal cord injury]" |
| Clancy et al., 201414 | CABG with IMA graft | No | No | "…routine intubation" | "...sponge was placed beneath the neck to allow neck extension …." "…, no excessive extension of the neck occurred." | Quadriplegia | Anterior cord compression C5-C6 and C6-C7 as a result of disc protrusion with extensive cord T2 signal | "...prolonged neck extension is the most likely cause of cervical spine stenosis in this case." |
| Kim et al., 201515 | L4-L5 laminectomy (prone) | No | No | "...endotracheal intubation was easily performed with the Pentax [AirwayScope] [videolaryngoscpe]" | No description | Quadriparesis | C4-C5 disc herniation, ligament flavum hypertrophy, and severe cord compression with increased cord T2 signal | "Vascular compromise in just a mildly flexed cervical vertebra, precipitated by her pre-existing cervical  spondylotic changes seems to be a plausible explanation of rapid progression of myelopathy. |
| Thenuwara et al., 201516 | Pancreaticoduodenectomy | No | No | "…intubation with minimum head extension" | Except during internal jugular line placement, "head in neutral position." | Central Cord Syndrome | Severe multilevel spondylotic changes with anterior and posterior cord compression at C3-C4, C4-C5, and C5-C6 levels | "…sustained 15-minute hypotension … result[ed] in temporary cord dysfunction." "...perfusion, rather than head/neck hyperextension, was the most critical factor in our patient." |
| Xiong et al., 201517 | Thyroidectomy | Yes | Yes | No description | No description | Quadriparesis | C5–C6 and C6– C7 disc herniation with cord compression and increased cord T2 signal from C4 to C7 | "During [surgery], the spinal canal become narrower due to neck extension. Moreover, neck hyperextension might squeeze the disc posteriorly, causing compression and injury of the spinal cord." |
| Shim et al., 201718 | Parotidectomy | No | No | "…gently intubated…" | "...surgical pad was placed under the shoulders to create extension of the neck." | Quadriparesis | Disc herniation and adjacent ossification of posterior longitudinal ligament at C4-C5 and C5-C6, and T2 cord signal from C3-C4 to C5-C6. | Cervical spine "hyperextension" |
| Mathkour et al., 201919 | Robotic Inguinal Hernia repair | Yes | Yes | "…intubation was performed via a C-Mac video laryngoscope without any further neck extension." | "After positioning the patient into 30 degrees of Trendelenburg, a neutral positioning of the head and neck was reconfirmed." | Worsening of prior myelopathic symptoms with new quadriparesis | Severe multi-level cervical cord stenosis with cord compression and T2 cord signal at C6-C7. | "...possible cord venous congestion which may have resulted in hypoperfusion when in steep Trendelenburg. "...inadequate venous drainage is a known cause of more subacute spinal cord infarcts in cervical myelopathy, we hypothesize that given the prolonged surgical time in our patient, this contributed to his more acute injury." |

CABG=coronary artery bypass graft. IMA= internal mammary artery

As shown in table S3-1, in the majority 17/22 (77%) of patients, cervical spine disease was not recognized preoperatively. In the majority 18/22 (82%), intubation appears to have been performed without difficulty using conventional direct laryngoscopy. Other intubation methods (e.g., awake intubation,1 minimal cord exposure and use of bougie,7 or videolaryngoscopy15,19) were used in 4/22 (18%), also without apparent difficulty. There are 3 publications (4/22 patients [18%]) in which the authors ascribed cervical cord injury to be caused by endotracheal intubation.3,4,6 There are 8 publications (9/22 patients [41%]) in which the authors ascribed cord injury to be caused by deliberate intraoperative maintenance of cervical spine extension to facilitate surgical exposure, for coronary artery bypass grafting,2,5,13,14 thyroidectomy,15,17 parathyroidectomy,8 and parotidectomy.18

A key determinant of strain-related injury is the strain duration. In animal models, in the absence of prior injury brief periods (seconds-minutes) of moderate cord compression are relatively well tolerated.20-22 In contrast, with preexisting cord injury/compression, the amount and duration of “tolerable” compression is much less.20,23 Intubation-mediated cord strain will usually be of brief duration, typically 20-30 seconds. In contrast, when the cervical spine is maintained in extension for the duration of surgery, strain durations of several hours can occur. In studies reporting associations between intraoperative events during cervical spine surgery and evoked potential changes, the most common events were direct surgical interventions (44 – 46%), hypotension (10 – 40%), shoulder taping (4 –31%), neck positioning for surgery (4 –11%), and, least frequent, intubation (0-3%).24,25 Therefore, although we hypothesize routine (normal force) intubation has the potential to cause strain-related cord injury in patients who have cervical spondylotic myelopathy, maintenance of the cervical spine in a non-neutral position during surgery may confer an even greater risk of strain-related cord injury in these patients.

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