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The Cervicothoracic Junction

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The cervicothoracic junction (CTJ) is a unique region in the spine. Biomechanically, it has unique mechanical properties because of the transition between the cervical and the thoracic spine. Radiographically, it is a region that is difficult to image, particularly in traumatic injury. Surgically, it may be difficult to access this region because of the manubrium, sternum, and neurovascular structures in the region. Anatomically, the posterior CTJ posterior has characteristics that pose special considerations to spinal instrumentation.

Strictly speaking, the CTJ should involve the C7 vertebra, the T1 vertebra, the disc between these two vertebrae, and their associated ligaments. Other investigators include the T2 and sometimes the T3 vertebrae when discussing the CTJ, however. Lesions involving the T2 and T3 vertebrae often face similar difficulties for getting access to them through an anterior approach. In addition, many of the spinal fusion constructs of the CTJ often involve the T2 or T3 vertebra, and for these reasons, the CTJ can be defined as the region involving the C7 to T3 vertebrae.

The CTJ represents a region that transitions from the fairly mobile cervical spine to the fairly rigid thoracic spine [1]. The thoracic spine is immobile because of the rib cage, which limits the mobility significantly. In addition, it represents a transition from the lordotic cervical spine to the kyphotic thoracic spine [1]. As a result, this puts significant stress on the CTJ in the static and dynamic states. Disruptions to the structures in this region can thus lead to instability. Common causes of instability include trauma, tumor, and iatrogenic causes [1–4]. These causes are discussed in this article, and the surgical approaches are also discussed.

Trauma to the cervicothoracic junction

Trauma to the CTJ ranges from 2% to 9% of all cervical spine trauma [5–7]. Most of the reports suggested an incidence range from 2% to 5% among all cervical spine trauma [7]. Especially important is that a significant number of CTJ injuries are missed during the initial evaluation [7]. Part of the reason is that the CTJ region is difficult to visualize on plain radiographs because of obstructions of the shoulders. Neither the oblique supine view nor the swimmer's view actually offers adequate visualization of the CTJ in most cases, and it may be particularly difficult in obese patients [8]. Therefore, it is recommended that CT or MRI be used to visualize the CTJ if cervical spine injury is suspected and plain radiographs do not offer an adequate view of the CTJ.

Injuries to the CTJ usually involve fractures or dislocations [1,7,9,10]. Ligamentous injuries, burst fractures, and facet fractures are common causes of fractures and dislocations [1,7,9,10]. Current treatment usually involves immediate closed reduction, followed by fusion with instrumentation [1,9–11]. Closed reduction is usually achieved by skull traction [1]. Surgical fixation is then usually performed; in most series, this is done within the first week, usually within the first 3 days of injury [1,9,10]. Posterior fixation is performed in almost all cases, and this may be supplemented with anterior fixation [1,9,10].

The choice of anterior versus posterior fixation depends on the surgeon's choice as well as on the pathologic findings of fractures. Although some authors have used only posterior fixation in

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trauma that included the anterior column, such as burst fracture, biomechanical studies have shown that in a three-column injury, posterior fixation is not sufficient to restore the stiffness to the level of intact spine [9,12]. It is therefore believed that a three-column injury is probably better treated with anterior and posterior fixation.

Tumors of the cervicothoracic junction

Tumors of the CTJ are a common cause of instability in the region. Metastatic lesions are much more common than primary tumors in this region. Primary tumors of the CTJ may include angiosarcoma, chordoma, lymphoma, plasmacytoma, schwannoma, osteosarcoma, and giant cell tumor [1,13]. Metastatic lesions include distant metastases (eg, prostate, breast) and local extension of tumor [13,14]. Especially common in this region is the Pancoast tumor from the lung [14]. A Pancoast tumor often extends into the junction between the rib and the vertebral body, but the vertebra is not always involved. Other local tumors include thyroid and esophageal tumors that erode into the vertebrae of the CTJ [14,15]. Surgical treatment depends on the tumor type, life expectancy of the patient, and elements that are involved. The two strategies are palliative cord decompression and spine stabilization versus curative with en bloc radical resection of the tumor and stabilization [14]. A decompression strategy usually involves laminectomy supplemented by posterior fusion [1,14]. A posterior approach may also be used for resection of tumors involving the anterior elements, such as through a transpedicular approach or costotransversectomy, thus avoiding the more morbid anterior approaches [13]. En bloc resection of local extension from tumors like a Pancoast tumor often involves vertebrectomy, however, and may include an anterior approach [14]. In most cases, an anterior-only approach is not sufficient for stabilization. In one series, an anterior-only approach was used in three cases, but two of them required revision with posterior fixation [13].

Other conditions that affect the cervicothoracic junction

In addition to trauma and tumor, several other conditions predispose the CTJ to deformity. Just like all other regions of the spine, osteomyelitis can occur in the CTJ region. One particularly interesting infection is tuberculosis (TB). TB has a predilection to the upper lobe of the lung; therefore, spread to the CTJ is not uncommon. Instability occurs when there is destruction of the anterior column [16]. Progressive kyphosis occurs as the mobile cervical spine topples over the thoracic spine [16]. In this case, an anterior fusion without posterior instrumentation may be sufficient for restoration of stability. In a series of 42 patients, Mihir and colleagues [16] showed that anterior instrumentation alone was sufficient to achieve a significant degree of correction of kyphosis.

A degenerative intervertebral disc can also occur in the CTJ, although it is rare. C7-T1 disc herniation accounted for less than 5% of all the cervical disc herniations [17]. In most of these patients, hand weakness and pain radiating to the lateral aspect of the hand were the most common presenting symptoms [17]. Myelopathy was rarely present [17]. Treatment usually involves an anterior cervical diskectomy with fusion, although disc arthroplasty has also been performed with good results [17–19].

Ankylosing spondylitis is another disorder that occasionally involves the CTJ. Ankylosing spondylitis is a rheumatologic disorder that leads to inflammation at the site of ligamentous insertion into the bone. As a result, there is ossification of the ligaments and fusion of the spinal column. It predisposes the spine to traumatic fractures and dislocation as well as to several deformities [20]. One interesting deformity is the chin-on-chest deformity, in which the severe kyphotic deformity results in patients being unable to lift their head [21]. Surgical intervention is often necessary to correct this lesion. In the past, osteotomies that involved laminectomies of the C6-C7 level or C7-T1 level were followed by open reduction and posterior instrumentation [21,22]. Recently, with the development of newer anterior instrumentation, a "front-back" approach has been advocated by some authors [21]. Mummaneni and colleagues [21] described a technique in which an anterior release was achieved with a C5-C6 diskectomy, along with a posterior wedge vertebral body osteotomy at C5-C6. The left pedicle of C6 was also removed [21]. This was followed by placement of lateral mass screws from C3 to C5 and pedicle screws from C7 to T2 [21]. The inferior articulating facet and the spinous process of C5, all the posterior elements of C6, and the cephalad half of the C7 spinous process and lamina were removed [21]. After the completion of the osteotomy, correction of the chin-on-chest deformity was performed by extending the head [21]. The posterior instrumentation was then finished by locking in the rod and screw system [21]. This was followed by anterior instrumentation with an iliac autograft and placement of a cervical plate at the C5-C6 level [21].

Finally, the CTJ is subject to iatrogenic instability. It has been recognized for a long time that a multilevel laminectomy in the cervical spine in children predisposes the CTJ to instability [2]. In addition, a laminectomy across the CTJ without instrumentation tends to introduce instability to the CTJ [1]. Other authors have advocated that fusion constructs should not end at the CTJ; rather, they should cross the CTJ [4]. Steinmetz and colleagues [3] performed a systematic analysis of iatrogenic CTJ instability and analyzed risk factors that contribute to it. The authors found that laminectomy without supplemental instrumentation and ventral fixation with a multilevel corpectomy across the CTJ were associated with a significant probability of introducing instability to the CTJ. In terms of patient factors, prior cervical surgery or CTJ surgery and smoking were associated with failure at the CTJ [3].

Surgical approaches: anterior approach to the cervicothoracic junction

The CTJ is unique in terms of its biomechanical properties, and pathologic change in the CTJ remains a challenge to spine surgeons. This is especially the case for lesions in the vertebral body, in which an anterior or ventral approach is needed. Because of the deep location of the vertebral body as a result of thoracic kyphosis and the presence of multiple vital organs and blood vessels in the region, access is often limited. Anterior approaches can be roughly divided into a low cervical approach, a transmanubrial/transsternal approach, and thoracotomy [23]. There are many different modifications and, occasionally, a combinatorial approach is used. The choice of which approach to use depends on the level of the lesion and the surgeon's experience. The low cervical approach is an extension of the cervical approach used for access to the cervical spine. In this approach, a longitudinal incision is used in most cases, although a transverse incision can be used in lesions in C7 and the neck anatomy is favorable. For a longitudinal incision, it is made medial to the sternocleidomastoid (SCM) and dissection is carried down to the vertebral body with the carotid sheath laterally and the esophagus/trachea medially [1,19,23,24]. The side of the incision partly depends on the site of the lesion [19,23,24]. Structures that are particularly at risk in this case include the recurrent laryngeal nerve and the thoracic duct [24]. In most cases, this allows access down to the T1 or T2 level [1,23,24].

The transsternal/transmanubrial approach is used if lesion access down to the T3 level is required [23]. This approach can be combined with a low cervical dissection for access to the low cervical spine. This approach also carries a higher risk of morbidity, however. The earlier experience of a transsternal approach carried a high risk of morbidity and led to several modifications [23]. Sundaresan and colleagues [25] modified the approach by using a T-shaped incision, resecting part of the manubrium as well as the clavicle. This approach also involves the splitting of the SCM muscle, however, and thus removes part of the accessory respiratory muscle. Modifications, such as using just a unilateral manubriotomy (if the lesion is more to one side and full spine access is not necessary) or leaving the SCM attachment to the clavicle, have been used [26,27]. Many series have used this approach successfully for treatment of lesions at the T3 or even the T4 level [1,16,23,26–28]. Because this approach requires the resection of the clavicle, nonunion of the clavicle remains an issue [28].

If access to below the T4 level is required, a thoracotomy has to be used. The biggest drawback of a thoracotomy is that it cannot be combined with a low cervical approach to access the cervical spine [23]. If access to the low cervical spine is needed, a "trap door" approach can be used [29]. The trap door approach combines a low cervical dissection with a transsternal approach with a thoracotomy [29]. An incision medial to the SCM is made extending down to the sternum at the T4 level and is then extended laterally at the fourth intercostal space to the midaxillary line [29]. This is followed by sternum splitting with a thoracotomy at the fourth intercostal space. This approach allows access from the C3 level down to the T4 or T5 level [29,30].

Posterior approach to the cervicothoracic junction

Because of the difficulty in accessing the spine through the anterior approach, the posterior approach to the CTJ has been used extensively. Modifications to the standard posterior approach allow limited access to elements to the anterior column. As discussed previously, however, posterior procedures to the CTJ often, if not always, require fusion for stabilization.

A standard midline posterior approach is useful for a laminectomy for decompression or for tumors located in the posterior column. A transpedicular approach may also be used for limited access to the anterior column. If more lateral access is needed, a costotransversectomy or lateral extracavitary approach can be used [1,23]. In a costotransversectomy, a midline or paramedian incision is used and the rib head and costotransverse joint are resected [31]. Sometimes, the superior or inferior pedicles may be removed [31]. The lateral extracavitary approach is used for limited access to the anterior column and if the patient cannot tolerate a thoracotomy or anterior approaches [31]. In this case, a short incision is made over the rib at the desired level, and the rib head is removed, along with the pedicle and the posterior-lateral vertebral body [31].

Because of the instability of the CTJ, almost any posterior procedures involving the CTJ should be followed by fusion of the CTJ. Posterior instrumentation and fusion have been a problem in the CTJ region because of the size of the posterior elements. In the cervical spine, posterior fusion and instrumentation are often achieved by lateral mass screws. The lateral mass decreases in thickness from C5 to C7 from 11 to 8.7 mm, however, the C7 lateral mass is in transition between a lateral mass of the cervical spine and the transverse process of the thoracic spine [32]. Conversely, the pedicle increases in size gradually from the low cervical spine to the thoracic spine. At the C5 level, the pedicle width is only 5.2 mm, but it increases to 6.5 mm at the C7 level [32]. The height of the C7 pedicle averages only 6.9 mm [32]. At the T1 level, the pedicles are significantly larger in size, averaging 7.8 mm in width and 8.8 mm in height; however, at the T2 level, the width decreases to 6.5 mm but the height increases to 10.5 mm [32]. The angle between the vertebral body and the axis of the pedicle decreases 4° to 6° per level from C5 to T1, changing from 50° at the C5 level to 34° at the T1 level [32]. Insertion of pedicle screws must take account of these changes in angulation.

As a result of these anatomic restraints, early experience with fusion involving the CTJ usually did not include the use of pedicle screws. Rather, spinous process wiring and lamina hooks were used more extensively [11,22]. There are significant limitations of these implants, however. Spinous process wiring is not as strong as a rod or plate system, and fusion failure was not infrequent. Moreover, the spinous processes are often removed during surgery, therefore severely limiting the application of fusion involving the CTJ. The lamina hooks allow use of a rod as a strut for the fusion [11]. Just like the spinous process, however, the laminae are frequently removed during surgery for decompression purposes. Therefore, use of a hook-rod system requires extension of fusion above and below the laminectomy levels [11]. If a multiple-level laminectomy were performed and long-fusion constructs were used, the number of fixation points would be proportionally small compared with the number of fusion levels. Moreover, a lamina hook presents a significant problem in patients with spinal stenosis [11]. Studies have shown that a hook can intrude into the spinal canal to approximately 27% of the diameter [11].

The experience with lateral mass and pedicle screw fixation across the CTJ has been fairly positive. Early constructs used a plate with holes drilled at a predetermined distance as a strut [9,14]. New constructs using a screw-rod system have been developed in the past 10 years [12,14,33–35]. Biomechanically, these constructs provide significant stabilization to the CTJ in cadaver studies [12]. Biomechanical studies have yielded important information about the number of levels that should be included and also the relative strength of anterior and posterior fixation. One study compared the insertion of pedicle screws versus lateral mass screws at C7. It showed that pedicle screw fixation is superior compared with lateral mass fixation at C7 in all biomechanical tests [33]. This can be partially corrected by adding another level of fixation with lateral mass screws at C6 [33], however.

Compared with the intact spine, posterior instrumentation with a screw-rod system can restore almost 100% of the strength in a two-column but not a three-column injury [12]. In the three commercial systems that were tested at that time, Kreshak and colleagues [12] showed that the stiffness on flexion and extension is similar between the intact spine and spines with two-column injuries that were fixed with these rod-screw systems. Conversely, in three-column injury models, posterior fixation alone is not sufficient to restore stiffness to the level of an intact spine [12].

The use of pedicle screws and lateral mass fixation at the CTJ is safe. In one study, breaching of the pedicle was found on postoperative CT scans in 9% of the screws when inserted without

Fig. 1. A 30-year-old man with ankylosing spondylitis presented with myelopathy. Stenosis at C6-C7 was found secondary to a fracture through his ankylosed spine.

any guidance, but the incidence was reduced to 3% when a navigation system was used [34]. The incidence of vascular injury is extremely rare, and radiculopathy is estimated to be in the range of 1% to 2% [14,36].

Fig. 2. The patient underwent a C7 corpectomy, followed by posterior C6-C7 osteotomies with correction by 15°. Posterior instrumentation was placed from C4 to T2. The patient was not placed in a halo.

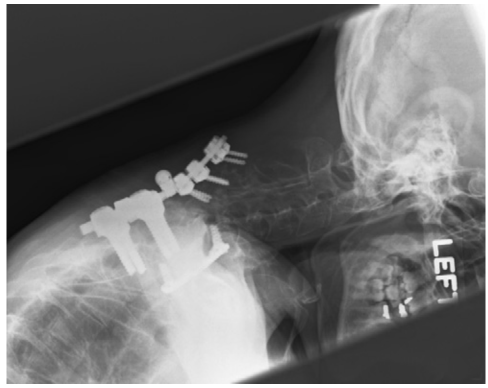

Fig. 3. Two months after surgery, the patient presented to the clinic with worsening ability to look up. A lateral cervical spine radiograph was taken. Pullout of the screws at the CTJ was noted.

In terms of the numbers of levels fused, there are no specific guidelines. In trauma, Chapman and colleagues [9] fused all motion segments. This usually involved two to three levels for a burst fracture but more if ligamentous injuries were present [9]. In tumor cases, Mazel and colleagues [14] recommend that the fusion be extended three levels above and three levels below if a vertebrectomy is performed.

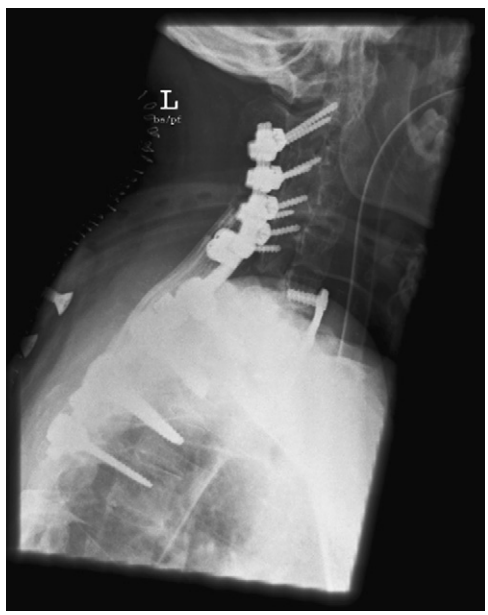

Fig. 4. The patient was brought back to the operating room for C2-T4 instrumentation, further correction of his deformity, and revision of the anterior graft and hardware. A halo was placed for 6 months.

Summary

The CTJ represents a unique region in the spine because of its biomechanical properties. It is predisposed to various traumatic injuries, tumor, and iatrogenic instability. It is also a difficult region to access anteriorly because of the vital structures ventral to the CTJ. The development of new surgical techniques and new instrumentation has allowed better access and fixation to the CTJ.

Case example

A 30-year-old man with a history of ankylosing spondylitis presented to the authors' institution with severe myelopathy secondary to cord compression and "fracture" of his ankylosed spine at C6-C7 (Fig. 1). An attempt was made not only to address his myelopathy but to correct his deformity (Fig. 2). Because of the long lever arm of his ankylosed spine, he pulled out of his hardware in 2 months, despite anterior and posterior stabilization (Fig. 3). Extension of instrumentation and halo immobilization for 6 months followed, and that led to ultimate stabilization of his spine (Fig. 4).

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