CASE REPORT

Massive Tibial Defect Treated with Plate-assisted Bone Segment Transport and A Novel Internal Cable–Pulley System

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Abstract

Aim: The treatment of massive diaphyseal tibial bone defects remains challenging with poor results seen from treatment modalities other than bone transport (BT). Current methods of BT require lengthy periods in a circular external fixator. Despite recent modifications in BT techniques via circular external fixator such as multifocal transport and immediate intramedullary nailing after docking, circular external fixation remains poorly tolerated with a high complication profile. Newer technologies such as magnetic lengthening nails have shown promise to provide alternatives to BT without resorting to long-term circular external fixation. Plate-assisted bone segment transport (PABST) has demonstrated success as an all-internal BT technique. Prior case reports have shown a modest ability to treat massive defects with varying success.

Technique: A novel all-internal cable and pulley augmentation to a PABST technique for a massive (185 mm) tibial defect was utilised during a retrograde transport. The authors describe a patient scenario in which this augment allowed continued transport that could not be treated with an additional Precice nail recharge.

Conclusion: Augmentation of PABST with a cable and pulley construct can successfully treat massive diaphyseal defects.

Clinical significance: This cable and pulley modification to PABST allows for the treatment of massive tibial defects without the need for magnetic lengthening nail exchange or conversion to external fixation.

Keywords: Bone transport, Cable transport, Case report, Limb salvage, Magnetic lengthening nail, Plate-assisted bone segment transport.

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Introduction

Orthopaedic surgeons continue to face challenges treating large tibial bone defects from trauma, tumour resection, and after debridement for infection.[1,2] There have been several approaches to repair critically sized bone defects including bone grafting, vascularised bone transfer, structural bone graft cages, formation of an induced pseudomembrane with subsequent bone grafting (i.e., masquelet technique), bone transport (BT) via distraction osteogenesis (DO), and amputation.[1–4] The treatment chosen ultimately depends on the size and location of the defect, but DO has proven reliable for treating large bone defects.[3] Historically, DO has been performed with the use of a circular external fixator and the Ilizarov technique (IT): A low-energy corticotomy followed by a latency period before actuating distraction at the corticotomy site.[5] The IT, while generally considered safe and effective, is associated with several potential complications, such as nerve damage, joint contracture, pin site infections, and scarring from the pin tracks.[6,7] Poor patient tolerance has been well documented with DO via circular fixation techniques, with one systematic review suggesting that although amputation rates are low, the majority of amputations were voluntary.[8]

New advances in DO utilising all-internal techniques have aimed at mitigating the complications of circular fixation.[9] Plate-assisted bone segment transport (PABST) has been described recently for osseous reconstruction.[10,11] Unlike the IT, which uses an external fixator to stabilise the bone, PABST uses a magnetically driven telescoping intramedullary nail to perform BT in combination with a plate only affixed to the most proximal and distal aspects of the affected bone in order to provide stability during the transport process. This technique eliminates the need for bulky external fixation and the risk of pin site infection encountered with the IT while simultaneously improving patient satisfaction.[12] An all-internal BT device (the Bone Transport Nail, NuVasive Specialised Orthopaedics, Inc.) has been described in two separate case series, although the implant is not currently available in the United States market at the time of writing this manuscript.[3,13]

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Although all-internal BT has changed the landscape of distraction osteogenesis in managing bone defects, it does not come without challenges, such as technical difficulty, cost, weight-bearing limitations, and limited facility for secondary correction of bone deformities or limb length discrepancies.

The Precice nail (NuVasive Specialised Orthopaedics, Inc.) used in PABST allows up to an 80 mm stroke length before needing to be 'recharged'. This has limited the overall defect size that can be treated with this technique. There have been some descriptions of supplementing the magnetic nail with cables for modest gains with the largest tibial defect treated with PABST being 150 mm.[14,15] The authors present a novel cable and pulley augmentation to the PABST technique which can allow for a substantially higher amount of transport than previously described without resorting to a magnetic nail exchange or conversion to external fixation.

Materials and Methods

The PABST technique has been described in the management of critically sized bone defects secondary to trauma, infection, or malignancy in the tibia and femur provided there has been prior elimination of residual infection and a soft tissue envelope amenable to an intramedullary device and plating.[9,11,12] For BTs greater than 80 mm or when the Precice nail has reached its stroke length limit but further transport is required, a 'recharge' can be performed. The patient is brought back to the operating room and a temporary unicortical screw is percutaneously placed into the transporting segment through the plate to prevent rebound of the transporting segment through the soft regenerate. The interlocking screws of the moving end of the Precice nail are removed and the nail is run in the reverse direction with an external magnet to reset the Precice nail position (see Figure, Supplemental Fig. 1, which demonstrates a Precice nail recharge). New interlocking screws are placed in the transporting segment so the transport may continue after the temporary locking screw is removed.

Technique

The patient is positioned supine on a radiolucent table with an ipsilateral hip support bag. All contamination or existing infection must have been eradicated before proceeding with implantation. The exposed bone ends are planed with an oscillating saw cooled with constant irrigation perpendicular to the mechanical axis to allow for optimal bony contact once BT has been completed.[3] An antibiotic-impregnated cement spacer may be placed within the defect to allow for calibrated full-length radiographs to be obtained for operative planning (Fig. 1).

After the appropriate amount of bone resection has been performed and the tibia is then positioned to ensure that length, alignment, and rotation are correct, the plate should be positioned ensuring screw placement proximal and distal to the corticotomy will not impede the path of the nail. At the planned corticotomy site, multiple drill holes are created with a 4.2 mm drill bit in preparation for the corticotomy. These perforations also allow for the deposition of autograft during the reaming process.[16] The bone is reamed 2.0 mm greater than the anticipated nail diameter. The Precice nail is then inserted and the end is positioned just proximal to the corticotomy site. The corticotomy is completed and the nail is then advanced to the appropriate depth and interlocking screws are inserted (Fig. 2). Once all implants are secured, a distraction of 0.5–1 mm of the corticotomy is performed to fluoroscopically confirm nail function and then retracted to its original position.[3]

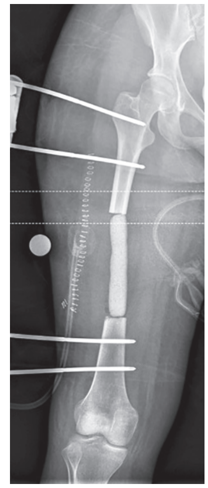


Fig. 1: A 13 cm midshaft femoral diaphyseal defect with an antibiotic-impregnated cement spacer after planning the fracture site

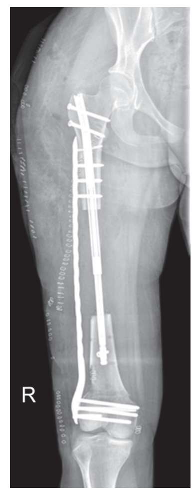


Fig. 2: Immediate post-operative A/P femur radiograph demonstrating a PABST technique with a distal femur plate, fully extended antegrade Precice nail, and a distal femoral corticotomy prior to initiation of a retrograde transport

Transport begins after a 7–10-day latency period and can be started at 0.25 mm two to three times daily. Depending on the quality of the regeneration, the rate may be increased or decreased at the surgeon's discretion. Patients are reviewed weekly or bi-weekly with radiographs to ensure satisfactory progress with the BT (Fig. 3).

Cable and Pulley Insertion and Assembly

In the setting of a massive segmental defect in which the interlocking screws after a Precice nail recharge would no longer gain osseous purchase in the transporting segment, an internal cable and pulley construct may be utilised. In an example of a retrograde transport (i.e., a pre-distracted Precice nail is being shortened), after a direct surgical exposure of the remaining bone defect, a 750 × 2.0 mm cable is transversely brought through the anterior tibia cortex of the proximal transporting segment via a 3.5 mm drill hole and wrapped over an internal pulley (screw), then subcutaneously brought through the interlocking screw hole of the Precice nail and then connected with itself. With this construct, lengthening the nail (going in the opposite direction) now would create tension on the cable over the pulley and continue the patient's retrograde transport. The pulley system is comprised of a 4-hole 3.5 mm locking reconstruction plate with three screws anchoring the plate into the proximal anteromedial tibia and the fourth screw acting as the pulley with the screw tail docked into the anterolateral plate in the most proximal aspect of the bone defect. A Precice nail interlocking peg can be used as the pulley screw as it can thread into the reconstruction plate. Utilising a peg with a larger core diameter allows for a mechanically stronger pulley and the lack of threads allowed for smoother gliding of the cable over the pulley (Fig. 4).

Docking and Nail Exchange

Once transport has nearly completed and docking of the bone ends is imminent (within 0–5 mm) it is recommended to perform exchange nailing to a standard tibial intramedullary nail with repeat reaming 1 mm over the desired nail diameter while pushing past the regenerate rather than reaming. A docking site procedure is performed to include the debridement of any interposed soft tissue and the addition of a bone graft of the surgeon's choice. As a consequence of the immaturity of the regenerated bone, rebound of the transporting segment may occur when performing a docking procedure and immediate exchange nailing (Figs 5 and 6). Maintaining compression of the transporting segment during exchange nailing is critical and may be achieved with a minifragment plate, continuous compression staple, custom interlocking screw placed in the trauma nail, or a locking screw placed through the plate into the transported segment.[3] Post-operatively, the patient is kept non-weight-bearing for an additional 4–6 weeks while the regenerate matures.

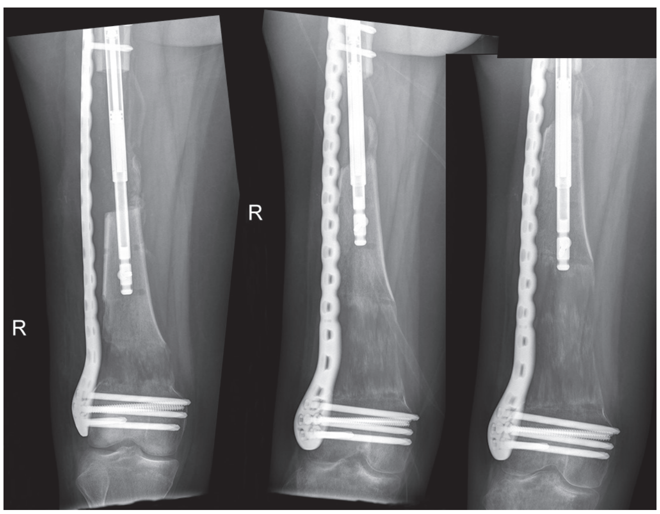


Fig. 3: Retrograde femoral transport at 6 weeks, 15 weeks, and 5 months, respectively, demonstrating healthy regenerate

Case Report

The patient is a 47-year-old male non-smoker involved in a motorcycle collision. There was no significant past medical history, and he was employed as a welder and fabricator at the time. The patient is 74" tall and weighs ~ 210 lbs (BMI: 27.0 kg/m^2). His orthopaedic injuries included a right type III open tibia fracture with extension into the proximal articular surface (Fig. 7), a closed right displaced femoral neck fracture with an open type IIIA ipsilateral femoral shaft fracture that extended into the distal articular surface, and a closed comminuted patella fracture. The open tibial wound was anteromedial, longitudinal, and ~12 cm in length with gross contamination of the exposed and stripped cortical fragments. His distal neurovascular status was intact and was able to be clinically monitored for compartment syndrome.

He underwent multiple debridements and lavage of his tibia with removal of the grossly contaminated cortical fragments, placement of external fixation, placement of an antibiotic-impregnated cement spacer, and a negative pressure dressing on the open wound. The skin was re-approximated after the removal of the remainder of the bone fragments. Multiple treatment modalities to manage his bone defect were discussed including bone grafting after the creation of an induced membrane (i.e., Masquelet technique), and BT. Owing to his strong desire to avoid a circular fixator, BT with an all-internal technique was chosen. On POD #6, he underwent repeat debridement and lavage, and the tibial bone ends were planed off with an oscillating saw cooled

Figs 4A to C: (A) A synthetic tibial model demonstrating a retrograde tibial PABST. An example of a massive proximal tibial defect and incomplete retrograde transport in which additional Precise nail recharge is not possible; (B) An internal cable–pulley construct has been applied to allow for continued retrograde transport via Precise nail extension utilising a pulley anchored from the small frag plate medially to the plateau plate laterally; (C) Retrograde bone transport has continued with the extension of the Precice nail

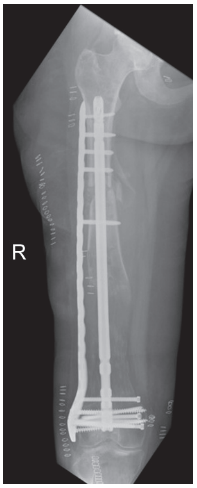


Fig. 5: Post-operative A/P femur radiograph after successful docking site procedure and exchange of the Precise nail with a standard retrograde femoral intramedullary nail

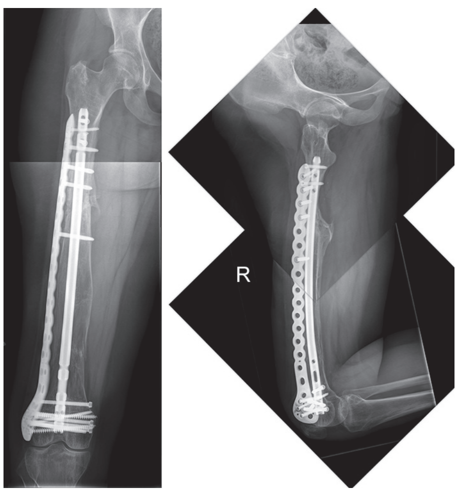


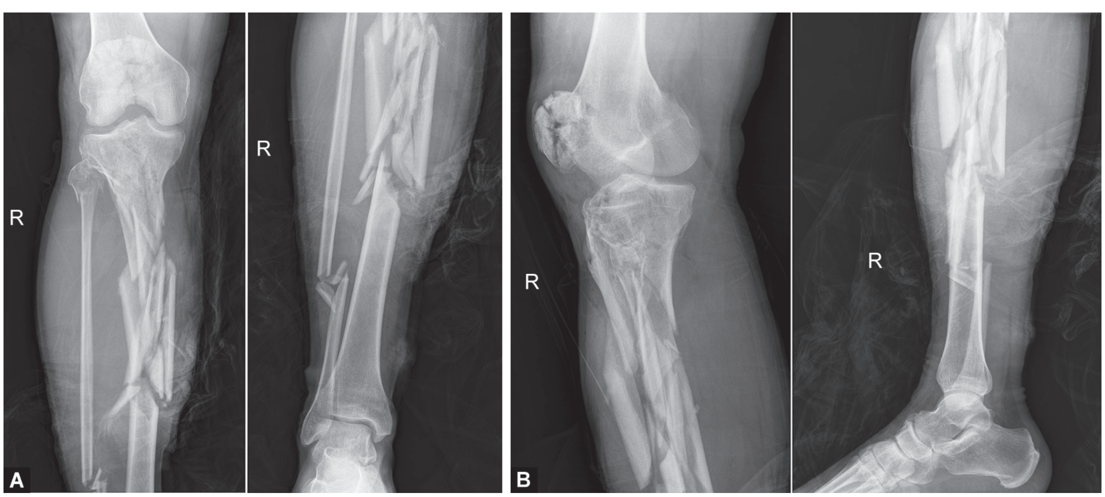
Fig. 6: Successful union of the docking site and regenerate maturation at 12 months post-operatively

with saline perpendicular to the mechanical axis of the tibia. The resultant defect was 185 mm (Fig. 8).

Definitive management of the tibia injury was on POD #13 with plans for PABST. Due to the length of his defect and the comminution of the proximal tibial metaphysis, a proximally based plate that could span his entire tibia (~420 mm in total length) was needed. As no such precontoured tibial plateau plate was available, a contralateral distal femoral plate was used (not FDA-approved, off-label use). Once the plate was positioned provisionally, an antegrade tibial Precice nail with a stroke length of 80 mm was placed with the nail fully distracted in preparation for retrograde BT with plans for two Precice nail recharges. With the proximal defect stabilised, an accurately placed distal tibial corticotomy was performed. The plate was submuscularly placed along the anterolateral aspect of the tibia and spanned the traumatic defect and distal tibial corticotomy. Cannulated locking screws – 4.5 mm cortical and 5.7 mm – were placed in the proximal tibia and one 4.5 mm locking screw along with one 3.5 mm cortical screw were placed as distal fixation of the PABST construct along with a tricortical syndesmotic screw (Fig. 9).

After a 7-day latency period, retrograde BT was initiated by shortening the distracted Precice nail at a rate of 0.25 mm twice per day through the external remote control. Due to the limited distal tibial fixation, immobilisation in a removable boot was used until the traumatic wounds had healed. The regenerate appeared healthy and after 6 weeks of transport, the BT rate was increased to 0.25 mm three times per day. At 4.5 months, a Precice nail was recharged back to its maximal stroke length to continue the BT. The transport rate was increased to 0.33 mm three times per day due to the excellent quality of the regenerate as seen on radiographs. At this time, the patient was noted to be developing an equinovarus contracture at his ankle and a mild distal tibial varus deformity through the regenerate despite the relative immobilisation from the supplementary removable boot (Fig. 10).

At 7.5 months, another Precice nail recharge was required. The neocortex in which the transporting interlocking screw was inserted was not secure enough in its hold to continue transport and began pulling through the bone. Therefore, the novel internal cable and pulley system as described above was implemented to continue transport keeping the current implants in place. A new corticotomy



Figs 7A and B: (A) Injury radiographs. A/P of the right tibia demonstrating a highly comminuted type III open tibial shaft fracture with extension into the proximal tibia, segmental fibula fracture, comminuted patella fracture, and intra-articular distal femur fracture; (B) Initial lateral right tibial radiographs

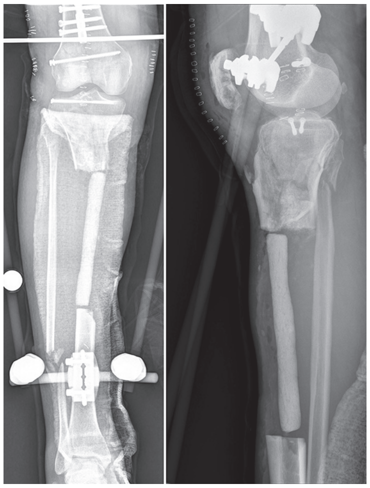


Fig. 8: A/P and lateral radiographs of the right tibia after debridement and irrigation, planing of the fracture ends, antibiotic-impregnated cement spacer placement, and external fixator placement demonstrating a 185 mm defect

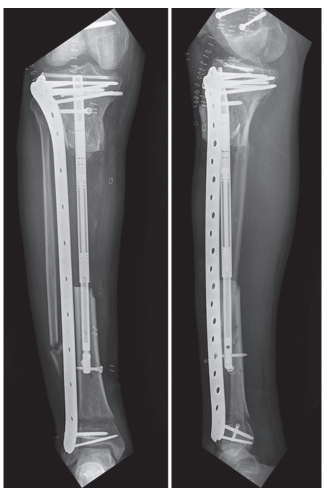


Fig. 9: A/P and lateral radiographs demonstrating a tibial spanning plate, fully extended Precise nail, and distal tibial corticotomy with plans for retrograde tibial bone transport

in the transporting segment was performed due to concerns for premature consolidation of the regenerate (Fig. 11).

After a 7-day latency, the Precice nail began a lengthening protocol of 0.33 mm three times per day until the transport segment reached the pulley screw (Fig. 12). The patient was then brought back to the operating room and the docking site was debrided, compressed, and bone grafted with allograft chips and demineralised bone matrix. The transport segment was secured with a minifragment plate after the Precice nail was removed. External fixator half pins were placed in the medial proximal tibia and connected to an Ilizarov foot ring attached with smooth wires in the hindfoot and midfoot (See Supplemental Fig. 2, which demonstrates the intraoperative external fixator construct) and this was used to correct the varus deformity through the regenerate (See Supplemental Fig. 3, which demonstrates correction of the varus deformity). Once the mechanical axis of the tibia had been restored, a standard trauma tibial nail was placed. The anterolateral plate was left in place.

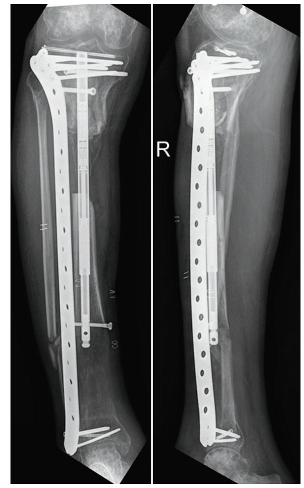


Fig. 10: A/P and lateral radiographs demonstrating a successful 'recharge' of the Precise nail to gain cortical purchase of the most distal aspect of the transporting segment

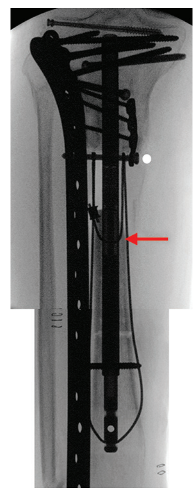


Fig. 11: A/P intraoperative fluoroscopic image demonstrating the construction of the internal cable/pulley system to continue transport utilising the same Precise nail along with a new tibial corticotomy. Arrow, cable traversing anterior tibial cortex. Dot, peg acting as a pulley for cable

Post-operatively, he was allowed to weight-bear as tolerated after 4 weeks and was enrolled in a physical therapy regimen with a focus on an ankle range of motion protocol. At his final follow-up 16 months after injury (Fig. 13), he was able to ambulate pain-free without assistive devices and returned to work full-time as a fabricator and welder. His bone healing time was 474 days and his bone healing index (BHI) was 25.6 d/cm.

Discussion

Bone transport with the IT has popularised limb lengthening and deformity correction while influencing the creation of various hexapod circular external fixators. High ratings of pain reported by patients, pin-track infections, psychosocial concerns, and long fixation periods have been the impetus for alternative modalities of treatment.[17] Massive osseous defects take a considerable time to heal and when limb salvage is pursued, the substantial time spent in circular fixation must be taken into account from a

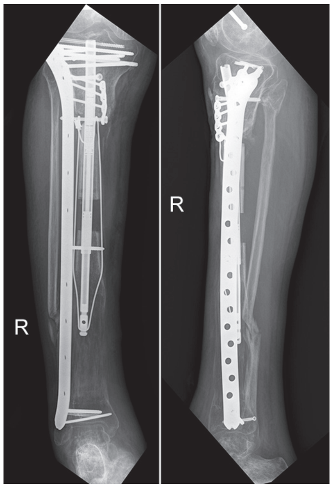


Fig. 12: A/P and lateral radiographs of the right tibia demonstrating docking of the transporting segment with the pulley screw

Fig. 13: Final A/P and lateral tibial radiographs 16 months after definitive fixation demonstrating union of the docking site and maturation of the regenerate

patient's perspective. PABST may address some of the psychosocial concerns of having a circular external fixator applied and the circular fixator complication profile may be mitigated through the use of all-internal BT techniques.[11] In this case, we present the treatment of a massive defect utilising the all-internal PABST technique. The innovation of a novel internal cable–pulley system allowed for continued transport without resorting to Precice nail exchange.

Literature on PABST is largely limited to small case series, making direct comparisons with this case difficult. This case may represent the largest tibial defect (185 mm) treated with PABST. Our PABST BHI of 25.6 d/cm is comparable to 56.9 d/cm by Barinaga et al. and 30.4 d/cm by Barakat et al.[9,18] Compared with other techniques of all-internal BT such as with a BT nail, our BHI is also comparable to 41.4 d/cm reported by Blair et al. and 63 d/cm reported by Geiger et al.[3,13]

Conclusion

With the advent of the current generation of magnetic lengthening nails, PABST has emerged as a valuable technique in osseous reconstruction and limb salvage, offering numerous benefits and advancements. Though not a panacea, PABST has its own complication profile which includes an increased risk of deep infection due to the presence of internal implants and prolonged weight-bearing restrictions which can lead to joint stiffness and soft tissue contractures. The authors present a novel solution for a massive bone defect which overcomes the limitation of the tibial PABST technique by using the motorised implant to power a cable and pulley system. With ongoing advancements in imaging, surgical planning, and regenerative approaches, PABST is poised to continue to evolve with a better definition of patient selection and treatment protocols.

Clinical Significance

Plate-assisted bone segment is a technique of BT without the need for external fixation. The application of the described cable and pulley construct allows for an all-internal BT in the treatment of massive defects with existing implants without resorting to more costly exchanges of the Precice nail or conversion to external fixation.

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Supplementary Materials

All the supplementary materials are available online on the website of www.stlrjournal.com.

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