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A comprehensive review of the treatment and management of Charcot spine

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***Abstract*:** Charcot spine arthropathy (CSA), a result of reduced afferent innervation, is an occurrence of Charcot joint, a progressive, degenerative disorder in vertebral joints, related mostly to spinal cord injury. The repeated microtrauma is a result of a lack of muscle protection and destroys cartilage, ligaments, and disc spaces, leading to vertebrae destruction, joint instability, subluxation, and dislocation. Joint destruction compresses nerve roots, resulting in pain, paresthesia, sensory loss, dysautonomia, and spasticity. CSA presents with back pain, spinal deformity and instability, and audible spine noises during movement. Autonomic dysfunction includes bowel and bladder dysfunction. It is slowly progressive and usually diagnosed at a late stage, usually, on average, 20 years after the first initial insult. Diagnosis is rarely clinical related to the nature of nonspecific symptoms and requires imaging with computed tomography (CT) and magnetic resonance imaging (MRI). Conservative management focuses on the prevention of fractures and the progression of deformities. This includes bed rest, orthoses, and braces. These could be useful in elderly or frail patients who are not candidates for surgical treatment, or in minimally symptomatic patients, such as patients with spontaneous fusion leading to a stable spine. Symptomatic treatment is offered for autonomic dysfunction, such as anticholinergics for bladder control. Most patients require surgical treatment. Spinal fusion is achieved with open, minimally-open (MOA) or minimally-invasive (MIS) approaches. The gold standard is open circumferential fusion; data is lacking to determine the superiority of open or MIS approaches. Patients usually improve after surgery; however, the rarity of the condition makes it difficult to estimate outcomes. This is a review of the latest and seminal literature about the treatment and chronic management of Charcot spine. The review includes the background of the syndrome, clinical presentation, and diagnosis, and compares the different treatment options that are currently available.

Keywords: back pain, Charcot-Marie-Tooth, nerve root compression, spinal cord injury, spine denervation, tabes dorsalis

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Introduction

Charcot spinal arthropathy (CSA) is a rare progressive degenerative disorder of vertebral joints.[1–3] CSA occurs due to reduced afferent innervation, and, although any joint may become a Charcot joint, the disorder tends to target peripheral joints in the lower extremity; it is estimated to target the spine in only 6–21% of patients with the condition.[4] Historically, CSA developed secondary to tabes dorsalis, but recently is related most commonly to spinal cord injury (SCI) and conditions that result in proprioceptive and nociceptive deficits.[2,3,5–17] These sensory impairments hinder the protective muscle contractions that stabilize the spine, rendering it vulnerable to microtrauma.[2,3,9,18–22] The uninhibited repeated microtrauma over time results in the destruction of cartilage, intraarticular ligaments, and a narrowing of the intervertebral disc space.[2,3,9,19,21,23,24] This can lead to the destruction of the vertebra itself and potential compression

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fractures, along with joint instability, subluxation, and dislocation, which can then transfer to neighboring joints.[2,3,9,18–21,23,25] L1–L2, L2–L3, and L4–L5 are the most frequent joints affected, although thoracolumbar and lumbosacral joints may be targeted as well.[3,9,25,26] The degenerative destruction of the joint may also compress the nerve root, which may result in pain, loss of sensation, and motor weakness, as well as further neurologic dysfunction such as loss of deep tendon reflexes, spasticity, and autonomic dysreflexia.[2,3,19,22,24,25,27,28] Another common consequence of the repetitive trauma is kyphosis, which, when severe enough, may even result in skin breakdown.[2,3,7,19,20,22,24,25,29,30] The incidence of CSA is unknown, as the disease has been described primarily in case reports and smaller case series. The largest recent study comparing treatment options included only 23 patients, and the largest review included only 201 cases.[23,24] While it is an uncommon disorder, the potential pain, deformity, and neurologic deficits can severely reduce functional capacity, earned income, quality of life, and potentially life expectancy.[26]

Epidemiology

Neuroarthropathy was initially described by Mitchell in 1831 in a patient with "caries of the spine" and polyarticular lower extremity arthritis.[31] In 1868, Jean-Martin Charcot, the condition's namesake, described neuropathic arthropathy in patients with tabes dorsalis.[32] A Charcot joint may apply to any joint in the body, typically affecting peripheral joints of the lower extremities. It was first described in the spine in 1884 by Kronig in a patient with tabes dorsalis.[33] In a 1917 experiment, Eloesser confirmed its pathophysiology secondary to trauma by creating a loss of pain sensation in cats by cutting through their posterior spinal cord roots.[34] While CSA was documented traditionally in patients with tertiary syphilis, with developed antibiotic therapy, this is an atypical cause of CSA in more recent decades. SCI, usually secondary to trauma, is now the most common condition resulting in CSA, with one review finding that it is responsible for 70% of reported CSA cases.[3,7,10,11,17,23,35–41] Other less common conditions associated with CSA include diabetic neuropathy, syringomyelia, meningocele, myelomeningocele, anesthetic leprosy, congenital insensitivity to pain, medullary AV malformation, Parkinson's disease, transverse myelitis, Guillain-Barré syndrome, Friedreich ataxia, Charcot-Marie-Tooth disease, arachnoiditis, and others.[3,12,19,39,42–50] Unfortunately, the incidence and prevalence of CSA are difficult to determine since CSA has been reported largely in case reports and small case series. The estimated prevalence of CSA developing after SCI is 1 in 220, and the incidence and prevalence of SCI in the United States (US) are 54 per 1 million (17,700 cases per year) and 288,000, respectively.[51,52] While neuroarthropathy occurs in 5–10% of patients with tabes dorsalis and 25–32% of those with syringomyelia (which afflicts only 8 in 100,000), spinal association, in particular, has been described, but comprehensive data have not been gathered.[2,19,53] Similarly, while the prevalence of Charcot arthropathy in diabetics is estimated to be between 0.1% and 7.5%, it is usually present in the foot, rarely in the spine, and numbers specific to the spine have not been reported.[54,55] CSA occurs most frequently during the fifth decade of life, and has been reported from the second decade until the ninth.[11,19] One study found CSA to occur in males three times as frequently as in females, but no other published literature has supported or refuted this claim directly.[11] Given that 70% of published CSA cases are secondary to SCI and 78% of new SCI cases are male, it is likely that most CSA cases are male, although this can be only speculative at this point.[52]

Risk factors

Risk factors for developing CSA are principally conditions and injuries that can result in the loss of proprioception and pain sensation in the spine. The genetic risk factors for developing CSA include some of the conditions listed above, such as congenital insensitivity to pain, Friedreich ataxia, and Charcot-Marie-Tooth disease. The environmental risk factors are largely behavioral, as conditions such as diabetic neuropathy and tertiary syphilis, which can lead to CSA, are typically preventable. Other risk factors about medical history, including conditions listed in the previous section and others such as neuromuscular scoliosis, which leaves the spine particularly vulnerable.[26,37,40] As mentioned earlier, the most notable risk factor is SCI, mostly from trauma such as vehicular accidents and falls.[52] Additional aggravating factors that predispose towards developing CSA include surgeries such as long spinal fusions and laminectomies performed to treat the underlying condition.[3,6,7,11,14,23,37,40,56] Long spinal fusions (greater than five vertebrae) produce lever arms that increase the joint forces on the vertebrae in nearby segments, usually below the

fusion, that are already vulnerable to increased joint damage and CSA.[7,23,26,39,40,56] Laminectomies weaken the posterior stabilizing elements of the spine and can risk damaging the paravertebral muscles with an aggressive incision, leaving the posterior facet joints and the junction of the intervertebral disc and vertebral body to carry a greater portion of the load.[3,6,11,14,23,37] This renders the vertebral segment of the laminectomy prone to developing CSA.[7,39] Other post-operative aggravating conditions are also related to mechanical factors. Lateral bending, torso rotation, activities such as weightlifting or competitive sports, and obesity all place excess stress on already susceptible joints.[3,7,40,57] For paraplegic patients, comprising a large portion of those with SCI, the act of transferring puts them at increased risk as moving the lower extremities during the transfer before or after the aggressive push from the triceps puts a large biomechanical stress on the spine.[3,23]

Ankylosing spinal hyperostosis (ASH) is another potential risk factor, since ASH reduces the mobility of the affected vertebrae, thus hindering their ability to effectively distribute and reduce the pressure of the biomechanical load.[58–60] When conservative treatment measures for ASH fail it is usually treated with fusion, which, as discussed above, further puts the patient at risk of CSA.[60,61] One study found CSA either within the spinal segment targeted by ASH or at the end of the ASH in seven of their nine patients.[35]

Clinical presentation

Patients with CSA can present clinically with a range of symptoms, many of which are nonspecific. The most common symptoms include back pain, spinal instability while sitting, spinal deformity (typically kyphosis), and audible noises such as clicking, cracking, or crunching coming from the spine during movement.[9,11,20,26,35,37,62] These symptoms are due to the increasing spinal instability after the vertebral joint is destroyed by the repetitive microtrauma discussed earlier. Back pain may appear paradoxical given the nociceptive deficits present in these patients. However, they may still be able to feel deep pain due to localized pain tracts that were not damaged by their primary condition or felt as a consequence of concomitant autonomic dysreflexia (AD) – another commonly reported symptom of CSA.[26,27,35,37,50] There is no published literature establishing a cause explaining the association between CSA and AD. Two ongoing hypotheses propose that AD is due to spinal instability applying pressure on the presacral plexus of nerves and retroperitoneal viscera, or that AD is a reaction to localized joint pain, even if not detected by the patient.[24,63] AD symptoms in CSA patients have also been reported to include bowel or bladder dysfunction with movement.[11,26,50] Other changes in neurologic function described in CSA patients include paresthesia, motor deficits, increased spasticity, and spastic to flaccid paraplegia.[9,11,26,35,37,47] It is important to note that, because of the slow progression of the disease, along with the loss of pain sensation and other preexisting neurologic deficits, most patients do not notice symptoms until CSA has progressed to an advanced stage of vertebral destruction. Patient presentation is, on average, roughly 20 years after the initial injury or impairment, but, in certain instances, symptoms can develop early in time.[3,35,39,64] Moreover, the symptoms of CSA are largely nonspecific and may mimic suppurative bacterial, fungal, or tuberculosis (TB) infection of the spine, florid degenerative disc disease, Paget's disease, or mass effect from a tumor. As a result of this, it can take additional years to make a clinical diagnosis after the initial patient presentation.[3] In addition to the symptoms listed above, the timing of diagnosis is critical due to disease complications. Advanced kyphosis in patients with CSA has been reported to create ulcers, which can progress to form fistulas between the spine and skin.[11,26,37] Together with long-destroyed and potentially necrotic vertebral joints, these fistulas can provide a nidus for infection, and there have been many reported cases of CSA where patients had associated bacterial infections.[23,26,35,47]

Diagnosis

Given that the Charcot spine arises secondary to the loss of deep sensation and proprioception, many patients do not develop symptoms until later in the disease process. Consequently, this makes it difficult to diagnose clinically and requires supportive findings *via* radiographic, computed tomography (CT), and/or magnetic resonance imaging (MRI) to reach a definitive diagnosis. Attention should be focused around areas of the spine that have experienced some type of neurologic injury or damage with retained or excessive motion – an aspect that is recognized as a hallmark of the Charcot spine. Specifically, the thoracolumbar and lumbosacral junctions have been identified as regions of the spine with

the most flexibility, and, therefore, more susceptible to developing Charcot spine/spinal neuroarthropathy.[3,21] It is also important to note that imaging may show severe or extensive disease with a relative lack of the symptoms previously mentioned.

Charcot spine can be separated into an early atrophic stage followed by a hypertrophic stage.[49] Imaging is used only rarely during the early atrophic stage due to lack of symptoms, but incidental findings may include minor endplate osteolysis and/or microfractures. Once the disease enters the later hypertrophic stage, imaging can demonstrate findings represented by what Wagner *et al.* describes as the "six D's": distention (secondary to a soft-tissue mass), density (preserved bone density and sclerosis), debris (osseous fragments), disorganization (altered articular contour with the incongruity of the intervertebral joint), dislocation (spondylolisthesis), and destruction (endplate and facet erosions).[21,65] Although this provides a solid framework, these symptoms are nonspecific and can be present in other diagnoses.

Radiographic and CT findings highlight osseous disease processes, with CT offering a more detailed view. One key radiographic finding that is highly specific to Charcot spine is the presence of gas within the disk space, secondary to what has been described as the vacuum phenomenon.[66] This finding indicates preserved or excessive motion – a key component of Charcot spine. Other radiographic findings include large fluffy marginal osteophytes and bone fragment debris caused by juxta-articular bone destruction and the appearance of enlarged vertebral bodies caused by new bone formation. CT findings are similar to those on radiography; however, the vacuum disk phenomenon is more easily appreciated. Additionally, CT can reveal disease involvement of the intervertebral joint as a whole, which includes the anterior discovertebral and posterior facet articulations. Because of this widespread involvement of the vertebral body, spondylolisthesis occurs and is another key finding on imaging.[21,65]

MRI provides information regarding soft-tissue involvement and is also able to detect inflammatory changes that are harder to elucidate on CT. This potentially allows for identifying early disease processes of Charcot spine.[21,49] Signs that support the diagnosis of Charcot spine on MRI include peripheral disk and vertebral body enhancement and homogenous T2 signal hyperintensity of the paravertebral soft-tissue masses secondary to edema, effusions around the involved facet joint or within disk spaces, and overall destruction and disorganization of the intervertebral joint as a whole.[21,65]

Aside from the specific findings described regarding imaging, a clinician may make the diagnosis of Charcot spine based on this previously suggested diagnostic criteria: the patient has an underlying disease that causes impairment of proprioception and pain sensation, radiologic imaging shows evidence of bone destruction and resorption and new bone formation, histologic exam shows nonspecific chronic inflammation, the histologic exam is needed to delineate Charcot spine from other serious life-threatening diagnoses such as a spinal infection or neoplasm.[3,21,36,67,68]

Conservative management

For management, surgical approaches have been well documented in the literature, and have been identified as being the definitive treatment for Charcot spine. These different avenues for surgical intervention are described in the following sections. Although the majority of patients with the disease undergo surgical operations, there are numerous reports of associated complications and treatment failure represented by non-unions, infections, and relapses, requiring reoperation at rates as high as 40%.[39] This leads to the question of whether or not all patients require surgery or if their symptoms can be managed conservatively. Conservative management is mentioned frequently, albeit briefly throughout the literature, but, to the best of our knowledge, few studies highlight the efficacy of conservative management for Charcot spine.

The goal of conservative management during active disease processes is to immobilize the affected joints to prevent fractures and progression of deformities. Prior to the advancement of surgical procedures involving the spine, this goal was achieved historically through bed rest and the use of orthoses and braces, which are the approaches still implemented today.[14,69] In a case report of two patients, prolonged bed rest for several weeks also proved to be sufficient to resolve autonomic dysreflexia symptoms secondary to Charcot spine.[27] When it comes to the use of orthoses and braces, they can achieve immobilization and symptomatic relief in certain patients, but only on a short-term basis.[9,69,70] These

methods may be unable to prevent the progression toward severe disease.[71] Other limitations of orthoses include the inability to reduce the dislocation of the spine, and the fact that most paraplegic patients do not tolerate their usage.[71]

Conservative management should be considered in several circumstances. Reasons to forego surgical treatment include if the patient is elderly or cannot be optimized for the procedure. Additionally, conservative management should be explored first if the patient presents with minimal pain and/or neurologic symptoms.[71,72] Surgery has also been shown not to be beneficial in the setting of a spontaneously fused or stable spine.[71] Should the patient's symptoms progress and develop neurologic dysfunction, then surgery should be considered. Given that infection is a common complication of surgical intervention, conservative management may be preferred to prevent sepsis. However, if a patient with Charcot spine develops an infection of the spine, surgery becomes the only option as conservative management alone in this setting will most likely fail.[25,70,71,73] Lastly, conservative management is used in cases where the patient declines surgical intervention.[70]

In a retrospective study following a total of 12 patients diagnosed with Charcot spine conducted by Moreau *et al.*, 7 patients were treated conservatively. This conservative management consisted primarily of a custom-made thoracolumbar brace to manage back pain. If the brace could not be tolerated, then bed rest was an alternative option. Adjunctive therapies for back pain included classic and neurotropic painkillers and physiotherapy. Symptoms associated with autonomic dysfunction were treated with lesion stabilization, physical repositioning in the wheelchair, and physiotherapy. Lastly, anticholinergic drugs were used to manage bladder dysfunction. During an average follow up of 4 years, five of the seven patients treated conservatively reported controlled symptoms, with one of these five patients achieving total regression of back pain. The other two patients who developed worsening symptoms and disease progression ultimately declined surgical intervention due to secondary complications. These results showed that conservative management is a valid approach in certain circumstances and that surgery should not always be the first option in management. Nonetheless, given that the presentation and progression of Charcot spine varies on a case by case basis, it becomes difficult to establish a standardized therapeutic regimen and, to the best of our knowledge, no such guidelines exist in the literature.[71]

This study also highlighted a unique point when considering how Charcot spine affects the paraplegic patient population. The increased mobility associated with the disease can be viewed as an aspect that increases the patient's autonomy in the seated position. Proceeding with surgery that involves spinal fusion will ultimately remove this element of mobility and may undermine the patient's autonomy. Thus, this study recommends that any wheelchair-bound or paraplegic patient undergo a brace test before surgery that simulates the spinal fusion postop and also gives the patient an idea of his or her functional capabilities following the procedure. All in all, clinicians should keep this specific patient population in mind when treating Charcot spine, and should first offer conservative management to preserve any autonomy and functional capacity.[71]

A potential strategy for further study in the realm of conservative management for Charcot spine is the use of bisphosphonates. We propose this based on the premise that Charcot neuroarthropathy of the foot and Charcot spine share similar pathophysiology involving repetitive cycles of injury followed by inflammation and bone destruction.[72,74] A study by Pakarinen *et al.* mentions the frequent, but controversial, use of bisphosphonates as adjunctive therapy in the management of Charcot neuroarthropathy of the foot in diabetic patients. This study further examined the effect of zoledronic acid, a bisphosphonate, on bone mineral density at the femoral neck of the Charcot neuroarthropathy affected side. Results showed a statistically significant increase in bone mineral density when compared with placebo. Although the clinical significance of this result was not established, the principle of using bisphosphonates may have implications in the conservative management of Charcot spine.[75] To the best of our knowledge, there are no current studies that examine or mention the use of bisphosphonate therapy in treating Charcot spine within the medical literature.

Minimally invasive management

CSA patients with minimal improvement of symptoms through conservative treatment should be considered for surgery. Minimally invasive surgery (MIS) shares the same indications as traditional open surgery, but it uses smaller incisions leading

to less soft tissue damage, decreased bleeding, fewer complications, faster recovery, and shorter hospital stays.[76] Minimally invasive techniques are now used commonly for spinal procedures such as endoscopic and laparoscopic percutaneous procedures, decompression, laminectomy, facetectomy, bone graft, and spinal fusion. The circumferential or combined anterior–posterior fusion of the spine is the current recommended surgical treatment for CSA; therefore, the focus is primarily on minimally invasive approaches to spinal fusion. Fusion is a biomechanical union between vertebral bodies through various surgical approaches, grafts, and implants.[77]

Fusions can be approached posteriorly by making incisions in the back muscles to reach the spine, termed posterior lumbar interbody fusion, or anteriorly by making incisions to the abdomen, known as anterior lumbar interbody fusion.[78] Historically, fusions were approached posteriorly, but, recently, anterior approaches, when well mastered, have been shown to lower morbidity and mortality.[79,80] Lateral and anterolateral approaches, which access the spine through the lateral aspect of the rectus abdominis muscle, along with laparoscopic anterior approaches, are examples of new minimally invasive techniques for lumbar fusion.[79] These approaches use a modified tubular retractor system to reduce tissue damage.[78] Although the techniques differ in logistics, these techniques approach the spine anteriorly to the vertebral canal, reducing the risk of nerve and vascular injury.

Mini-open approaches (MOA) are also a form of MIS. These surgeries are under direct visualization and use sequential tubular dilators, special expandable retractor systems, and intraoperative electromyography to reduce soft-tissue damage.[81] A mini-open lateral approach to fusion on 74 patients, with one case of CSA, had reduced blood losses, fewer complications, and lower operation times; however, it also had longer average admission periods.[81] Complications were limited to two cases of retroperitoneal hematoma, one case of pneumonia, three cases of transient lumbosacral plexus paralysis, one case of inadequate kyphosis, and one case of failure to insert lateral cages. In their study, Zdeblick and David also found a low complication rate of 4% for mini-open surgery, as opposed to 20% for closed laparoscopic surgery.[82] MOA advantageously allows access to the T12–L1 bodies without incising the diaphragm, reduces the chance of damaging the peritoneum or great vessels, and offers a simple approach compared with others. However, it does not allow access to the L5–S1 bodies, creates a risk of lumbosacral plexus injury, and has a deep and narrow surgical field. Despite this, Chong *et al.* concluded that the MOA to fusion is an effective and safe technique, preferable for one or two-level fusions.[81]

Kim *et al.* performed MIS fusion for CSA through a single-stage posterolateral costotranversectomy approach to avoid the additional morbidity associated with multi-stage anterior-posterior fusion.[20,37,39] The patient tolerated surgery well, with no intraoperative or postoperative complications. At 2-year follow up, the patient returned to daily activities. Plain radiographs showed a solid fusion, but follow-up CT images showed inadequate endplate preparation and incorrect placement of a mesh cage. They posited that this approach has limited visualization, but also acknowledge that extensive hypertrophic reactive tissue around the Charcot segment may have played a role.[20]

It is difficult to conclude the effectiveness and viability of MIS in the management of CSA due to a considerable lack of cases. MIS procedures with short stabilization and percutaneous pedicle screws should be reserved solely in instances of initial stage disease without great instability and can avoid conservative treatment. Each consideration for MIS in patients with CSA should be one approached cautiously and made on a case-by-case basis. Nevertheless, with rapid advances in surgical technique and instrumentation, MIS can potentially become a safer treatment option for patients and is an area of research requiring further investigation.

Surgical management

Surgery is the primary treatment for CSA, but an optimal treatment protocol has yet to be established. Many consider surgery the best treatment modality due to recent advancements in surgical instrumentation and technique. The goal is to create a stable fusion of the diseased spinal segment, and the majority of studies show good radiographic outcomes.[71] According to Barrey *et al.*, the main surgical principles involve debridement of inflamed tissue, decompression of spinal canal stenosis, stabilization, 360° bone graft in either two stages *via* combined anterior-posterior approach or one stage *via* posterior lumbar interbody fusion, and collection of bacteriological and histological samples.[3]

Most of the surgical procedures performed today are circumferential 360° long-segment spinal fusions involving a combined anterior–posterior vertebral column construct at the level of the Charcot segment.[22,47] Posterior-only reconstruction has been indicated in mild cases with minimal bony involvement.[22] Cassidy *et al.* emphasizes that, "Without circumferential fusion, patients are likely to have implant failure due to repetitive motion and lack of protective sensation".[47] Other authors also advise against posterior-only fusions due to a high rate of pseudoarthrosis and wound healing delays.[67] Lee *et al.* further support this notion by showing that construct failure resulting in revision surgery occurred in only 29.6% of patients receiving combined fusion *versus* 58.3% of patients receiving a single posterior fusion.[22]

The primary treatment, with low hardware failure rates, to improve stability and pain in CSA patients is circumferential fusion.[26] Many authors report successful circumferential fusion with improvements in functional status, pain, and sagittal imbalance during follow up varying from 1 to 10 years.[11,37] Suda *et al.* suggest a single-stage circumferential fusion in patients with no major comorbidities.[36] For patients with medical comorbidities, multi-staged circumferential fusion should be pursued.[36] However, the two-staged procedure is often associated with considerable patient morbidity, surgical time, and blood loss.[36]

Posterior three-column shortening procedure, when combined with fusion, is another option that has been successful in patients with multilevel disease and major fixed frontal or sagittal plane deformities.[20] David *et al.* advise that single-stage, posterior 3-column resection with a primary shortening approach avoids the potential complications of a long anterior cage or allograft segment by enhancing direct bony contact.[83]

Another surgical approach is four-rod fusion. Quadruple rods have been touted as biomechanically superior in complex spinal reconstruction.[84,85] A patient with C6 quadriplegia saw improvement in autonomic dysreflexia symptoms after four-rod thoracolumbar posterior fusion.[86] Resolution of infection and baseline sitting balance was seen in a patient of Yelamarthy *et al.* with infected CSA treated by four-rod fusion.[87]

Common complications of CSA include infection of Charcot segments. Management should include aggressive debridement and circumferential fusion in addition to the appropriate medications to control the infection.[87] A case series reported by Yelamarthy *et al.* showed no infection recurrence in three cases of superimposed infection of the Charcot spine when treated with parenteral antibiotics for 6 weeks and no oral regimen.[87]

A recent introduction of a multimodal treatment model with the use of bone morphogenetic protein (BMP) has been shown to promote union and reduce treatment failure rates in circumferential fusion.[23] It also is beneficial in vertebral pyogenic infections.[88,89] Jacobs *et al.* saw favorable outcomes in 23 patients through the use of BMP and circumferential fusion with fixation to the pelvis using four rods.[23]

Although many authors support circumferential fusion, there is no clear consensus on the specific guidelines for performing the surgery. The extent of instrumentation necessary to maintain stability and reduce hardware failure remains subject to debate. After fusion, there is a risk of developing damage above and below the operated spinal segment.[3,25] Some authors recommend extended fusion to the ilium or sacrum through a four-rod lumbopelvic construct to reduce the development of additional CSA below the instrumentation.[20,23] Patients with sacropelvic fusion had higher fusion rates and lower risks of developing secondary CSA than patients with fusion to the lumbar spine.[40] However, it has been shown to cause a significant loss of function and increase the risk of femoral insufficiency fractures.[25,90] For patients with CSA of the lumbar spine, pelvic fusion is recommended.[20] Adjacent prior fusion levels should be combined with the surgical levels to prevent pseudoarthrosis.[39] Surgeons should advise patients that fusion to the lumbar spine, as opposed to the pelvis or sacrum, may preserve flexibility, but raises the risk of CSA recurrence and revisional surgery in the future.[20]

While most patients have favorable short-term outcomes, there is a clear lack of studies showing long-term results. Surgery remains the favored option, but many authors support the addition of BMP, if possible, as a multimodal approach. Ultimately, the exact surgical approach is dictated by the preference and training of the surgeon.

Conclusion

In summary, CSA is a complex progressive degenerative disorder of the spine that commonly

manifests as part of the sequelae following SCI due to the loss of proprioceptive and nociceptive protective factors. The resultant repeated cycles of microtrauma over time lead to global destruction of the vertebral joints and further neurologic deficits. One must have a high clinical suspicion of this disease, but symptoms that would support the diagnosis of CSA include instability while in the seated position and audible noises produced by the spine during movement or transfer of the patient. Imaging is required to aid in the diagnosis, especially in the advanced stages of the disease. Supportive imaging findings for CSA include gas within the disc space, marginal osteophytes appearing fluffy, and spondylolisthesis. The mainstay of treatment for CSA is surgery through various techniques that have been developed over the years to achieve adequate fusion and stabilization of the Charcot spinal segment while minimizing surgical complications. Conservative management of this disease has not been studied in depth; however, a recent study suggests that surgery may not be required in all cases of CSA. Each patient should be managed on a case-by-case basis, taking into consideration the severity of symptoms, functional capacity of the patient, and how surgical management may affect the patient's autonomy postoperatively. Additional research is required to establish guidelines for both surgical and conservative management of this complicated disease.

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