Mini-open anterior approach for cervicothoracic junction fracture: technical note

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Elderly patients with diffuse idiopathic skeletal hyperostosis are at high risk for falls, and 3-column unstable fractures present multiple challenges. Unstable fractures across the cervicothoracic junction are associated with significant morbidity and require fixation, which is commonly performed through a posterior open or percutaneous approach. The authors describe a novel, navigated, mini-open anterior approach using intraoperative cone-beam CT scanning to place lag screws followed by an anterior plate in a 97-year-old patient. This approach is less invasive and faster than an open posterior approach and can be considered as an option for management of cervicothoracic junction fractures in elderly patients with high perioperative risk profile who cannot tolerate being placed prone during surgery.

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KEY WORDS diffuse idiopathic skeletal hyperostosis; spinal fracture; cervicothoracic junction; minimally invasive surgery; navigation-assisted surgery; intraoperative cone-beam computed tomography; mini-open

DIFFUSE idiopathic skeletal hyperostosis (DISH) is characterized by calcification and ossification of soft tissue and is diagnosed according to the Resnick and Niwayama criteria: bridging ossifications in at least 4 continuous vertebrae, preservation of the intervertebral disc space, and absence of involvement of the sacroiliac or facet joints.^{28,36} The presence of DISH limits the motion of the spine, tends to increase overall kyphosis, and increases the risk of fractures. Minor trauma in patients with DISH, or other disorders limiting spinal motion, such as ankylosing spondylitis (AS), can lead to severe 3-column injuries.

Cervical spine fractures are associated with significant morbidity in the elderly population with the 60-day mortality rate in patients older than 60 years reported to be nearly 10%.^{9,20} Patients older than 60 years have the highest incidence of cervical spinal fractures.¹⁹ When an unstable cervical fracture occurs, such as 3-column injury in patients with ankylosing spinal disease, it is important to perform vertebral fracture reduction and fusion followed by definitive immobilization and spinal stabilization. The choice of operative versus nonoperative management can

be difficult, particularly in elderly individuals with decreased physiological reserve. Generally, nonoperative treatment (e.g., bed rest, cervical collar, or halo brace) has significant risks for complications including dysphagia, pin-site infection, skin breakdown, pressure ulcers, and respiratory problems.^{13,17,18,27,30} The perioperative mortality rate in elderly patients with cervical spine injury has been reported as high as 12.2%, but for those managed nonoperatively, it can be as high as 40%.^{21,29,40}

Fractures of the cervicothoracic junction (CTJ) are relatively uncommon compared with fractures in the rest of the cervical spine. They account for 2%–9% of all cervical spine fractures.^{12,33} The CTJ has a unique biomechanical composition as the transition point between the lordosis of the mobile cervical spine and kyphosis of the rigid thoracic spine.^{1,2,6} The location of the sternum can limit anterior surgical approaches to the CTJ. Additionally, the CTJ is difficult to visualize fluoroscopically during surgery due to the radiopaque clavicles, shoulders, and ribs.^{6,44}

Intraoperative cone-beam CT (ICBCT)–based navigation systems can assist the surgeon with accurate placement of spinal instrumentation, particularly in difficult

ABBREVIATIONS AS = ankylosing spondylitis; CTJ = cervicothoracic junction; DISH = diffuse idiopathic skeletal hyperostosis; ICBCT = intraoperative cone-beam CT.

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FIG. 1. CT scans of the cervical spine demonstrating a fracture of the posterior inferior corner of the C-7 vertebral body (A) and bilateral C-7 pedicles (B: left pedicle [upper] and right pedicle [lower]). Sagittal T2-weighted MR image revealing C7–T1 intervertebral disc injury and anterior longitudinal ligament disruption (C).

locations, such as the CTJ, in patients with degenerative disorders, trauma, and deformity.^{11,38,41} This system can provide useful information and guide accurate implant placement even in cases with limited surgical exposure or in those involving minimally invasive approaches. It is also very useful when instrumenting levels that are difficult to visualize fluoroscopically, such as the CTJ. Here, we describe this technique utilizing an ICBCT-navigated anterior mini-open approach to place lag screws and an anterior plate in an illustrative case of a 97-year-old man with DISH who suffered a 3-column spinal fracture of the CTJ.

Case Report

History and Examination

A 97-year-old man was admitted to our institution with neck pain after a fall from the standing position. He had a history of hypertension, diabetes mellitus, and prostate cancer. He did not experience loss of consciousness or posttraumatic amnesia. He had no numbness, weakness, or bowel or bladder dysfunction. On neurological examination, he had full strength and sensation throughout all extremities. He had a negative Hoffmann sign, normal deep tendon reflexes, and downgoing toes. He had midline posterior cervical tenderness over the lower cervical and upper thoracic spine. At baseline, he was high functioning, lived by himself, was independent in activities of daily living, and ambulated without the aid of a walker or cane.

Cervical spine CT showed an acute fracture through bilateral C-7 pedicles (Fig. 1A and B), extending into the posterior inferior corner of the C-7 vertebral body (Fig. 1A). The patient had nearly complete autofusion of the cervical and thoracic spine due to DISH. Cervical spine MRI showed fracture extension through the C7–T1 intervertebral disc space and anterior and posterior longitudinal ligamentous disruption (Fig. 1C). It also showed that there was anterior translation of C-7 on T-1 compared with the imaging done a few hours prior, reflecting the instability of the fracture.

Conservative treatment consisting of external fixation and bed rest was considered initially given the patient's

age and medical comorbidities. However, due to the unstable nature of the fracture, the patient, with support of his family, elected to undergo surgical fixation. Prone positioning was considered but was deemed high risk by the anesthesia team given documented labile hypertension following admission and his medical comorbidities.

Operative Technique

See Video 1 for a depiction of the surgical technique.

VIDEO 1. Surgical technique. The video presents the case illustration and shows the surgical setup in the operating room, the intraoperative photographs/videos, navigation screenshots/live images, surgical techniques, and follow-up radiographs. Copyright University of California, San Francisco. Published with permission. [Click here to view.](#)

The patient was positioned supine. Fiber optic intubation was performed, maintaining a neutral neck position. Baseline motor evoked potential, somatosensory potential, and free-run electromyography signals were monitored. His shoulders were taped to the end of the bed to better expose the CTJ. A reference frame arm was attached to the head of the bed and positioned just left and superior to the patient's head for a right-sided neck approach. The patient was prepared and draped in the normal sterile fashion. An intraoperative O-arm spin was performed and uploaded for navigation. A vertical incision was made just medial to the sternocleidomastoid border. The platysma was opened vertically along the fibers. The fascial plane medial to the sternocleidomastoid was bluntly dissected to the prevertebral fascia, which was opened. The C-6 vertebral body was identified with the navigation system.

Self-retaining retractors were placed. Two trajectories crossing the C6–7 and C7–T1 intervertebral spaces were planned, running from an anteromedial entry point in a posterolateral direction (Fig. 2A). A power drill was used in the navigated drill guide to drill two pilot holes to a depth of 32 mm (Fig. 2B). The trajectory was confirmed with the neuronavigation. Two K-wires were placed in the holes and a tap was used to enlarge the previously drilled pilot holes. Bilateral 4.0 × 36-mm cannulated lag screws were placed through the tapped holes from the C-6 verte-

FIG. 2. Intraoperative navigation system being used to determine the correct entry point and length of anterior lag screw (A) and the position while drilling the pilot hole for the screw trajectory (B).

bral body, through the C-7 vertebral body, across the fracture, and into the T-1 vertebral body. This was done to gain compression perpendicular to the plane of the fracture and to realign and reduce the fracture fragments. The lag screws were placed with 7-mm washers. The screws were noted to have good purchase. The K-wires were removed.

We selected a 30-mm anterior locking plate to supplement the lag screws and prevent screw backout. We bent the anterior plate to match the patient's hyperlordotic cervical spine. We drilled, tapped, and placed 4.0 × 17-mm variable-angle screws into the C-6 and C-7 vertebral bodies with the plate overlying the lag screws to prevent lag-screw backout (Fig. 3A).

A final O-arm spin was used to confirm the final hardware position placement (Fig. 3B). The spin confirmed screw position and final reduction of the fracture. A single Jackson-Pratt drain was placed in the wound, which was closed in the usual layered fashion. Estimated blood loss was 50 ml, and total time for the procedure was 2 hours.

Postoperative Course

The patient's postoperative neurological examination was stable, with full strength and sensation. The patient tolerated swallowing thin liquids on the day of surgery, passed a dysphagia screen on postoperative Day 1, and was able to consume soft foods. He had no complications during his hospital course. His brace was removed at 3 months after cervical spine flexion-extension radiography confirmed good hardware fixation. At last follow-up, 12

months postoperatively, the patient was living on his own at home and was ambulating independently without neck pain. Cervical spine CT at that time demonstrated good bridging fusion across the interbody space and pedicles (Fig. 4). He remains independent in his activities of daily living.

Discussion

Management decisions for cases of unstable cervicothoracic fractures in elderly patients with high surgical risks can be challenging. There are multiple options for treatment including traction and bed rest, immobilization with a hard cervical collar or halo vest, and surgical fixation. Traction can be very useful for reduction of dislocated fractures.¹⁴ Bed rest is poorly tolerated in the elderly, who need mobilization to maintain functioning. Thus, once reduced, most fractures are managed with immobilization or surgical fixation. The halo vest system is traditionally thought of as the most efficacious form of cervical spine immobilization,²⁹ but it is not without its own complications. These include pin loosening, pin-site infections, sensory nerve injury, pulmonary injury, pressure sores, and aspiration pneumonia.^{16,29} Additionally, a few studies have suggested that motion persists in unstable fracture areas despite the halo vest immobilization.^{15,49} Thus, surgical fixation in patients who can tolerate surgery is the treatment of choice for unstable cervical fractures.

Patients with DISH or AS, in particular, are at high risk

FIG. 3. The technique allows insertion of anterior lag screws and plating system through a small incision with the patient in the supine position (A). A final ICBCT scan confirms the implant position (B).

for unstable low cervical fractures, and they tend to have better outcomes when surgical fixation is performed rather than immobilization alone.⁴⁸ The incidence of DISH is 10.8%–25% in the healthy population.^{25,32,45} Elderly individuals and males are at higher risk of developing DISH.²⁴ Spinal fractures in patients with DISH and AS are often unstable due to the substantial lever created by the fused spine; thus, surgical fixation is the mainstay in treatment. Indeed, in one study, patients treated conservatively had a higher rate of complications, and the 1-year mortality rate was significantly higher in patients treated nonoperatively versus operatively (51% vs 23%).⁵ A variety of surgical approaches have been used to treat these fractures including anterior, posterior, and combined anterior-posterior approaches.^{4,7,8,10,31,34,39,42}

Surgery for fractures in patients with DISH is associated with high surgical risks and morbidity, as these patients

tend to have more medical comorbidities than a younger or healthier population.^{5,43,47} Surgical risks are also elevated in older patients who also have an increased incidence of DISH.^{37,46} Surgical risks, especially cardiopulmonary complications, are exacerbated by the prone positioning needed for posterior fixation.^{23,26} Thus, alternative approaches, whether minimally invasive or anterior-based approaches, are needed to minimize surgical morbidity and operative duration.

Minimally invasive spinal surgery has recently gained popularity and is used to treat patients with cervical fractures and DISH. The presence of DISH alone is an independent risk factor for death after spine fracture.⁴⁶ Patients with spinal fractures and ankylosing disorders such as DISH/AS have also been treated with posterior percutaneous screw/rod fixation without bone grafts given the patients' propensity for bone formation, with good results and low complication rates.^{10,41,50} However, the management of very elderly patients with several medical comorbidities who cannot tolerate prone positioning is problematic.

In this technical note, we described a novel anterior mini-open technique using intraoperative navigation-assisted lag-screw fixation. There are several advantages to this approach, particularly in patients like the gentleman in this case illustration. First, we avoid prone positioning and the associated cardiopulmonary risks. The supine position decreases operative duration and avoids the potential for delayed extubation. Second, the lag-screw technique provides stabilization across the fracture with compression force between the two fractured segments, which is important, given that anterior plating alone may not be sufficient to provide stabilization of the CTJ.³⁵ Third, the

FIG. 4. One-year follow-up sagittal (A) and axial (B) CT scans of the cervical spine demonstrating bony fusion and implant position.

intraoperative CT-based navigation system allows easy access and rapid navigation of the CTJ, an area that is difficult to visualize fluoroscopically due to bony obstruction and the autofused bones in patients with ankylosing spinal diseases.⁴⁴ Finally, use of the intraoperative navigation system decreases radiation exposure to the surgeon and medical staff during spinal implant placement. Lag screws are commonly used to reduce odontoid fractures and to bring transpedicular fractures into union from a posterior approach.^{3,22} However, this is the one of the first reports using a lag screw and anterior plating system for cervicothoracic fractures. This construct worked well and allowed us to reduce potential operative morbidity that is associated with the prone position in an elderly patient with multiple comorbidities.

Conclusions

Rigid fixation is the gold standard for surgical management of patients with cervical fractures and ankylosing spinal diseases. Here, we present a novel anterior mini-open approach using intraoperative navigation-guided lag screw and plate construct, which can be considered as an option for stabilization of fractures at CTJ, even in a 97-year-old patient with medical comorbidities. This approach minimizes operative time and some of the potential morbidities associated with open posterior approaches in the prone position.

References

- Ames CP, Bozkus MH, Chamberlain RH, Acosta FL Jr, Papadopoulos SM, Sonntag VKH, et al: Biomechanics of stabilization after cervicothoracic compression-flexion injury. *Spine (Phila Pa 1976)* **30**:1505–1512, 2005
- An HS, Wise JJ, Xu R: Anatomy of the cervicothoracic junction: a study of cadaveric dissection, cryomicrotomy, and magnetic resonance imaging. *J Spinal Disord* **12**:519–525, 1999
- Apfelbaum RI, Lonser RR, Veres R, Casey A: Direct anterior screw fixation for recent and remote odontoid fractures. *J Neurosurg* **93** (2 Suppl):227–236, 2000
- Balling H, Weckbach A: Hyperextension injuries of the thoracolumbar spine in diffuse idiopathic skeletal hyperostosis. *Spine (Phila Pa 1976)* **40**:E61–E67, 2015
- Caron T, Bransford R, Nguyen Q, Agel J, Chapman J, Bel-labarba C: Spine fractures in patients with ankylosing spinal disorders. *Spine (Phila Pa 1976)* **35**:E458–E464, 2010
- Chapman JR, Anderson PA, Pepin C, Toomey S, Newell DW, Grady MS: Posterior instrumentation of the unstable cervicothoracic spine. *J Neurosurg* **84**:552–558, 1996
- Cooper PR, Cohen A, Rosiello A, Koslow M: Posterior stabilization of cervical spine fractures and subluxations using plates and screws. *Neurosurgery* **23**:300–306, 1988
- Cornefjord M, Alemany M, Olerud C: Posterior fixation of subaxial cervical spine fractures in patients with ankylosing spondylitis. *Eur Spine J* **14**:401–408, 2005
- Daneshvar P, Roffey DM, Brikeet YA, Tsai EC, Bailey CS, Wai EK: Spinal cord injuries related to cervical spine fractures in elderly patients: factors affecting mortality. *Spine J* **13**:862–866, 2013
- El Masry MA, Badawy WS, Chan D: Combined anterior and posterior stabilisation for treating an unstable cervical spine fracture in a patient with long standing ankylosing spondylitis. *Injury* **35**:1064–1067, 2004
- Epstein NE: Commentary: Utility of the O-Arm in spinal surgery. *Surg Neurol Int* **5** (Suppl 15):S517–S519, 2014
- Evans DK: Dislocations at the cervicothoracic junction. *J Bone Joint Surg Br* **65**:124–127, 1983
- Garfin SR, Botte MJ, Waters RL, Nickel VL: Complications in the use of the halo fixation device. *J Bone Joint Surg Am* **68**:320–325, 1986
- Gelb DE, Hadley MN, Aarabi B, Dhall SS, Hurlbert RJ, Roz-zelle CJ, et al: Initial closed reduction of cervical spinal fracture-dislocation injuries. *Neurosurgery* **72** (Suppl 2):73–83, 2013
- Glaser JA, Myers MA, McComis GP, Simons MP, Butler VH, Rust PF: Cervical motion after adding a posterior pad to the halo vest. *Am J Orthop* **29**:557–562, 2000
- Glaser JA, Whitehill R, Stamp WG, Jane JA: Complications associated with the halo-vest. A review of 245 cases. *J Neurosurg* **65**:762–769, 1986
- Ham W, Schoonhoven L, Schuurmans MJ, Leenen LPH: Pressure ulcers from spinal immobilization in trauma patients: a systematic review. *J Trauma Acute Care Surg* **76**:1131–1141, 2014
- Houghton DJ, Curley JW: Dysphagia caused by a hard cervical collar. *Br J Neurosurg* **10**:501–502, 1996
- Hu R, Mustard CA, Burns C: Epidemiology of incident spinal fracture in a complete population. *Spine (Phila Pa 1976)* **21**:492–499, 1996
- Irwin ZN, Arthur M, Mullins RJ, Hart RA: Variations in injury patterns, treatment, and outcome for spinal fracture and paralysis in adult versus geriatric patients. *Spine (Phila Pa 1976)* **29**:796–802, 2004
- Jackson AP, Haak MH, Khan N, Meyer PR: Cervical spine injuries in the elderly: acute postoperative mortality. *Spine (Phila Pa 1976)* **30**:1524–1527, 2005
- Jeanneret B, Gebhard JS, Magerl F: Transpedicular screw fixation of articular mass fracture-separation: results of an anatomical study and operative technique. *J Spinal Disord* **7**:222–229, 1994
- Jules-Elysee K, Urban MK, Urquhart BL, Susman MH, Brown AC, Kelsey WT: Pulmonary complications in anterior-posterior thoracic lumbar fusions. *Spine J* **4**:312–316, 2004
- Julkunen H, Heinonen OP, Knekt P, Maatela J: The epidemiology of hyperostosis of the spine together with its symptoms and related mortality in a general population. *Scand J Rheumatol* **4**:23–27, 1975
- Kagotani R, Yoshida M, Muraki S, Oka H, Hashizume H, Yamada H, et al: Prevalence of diffuse idiopathic skeletal hyperostosis (DISH) of the whole spine and its association with lumbar spondylosis and knee osteoarthritis: the ROAD study. *J Bone Miner Metab* **33**:221–229, 2015
- Kumagai G, Takeuchi K, Aburakawa S, Yokoyama T, Ono A, Numasawa T, et al: Perioperative cardiopulmonary complications after cervical spine surgery in the prone position: the relationship between age and preoperative testing. *Arch Orthop Trauma Surg* **131**:911–916, 2011
- Lieberman IH, Webb JK: Cervical spine injuries in the elderly. *J Bone Joint Surg Br* **76**:877–881, 1994
- Mader R, Sarzi-Puttini P, Atzeni F, Olivieri I, Pappone N, Verlaan JJ, et al: Extraspinal manifestations of diffuse idiopathic skeletal hyperostosis. *Rheumatology (Oxford)* **48**:1478–1481, 2009
- Majercik S, Tashjian RZ, Biffi WL, Harrington DT, Cioffi WG: Halo vest immobilization in the elderly: a death sentence? *J Trauma* **59**:350–358, 2005
- Molinari WJ III, Molinari RW, Khera OA, Gruhn WL: Functional outcomes, morbidity, mortality, and fracture healing in 58 consecutive patients with geriatric odontoid fracture treated with cervical collar or posterior fusion. *Global Spine J* **3**:21–32, 2013
- Mountney J, Murphy AJ, Fowler JL: Lessons learned from cervical pseudoarthrosis in ankylosing spondylitis. *Eur Spine J* **14**:689–693, 2005

32. Nardo L, Lane NE, Parimi N, Cawthon PM, Fan B, Shepherd J, et al: Diffuse idiopathic skeletal hyperostosis association with thoracic spine kyphosis: a cross-sectional study for the Health Aging and Body Composition Study. **Spine (Phila Pa 1976)** **39**:E1418–E1424, 2014
33. Nichols CG, Young DH, Schiller WR: Evaluation of cervicothoracic junction injury. **Ann Emerg Med** **16**:640–642, 1987
34. Payer M: Surgical management of cervical fractures in ankylosing spondylitis using a combined posterior-anterior approach. **J Clin Neurosci** **13**:73–77, 2006
35. Ramieri A, Domenicucci M, Ciappetta P, Cellocchio P, Raco A, Costanzo G: Spine surgery in neurological lesions of the cervicothoracic junction: multicentric experience on 33 consecutive cases. **Eur Spine J** **20** (Suppl 1):S13–S19, 2011
36. Resnick D, Niwayama G: Radiographic and pathologic features of spinal involvement in diffuse idiopathic skeletal hyperostosis (DISH). **Radiology** **119**:559–568, 1976
37. Schoenfeld AJ, Ochoa LM, Bader JO, Belmont PJ Jr: Risk factors for immediate postoperative complications and mortality following spine surgery: a study of 3475 patients from the National Surgical Quality Improvement Program. **J Bone Joint Surg Am** **93**:1577–1582, 2011
38. Schouten R, Lee R, Boyd M, Paquette S, Dvorak M, Kwon BK, et al: Intra-operative cone-beam CT (O-arm) and stereotactic navigation in acute spinal trauma surgery. **J Clin Neurosci** **19**:1137–1143, 2012
39. Shen FH, Samartzis D: Surgical management of lower cervical spine fracture in ankylosing spondylitis. **J Trauma** **61**:1005–1009, 2006
40. Sokolowski MJ, Jackson AP, Haak MH, Meyer PR Jr, Sokolowski MS: Acute mortality and complications of cervical spine injuries in the elderly at a single tertiary care center. **J Spinal Disord Tech** **20**:352–356, 2007
41. Tabaraee E, Gibson AG, Karahalios DG, Potts EA, Mobasser JP, Burch S: Intraoperative cone beam-computed tomography with navigation (O-ARM) versus conventional fluoroscopy (C-ARM): a cadaveric study comparing accuracy, efficiency, and safety for spinal instrumentation. **Spine (Phila Pa 1976)** **38**:1953–1958, 2013
42. Taggard DA, Traynelis VC: Management of cervical spinal fractures in ankylosing spondylitis with posterior fixation. **Spine (Phila Pa 1976)** **25**:2035–2039, 2000
43. Verlaan JJ, Westerveld LA, van Keulen JW, Bleys RLAW, Dhert WJ, van Herwaarden JA, et al: Quantitative analysis of the anterolateral ossification mass in diffuse idiopathic skeletal hyperostosis of the thoracic spine. **Eur Spine J** **20**:1474–1479, 2011
44. Wang VY, Chou D: The cervicothoracic junction. **Neurosurg Clin N Am** **18**:365–371, 2007
45. Weinfeld RM, Olson PN, Maki DD, Griffiths HJ: The prevalence of diffuse idiopathic skeletal hyperostosis (DISH) in two large American Midwest metropolitan hospital populations. **Skeletal Radiol** **26**:222–225, 1997
46. Westerveld LA, van Bommel JC, Dhert WJA, Oner FC, Verlaan JJ: Clinical outcome after traumatic spinal fractures in patients with ankylosing spinal disorders compared with control patients. **Spine J** **14**:729–740, 2014
47. Westerveld LA, Verlaan JJ, Oner FC: Spinal fractures in patients with ankylosing spinal disorders: a systematic review of the literature on treatment, neurological status and complications. **Eur Spine J** **18**:145–156, 2009
48. Whang PG, Goldberg G, Lawrence JP, Hong J, Harrop JS, Anderson DG, et al: The management of spinal injuries in patients with ankylosing spondylitis or diffuse idiopathic skeletal hyperostosis: a comparison of treatment methods and clinical outcomes. **J Spinal Disord Tech** **22**:77–85, 2009
49. Whitehill R, Richman JA, Glaser JA: Failure of immobilization of the cervical spine by the halo vest. A report of five cases. **J Bone Joint Surg Am** **68**:326–332, 1986
50. Yeoh D, Moffatt T, Karmani S: Good outcomes of percutaneous fixation of spinal fractures in ankylosing spinal disorders. **Injury** **45**:1534–1538, 2014

Disclosures

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Conception and design: Mummaneni, Ohya, Vogel, Berven. Acquisition of data: all authors. Analysis and interpretation of data: Mummaneni, Ohya, Bray, Magill, Vogel. Drafting the article: Ohya, Bray, Magill, Vogel. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Mummaneni. Study supervision: Mummaneni.

Supplemental Information

Videos

Video 1. <https://vimeo.com/220793256>.

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