Surgical Technique

Multi-rod fixation in spinal neuroarthropathy: a novel surgical technique

Michael Fiechter, Denis Bratelj, Phillip Jaszczuk, Crescenzo Capone, Cristian Dragalina, Tobias Pötzel

Department of Spine Surgery, Swiss Paraplegic Center, Nottwil, Switzerland

Correspondence to: Michael Fiechter, MD, PhD. Deputy Head, Department of Spine Surgery, Swiss Paraplegic Center, Nottwil, Switzerland. Email: michael.fiechter@paraplegie.ch.

Abstract: Spinal cord injury (SCI) leads to compromised biomechanical stability due to impaired neuroprotection. This may trigger deformity and destruction of multiple segments of the spine which is known as spinal neuroarthropathy (SNA) or Charcot arthropathy. Surgical treatment of SNA is highly demanding in terms of reconstruction, realignment, and stabilization. In particular, construct failure due to the combination of high shear forces and reduced bone mineral density in the lumbosacral transition zone is a frequent complication in SNA. Notably, up to 75% of SNA patients need multiple revisions within the first year after surgery in order to achieve successful bony fusion. The purpose of this technical report is to present a novel surgical approach with higher overall construct stability to efficiently treat SNA and avoiding repetitive revisions. The new technique of triple rod stabilisation of the lumbosacral transition zone in combination with the introduction of tricortical laminovertebral (TLV) screws is demonstrated in three patients with complete SCI of the thoracic spinal cord. After surgery all patients reported an improvement of the Spinal Cord Independence Measure III (SCIM III) and none of the reported cases showed construct failure within an at least 9 months follow up period. Although TLV screws violate the integrity of the spinal canal, there were no complications with regard to cerebral spinal fluid fistulas and/or arachnopathies so far. The new concept of triple rod stabilization in combination with TLV screws provides improved construct stability in patients with SNA and thus could help to reduce revision and complications rates and improve patient outcome in this disabling degenerative disease.

Keywords: Spinal neuroarthropathy (SNA); Charcot arthropathy; tricortical laminovertebral screws (TLV screws); multi-rod constructs; surgical technique

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Introduction

Spinal neuroarthropathy (SNA; also known as Charcot arthropathy of the spine) is a severe degenerative disease with progressive destruction of vertebral joints causing deformity of the spine and pain (1-3). The loss of neuroprotective elements (such as deep sensation and nociceptive pain) in spinal cord injury (SCI), compromises biomechanical stability of the spine and is acknowledged as the main cause of SNA. Due to late onset of SNA after SCI, slow progression, and unspecific symptoms, diagnosis of SNA is often made years after SCI and usually at an advanced stage with severe destruction of the affected elements of the spine. As SNA is a progressive disease and resulting symptoms such as sitting instability, exacerbating spasticity, severe neuropathic pain, and pressure marks/ulcers due to spinal deformity are highly disabling, frequently a surgical treatment strategy by long construct stabilisation and circumferential fusion with realignment of the spine is required. Due to missing deep sensation in SCI patients with high mechanical shear stress in regions lacking neuroprotection and often reduced bone mineral density (4), construct failure rates are high in SNA patients resulting in increased revision rates of up to 75% (5).

As a consequence, sophisticated and alternative surgical techniques are required to overcome this issue (6). In this technical note, we present three clinical cases who underwent to our knowledge a novel surgical technique with triple rod fixation of the lumbosacral transition zone using additionally tricortical laminovertebral (TLV) screws for improved stability of the fusion constructs in order to optimize outcome and potentially reduce excessive revision rates. We present this article in accordance with the SUPER reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-22-103/rc) (7).

Preoperative preparations and requirements

Surgical procedures are classified as open techniques under general anaesthesia and were all performed in the Swiss Paraplegic Center (a tertiary care centre for spine surgery) by an interdisciplinary team of senior neuro- and orthopaedic surgeons. Surgical access was established by classic midline incision under sterile conditions in the operating theatre in knee elbow position. Blood loss was rigorously controlled by application of Aquamantys™ bipolar sealers (Medtronic) and by recycling with a cell saver. Screw placement was performed by assistance of X-ray and/or navigation (O-arm™ system, Medtronic) and the CD Horizon™ Solera™ spinal stabilization system (Medtronic). As intervertebral spacers either an anterior lumbar interbody fusion (ALIF) cage (Titan Endoskeleton™, Medtronic) or a transforaminal lumbar interbody fusion (TLIF) cage (Acron, PEEK-titan coated, Acron Medical) was implanted.

Highlight box

Surgical highlights

- In patients with complete SCI and development of SNA, triple rod stabilization in combination with TLV screws provide improved construct stability with decreased revision rates.

What is conventional and what is novel/modified?

- Circumferential fusion using single or double rod constructs are perceived as the standard of care in the treatment of SNA. However, 75% of patients need multiple revisions within the first year of surgery.
- By the use of triple rods and TLV screws, the strength of the fusion construct is increased with better distributed shear forces and consequently improved stability over the SNA region.

What is the implication, and what should change now?

- We introduce a novel surgical technique with a new type of screw to improve construct strength in SNA and potentially reduce revision rates. The technique provides a novel option of treatment in SNA of the lumbosacral transition zone.

Step-by-step description

Surgical case 1

A 63-year-old man with a complete SCI sub thoracic vertebra 6 [Th6; Asia Impairment Scale (AIS), grade A] since 1980 presented with invalidating spasticity along with neuropathic pain and sitting instability in the last 2 years. As symptoms were progressive within months and imaging revealed a severe destruction of the 4th to the 5th lumbar segment (L4/5) suggestive for SNA (*Figure 1A-1D*), indication for surgical management was warranted. Due to advanced osteolysis of lumbar vertebra 5 (L5) with severe destruction of the vertebral body, a vertebral column resection (VCR) of L5 with column shortening of L4 to sacral vertebra 1 (S1) was justified. The Spinal Cord Independence Measure III (SCIM III) before surgery was 29 and the Fracture Risk Assessment Tool (FRAX) revealed an intermediate risk for 10-year probability of fracture. The surgery was performed in a staged fashion with instrumentation from Th10 to pelvis in a first step and VCR L5 in a second step (interval of 10 days). Column shortening of L4 to S1 was achieved by using compression and distraction clamps on rods in parallel linked with side-to-side domino connectors over the SNA region. To ensure bony contact an ALIF cage (24° lordotic) was implanted in a reversed orientation to achieve kyphosis of the lower lumbar segments for optimal sitting position in the wheelchair. In a final step and to ensure maximal construct stability over the SNA region, TLV screws were placed in L4 and connected to the main rod by side-to-side domino connectors as well as to the pelvic screws (*Figures 1E,1F,2*). Finally, the lumbosacral transition zone including the SNA region were stabilized by triple rod constructs on both sides. The following hospitalization of the patient was uneventful. The postoperative follow up presented a stable situation until 3-month after surgery. Unfortunately, the patient has then accidentally fallen out of his wheelchair and suffered from a fracture of Th9 and Th10 without any signs of construct failure over the former SNA region. The construct was subsequently extended to Th3 and the cranial were linked to the caudal rods by side-to-side domino connectors. In the 12-month follow-up visit, the whole construct is still stable without any signs of failure and SCIM III improved to 45.

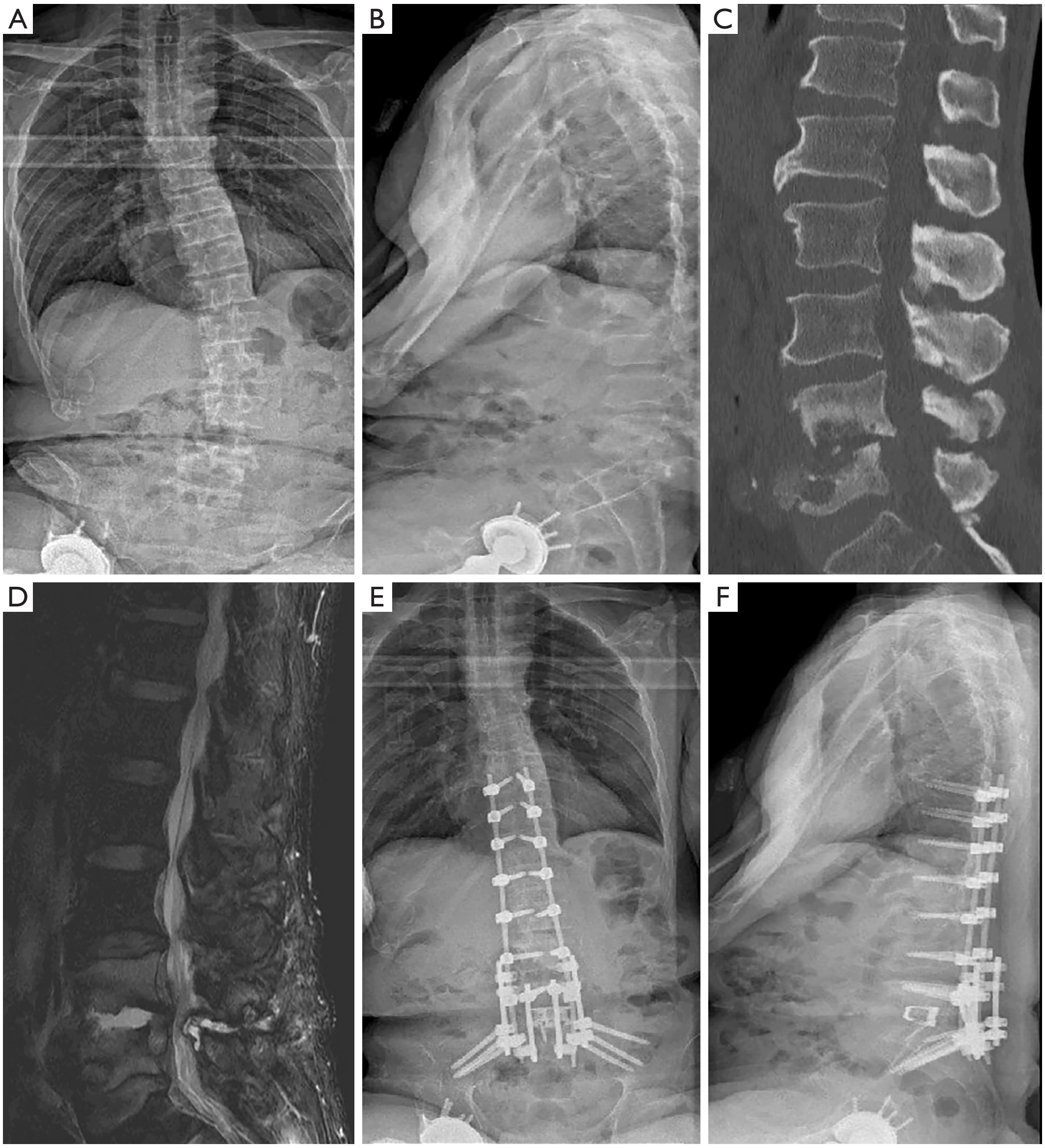

Figure 1 SNA of the segment L4/5 (patient 1). Whole spine X-ray view [coronal (A); sagittal (B)] show collapse of the segment L4/5 due to an advanced stage of SNA. Complete dorsoventral dissociation of the segment L4/5 with advanced osteolysis of both vertebras L4 and L5 in CT (C) together with an activated osteochondrosis in MRI (D) is illustrated. A long construct stabilization from Th10 to pelvis with lumbar realignment in kyphosis, VCR of L5, column shortening between L4 and S1, and triple rods over the lumbosacral transition zone including TLV screws in L4 was performed [coronal (E); sagittal (F)]. Note the inversely implanted ALIF cage (24° lordotic) which both provides ventral support in the SNA region and bony contact for successful fusion and leads to a kyphotic realignment of the lumbar spine. SNA, spinal neuroarthropathy; L4/5, the 4th to the 5th lumbar segment; L4, lumbar vertebra 4; L5, lumbar vertebra 5; CT, computed tomography; MRI, magnetic resonance imaging; Th10, thoracic vertebra 10; VCR, vertebral column resection; S1, sacral vertebra 1; TLV, tricortical laminovertebral; ALIF, anterior lumbar interbody fusion.

Surgical case 2

A 56-year-old man with a complete thoracic SCI sub Th8 (AIS grade A) in 1988 was referred for further evaluation due to progressive sitting instability with a cracking noise during transfers and abdominal sweating. Repetitive readjustments of the wheelchair did not resolve the issue.

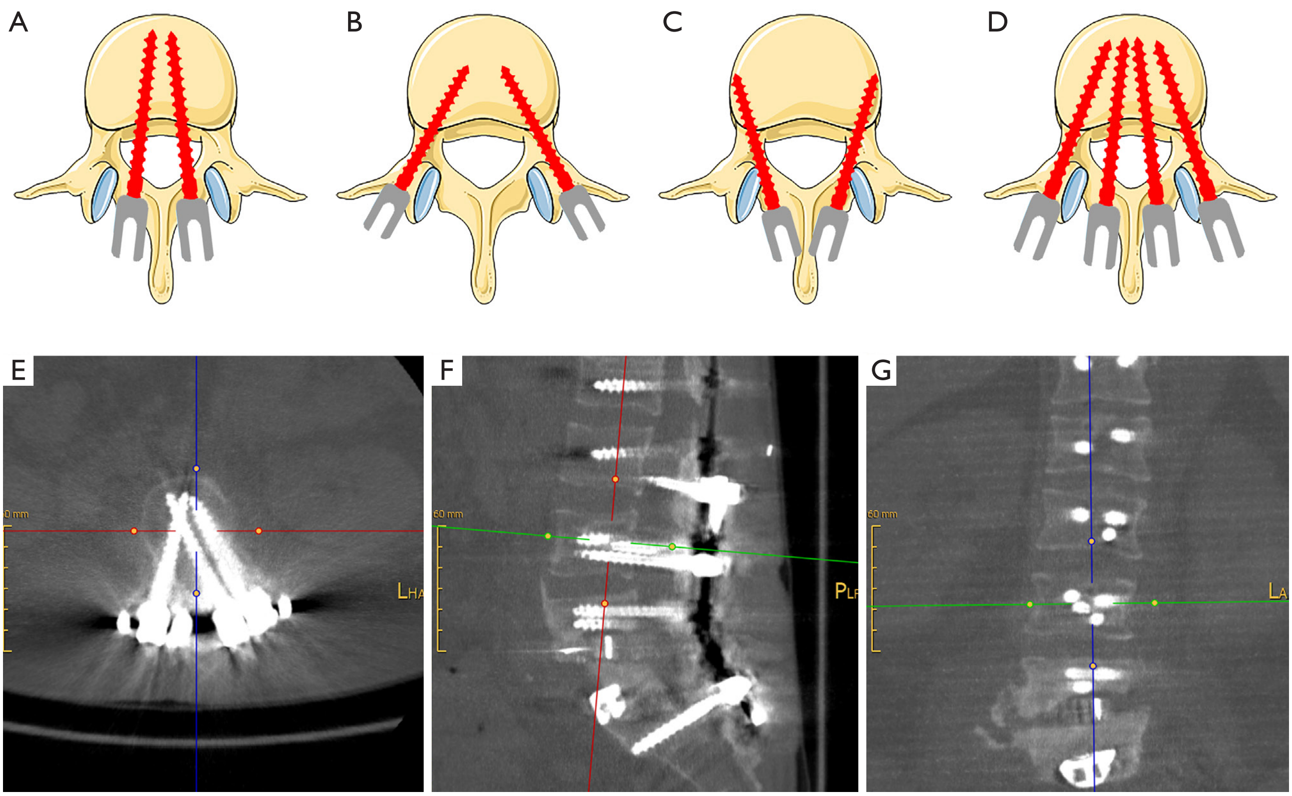

Figure 2 Lumbar screw types in spine surgery. Various placements of lumbar screws are illustrated as TLV screws (A), pedicle screws (B), and cortical trajectory screws (C). Of note, the combination of pedicle with TLV screws (D) provides improved overall screw hold. The trajectory of the TLV screws (in parallel to pedicle screws) is shown in axial (E), sagittal (F), and coronal view (G). Note the tricortical placement of the TLV screw by crossing the dorsal as well as the ventral aspect of the laminar cortical bone including the dorsal cortical bone of the vertebral body. The tricortical placement of the TLV screw leads to increased screw hold and thus diminished rate of screw loosening, pull out's, and finally construct failure. The parallel placement of pedicle screws next to TLV screws allows improved construct stability (D-G). The figure was partly generated using Servier Medical Art, provided by Servier, licensed under a Creative Commons Attribution 3.0 unported license. L_{HA}, left, head, anterior; P_{LF}, posterior, left, foot; L_A, left, anterior; TLV, tricortical laminovertebral.

Imaging revealed a SNA with moderate destruction of the 5th lumbar to 1st sacral segment (L5/S1) with advanced osteochondrosis and vacuum phenomena (*Figure 3A-3D*). As the clinical symptoms were progressively disabling for the patient (SCIM III of 40, FRAX with low risk for 10-year probability of fracture), a surgical management was decided for and conducted in a single stage procedure. The construct length was chosen from Th9 to pelvis according to the patients SCI level. Again, lumbar kyphosis was achieved by reverse implantation of an ALIF cage (24° lordotic) in the segment L5/S1. TLV screws were placed in L4, L5, and S1, and connected by rods to S1 screws on both sides. Finally, the lumbosacral transition zone including the SNA were stabilized and fused by triple rod constructs bilaterally (*Figure 3E,3F*). The following hospitalization was without any complications and the patient's follow-up was without signs of construct failure up to 9 months after surgery with an improvement of SCIM III to 53.

Surgical case 3

A 37-year-old man with a complete thoracic SCI sub Th10 (AIS grade A) since 2012 reported with repetitive pressure ulcers on the buttocks with severe sitting instability. Imaging revealed an advanced SNA with a severe destruction of the segment L4/5, osteolysis of the vertebral body L4 and dislocation/instability (*Figure 4A-4D*). After successful secondary healing of the pressure ulcers during hospitalization, a surgical management of the SNA was conducted. The SCIM III before surgery was 32

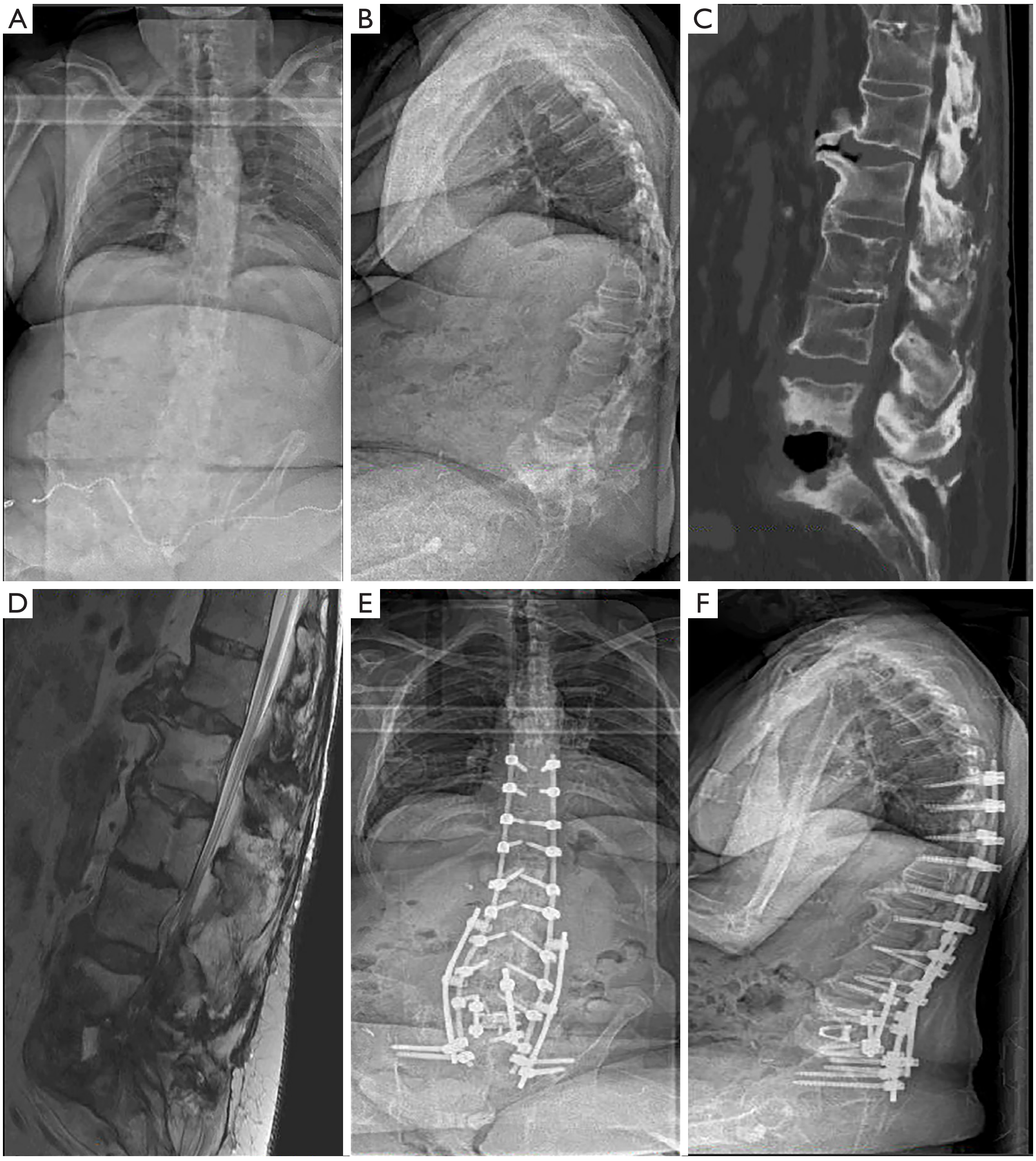

Figure 3 SNA of the segment L5/S1 (patient 2). Lumbosacral dissociation is visualized in coronal (A) and sagittal (B) whole spine X-rays. Mild osteolysis with osteosclerosis including vacuum phenomena of L5 and S1 in CT (C) and activated and advanced stage osteochondrosis in MRI (D) are illustrated. Finally, a long spine construct from Th9 to pelvis was performed with an inverse ALIF cage in L5/S1 (24° lordotic), TLV screws in L4, L5 and S1, and triple rod fixation over the SNA region including the lumbovertebral transition zone [coronal (E); sagittal (F)]. SNA, spinal neuroarthropathy; L5/S1, the 5th lumbar to 1st sacral segment; L5, lumbar vertebra 5; S1, sacral vertebra 1; CT, computed tomography; MRI, magnetic resonance imaging; Th9, thoracic vertebra 9; TLV, tricortical laminovertebral; L4, lumbar vertebra 4; ALIF, anterior lumbar interbody fusion.

and FRAX revealed a low risk for 10-year probability of fracture. Initially, a construct length of Th11 to pelvis with a VCR L4 and implantation of an expandable interbody cage was performed. After 3 weeks, wound-healing was not satisfying. Further, imaging revealed a cage dislocation and as such a construct failure. After revision surgery with refixation of the lumbosacral transition zone by double rod constructs including exchange and repositioning of the

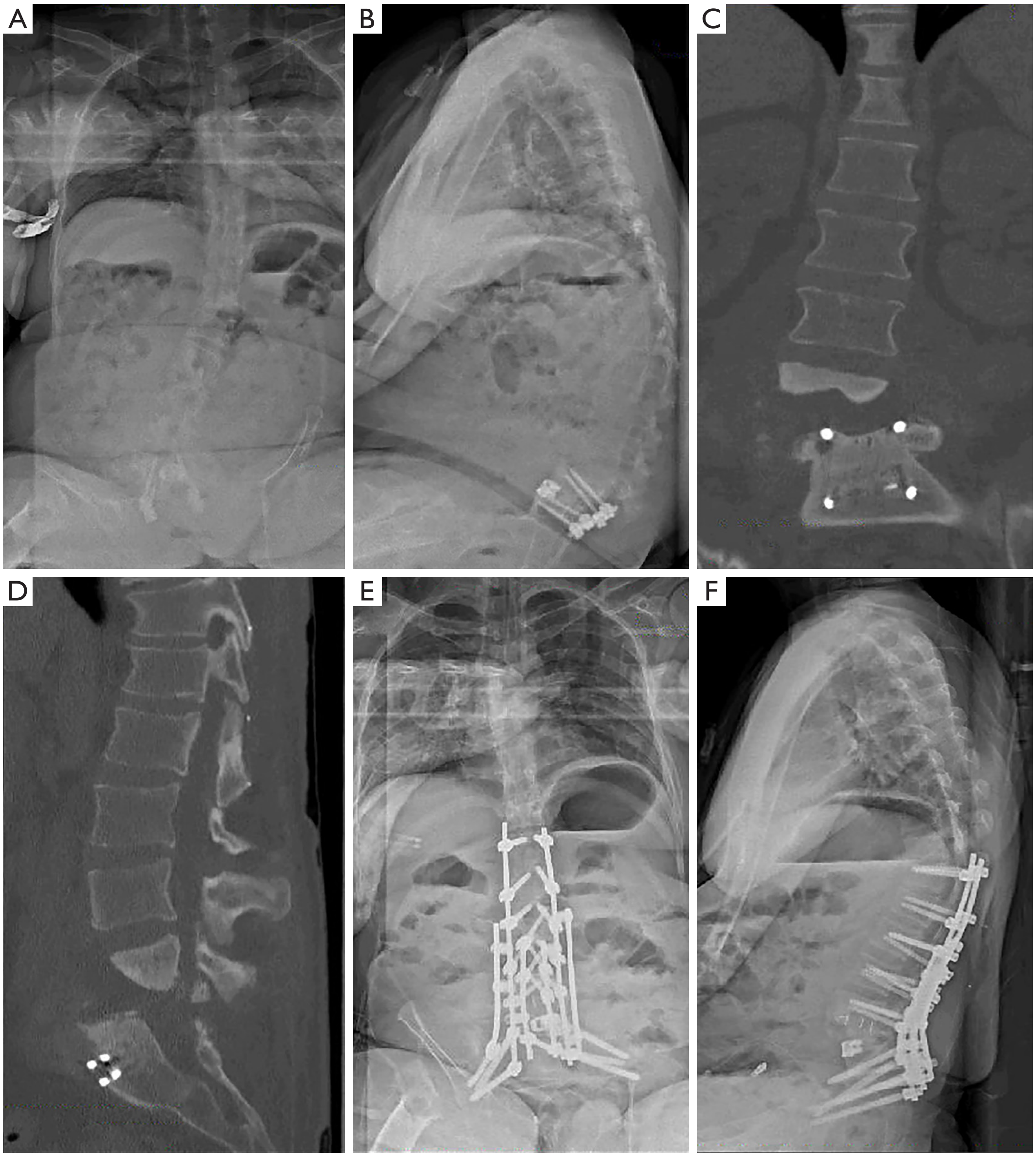

Figure 4 SNA of the segment L4/5 (patient 3). A severe form of SNA in L4/5 is demonstrated in whole spine X-rays and CT, respectively [coronal (A,C); sagittal (B,D)]. Reconstruction and lumbar kyphotic realignment were achieved by a fixation from Th11 to pelvis with TLV screws in L2, L3, L5, and S1, VCR of L4 including column shortening, and triple rod fixation over the SNA region [coronal (E); sagittal (F)]. A TLIF cage was placed between L3 and L5 to achieve bony contact. SNA, spinal neuroarthropathy; L4/5, the 4th to the 5th lumbar segment; CT, computed tomography; Th11, thoracic vertebra 11; TLV, tricortical laminovertebral; L2, lumbar vertebra 2; L3, lumbar vertebra 3; L5, lumbar vertebra 5; S1, sacral vertebra 1; VCR, vertebral column resection; TLIF, transforaminal lumbar interbody fusion.

cage, the construct failed again after 4 weeks. A second re-instrumentation was performed with column shortening between L3 to L5 using linked rods in parallel and side-to-side domino connectors. To establish a stable bony contact between L3 and L5 a TLIF cage (20° lordotic) was implanted with the use of bone morphogenetic protein. TLV screws were placed in L2, L3, L5, and S1, and a triple rod construct on both sides with kyphotic alignment of the lumbar spine was achieved (*Figure 4E,4F*). Following the final surgery, the further hospitalization was uneventful the patient showed a stable construct after 9 months of follow-up as well as an increase of SCIM III to 62.

Postoperative considerations and tasks

After surgery, patients were monitored for at least 24 hours on the intensive care unit (ICU). Mobilization of patients into their wheel chair was subject to the following limitations for 6 weeks: patient transfer only with aid, hip flexion of maximally 90 degrees, and omission of lumbosacral rotation. The mean hospital stay was 14 days followed by a rehabilitation of several weeks. Regular clinical and whole-spine X-ray exams were performed directly after surgery and at regular intervals of maximally 3 months.

Tips and pearls

With regard to clinical practice, our technique of triple rods and TLV screws should primarily be considered in any cases of SNA with moderate to advanced destruction of the lumbosacral transition zone (L4-S1). Additionally, the following three recommendations should be respected before applying our technique: First, only SNA patients with a complete thoracic SCI (AIS grade A) without any relevant residual neurologic function in and below the lumbosacral transition zone should undergo placement of TLV screws. TLV screws violate the spinal canal and could potentially deteriorate residual neurological function in patients with partial SCI. However, in patients with moderate to advanced SNA usually only remnants of neurologic structures are present due to advanced and atrophic destruction of the SNA region. Second, in mild cases of SNA with only minimal destruction, long spinal constructs with adequate anterior and posterior stabilization including single or double rods should result in sufficient construct stability for successful fusion. In cases of moderate to advanced destruction of the SNA region and necessity for a partial or complete VCR with column shortening in order to establish sufficient bony contact for fusion, our technique might provide decreased construct failure rates due to improved stability with better distribution of shear forces. Finally, concerning the permanent sitting position of patients with a complete SCI, the lumbar alignment should aim for kyphosis and not lordosis as routinely applied in the walking population, and the length of constructs should ideally include the level of SCI to reduce the risk of proximal junctional failure (due to preserved sensory feedback mechanisms). Introduction of lordosis according to the current guidelines of sagittal alignment and balance will inevitably lead to a suboptimal sitting position in the wheelchair and thus significantly increase shear forces in the lumbosacral transition zone with higher risk of construct failure.

All procedures performed in this study were in accordance with the ethical standards of the institutional review board (No. KEK 2022-01293) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from each patient for publication of the reported clinical cases and accompanying images (and is available upon written request under consideration of data privacy in respect to national law).

Discussion

Construct failure in SNA is a common complication and the main reason for manifold revision surgeries. In particular, the lumbosacral transition zone is subject to highest axial loading and shear forces. In combination with SCI and the associated missing neuroprotection of the spine below the level of injury, fusion constructs are subject to great strains and thus need to be of maximal stability in order to allow an SNA to fuse and finally heal. Although circumferential fusion with long constructs is regarded as the gold standard in surgical treatment of the disease, and patients usually improve after such interventions, solid long-term outcome data is mostly missing due to the rarity of SNA (6). Notably, over 75% of surgically treated SNA patients need multiple revision surgeries within the first year to achieve successful bony fusion (5). In this technical note, we present three surgical cases suffering from SNA who underwent successful and novel triple rod lumbosacral fixation using TLV screws (*Figure 2A,2D-2G*), additionally. None of the patients were subject to construct failure in whole-spine X-rays within an at least 9-month follow up period. Of note, the well-accepted rules of sagittal balance of the spine in the walking population (8) apply only in an upright and standing but are of limited use in a sitting position. In the sitting position, the lumbar aspect of the spine becomes kyphotic while the pelvis is retroverted. In SCI patients, the aim for a kyphotic realignment of the lumbar spine is thus critical for optimal sitting in a wheelchair and to avoid construct failure.

Achievement of bony fusion is the key of treatment in SNA but also in many other pathologies of the spine. This goal can only be reached if the stabilized segments are not subject to micro-instability due to missing ventral support or insufficient dorsal instrumentation. Thus, whenever bony contact cannot be established, an implantation of a cage is nowadays regarded as the standard of care to promote fusion and omit construct failure (9). Here, several bone stimulators are used as an adjunct to promote bone growth. Recently, dibotermin alfa, a recombinant human bone morphogenetic protein-2 (rhBMP-2), has been documented as effective bone growth promoting agent which is also cost-effective (10,11). In SNA, the use of rhBMP-2 might further help to prevent non-union and thus construct failure. Apart from the interposition of cages as ventral support, the rigidity of the dorsally implanted rods and the screw hold are at least equally important to promote fast and solid fusion (12). Rods are available in different alloys of metals, whereas Cobalt chromium (CoCr) is presently one of the most widely used metal alloy when a high stiffness of the rod is important (i.e., reposition of traumatic fractures of the spine, adolescent scoliosis correction surgeries). Although in degenerative spine, increased rod stiffness is known to correlate with screw loosening, in SNA we nevertheless recommend the use of 6.0 mm CoCr rods over the SNA region to reach maximal stability of the constructs and to avoid rod breakage and construct failure. Additionally, the approach to use three rods in parallel on both sides of the SNA, gradually reduces the forces on each implant and thus apparently diminishes the risk of construct failure. In combination with one S2 alar iliac (S2AI) and two iliac screw per side, the three rods are not just used as parallel construct to the main rod but as partly independent extra rods to reduce shear forces, distribute forces on the different rods, and thus strengthen the stability over the SNA and lumbosacral transition zone.

Presently, pedicle screws (*Figure 2B*) are the most frequently used type of screws in thoracolumbar instrumented cases (13). Newer developments and successful application of navigation have further allowed save and accurate placement of cortical bone trajectory (CBT; *Figure 2C*) screws which are supposed to provide better screw hold in particular in cases of osteoporosis (14,15). Finally, transdiscal pedicle screws (16) provide a third option of lumbar pedicle screws with improved screw hold (often used in high-grade spondylolisthesis). However, this type of screw limits adequate lumbar realignment including column shortening after a potential VCR. Further, only the tip of the screw is placed in the adjacent upper vertebral body while the vertebral bone quality around the SNA zone is usually poor and screw hold might be limited. In this technical note, we introduce TLV screws (*Figure 2A,2D-2G*) which have so far and to our knowledge not been documented in the present literature. The combination of pedicle and TLV screws allows placement of four screws per vertebral body (two per side) which increases anchoring strength and distributes shear forces on multiple rods (*Figure 2D*). Although in patients without SCI or incomplete SCI, the placement of TLV screws would be regarded as misplaced screws and inevitably violate the integrity of the spinal canal and thus potentially harm neurologic structures, in complete SCI patients (AIS grade A), neurological function below the level of injury is not endangered. The fact that the screw is crossing both cortical bones of the lamina including the dorsal cortical bone of the vertebral body renders it a tricortical screw which apparently provides significantly improved screw hold as compared to other screw types. In particular, this is supported by the fact that the main screw hold is due to the cortical and not due to the spongiotic bone (17). As for the violation of the spinal canal and potential cerebrospinal fluid (CSF) fistula, the successful placement of a TLV screw is self-tapping a potential CSF loss. Further, in SNA cases of moderate to advanced destruction of the vertebral column, neurologic structures around the SNA region are frequently highly atrophic with usually complete obstruction of the spinal canal in cases of lumbosacral dislocation which renders the risk for a CSF fistula to a minimal level. Notably, none of the reported three patients reported orthostatic symptoms or symptomatic CSF fistula. Finally, our proposed technique of TLV screws in combination with pedicle screws provides an option of improved screw hold per vertebral segment (*Figure 2D*) in moderate to advanced SNA. In consideration of the current revision rates of over 75% in 1 year (5) including the potential complications for repetitive surgeries (i.e., infections, wound healing issues, etc.), the risk of TLV screws to impose negative effects on the patients is perceived lower than the risks for repetitive revision surgeries due to construct failures. In combination with the here newly introduced concept of lumbar triple rod fixation over the SNA region including the lumbovertebral transition zone, TLV screws increase the hold of the construct and help to distribute shear forces over the parallel implanted rods.

As this is a technical note with a case series of three patients, limitations need to be pointed out: firstly, this a descriptive study without any statistical analysis. As such all conclusions made in this study are concept generating and should not be generalized to the main population of patients suffering from SNA. Secondly, the new technique to place TLV screws and thus potentially violate the integrity of the spinal canal might represent a two-edged sword. We cannot estimate whether intractable CSF fistulas or even symptomatic arachnopathies could be triggered by this approach. Thus, the indication to place TLV screws has to be evaluated with caution and should be reserved for patients with moderate to advanced SNA. Further, visual confirmation for successful bony fusion is not available for the three cases, however, the fact that the patients are well-controlled without any clinical or imaging signs of construct failure allows the conclusion that the constructs are sufficiently stable and bony fusion should be at least in progress. Finally, there is a need for prospective trials with higher patient numbers and longer follow-ups in order to validate our findings. However, as SNA is very rare disease and cases qualifying for use of triple rods and TLV screws are even more seldom, the conduction of such a study might be a great challenge and could probably only reach sufficient patient numbers in a multicenter and international setting.

Conclusions

Although SNA is a rare degenerative disease in SCI patients it leads to severe deformity and disability of the spine. The here newly introduced concept of triple rod fixation over the SNA region including the lumbovertebral transition zone in combination with the TLV screws provide an increased construct strength due to better distribution of shear forces. This novel surgical technique potentially could help to reduce extensive revision rates with overall better patient outcomes and reduced costs in this disabling degenerative disease.

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Footnote

Reporting Checklist: The authors have completed the SUPER reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-22-103/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-22-103/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work and in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in this study were in accordance with the ethical standards of the institutional review board (No. KEK 2022-01293) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from each patient for publication of the reported clinical cases and accompanying images (and is available upon written request under consideration of data privacy in respect to national law).

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