Technical Note

Corresponding Author

John H. Shin

https://orcid.org/0000-0001-7490-8108

Massachusetts General Hospital, Harvard
Medical School, 15 Parkman Street, WAC
745, Boston, MA 02114, USA
E-mail: shin.john@mgh.harvard.edu

Novel Technique for C1–2 Interlaminar Arthrodesis Utilizing a Modified Sonntag Loop-Suture Graft With Posterior C1–2 Fixation

Robert M. Koffie, Alexandra M. Giantini Larsen, Benjamin L. Grannan, Muhamed Hadzipasic, Vijay Yanamadala, Laura Van Beaver, Ganesh M. Shankar, John H. Shin

Department of Neurosurgery, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

Objective: Conventional techniques for atlantoaxial fixation and fusion typically pass cables or wires underneath C1 lamina to secure the bone graft between the posterior elements of C1–2, which leads to complications such as cerebrospinal fluid (CSF) leak and neurological injury. With the evolution of fixation hardware, we propose a novel C1–2 fixation technique that avoids the morbidity and complications associated with sublaminar cables and wires.

Methods: This technique entails wedging and anchoring a structural iliac crest graft between C1 and C2 for interlaminar arthrodesis and securing it using a 0-Prolene suture at the time of C1 lateral mass and C2 pars interarticularis screw fixation.

Results: We identified 32 patients who underwent surgery for atlantoaxial with our technique. A 60% improvement in pain-related disability from preoperative baseline was demonstrated by Neck Disability Index (p < 0.001). There were no neurologic deficits. Complications included 2 patients CSF leaks related to presenting trauma, 1 patient with surgical site infection, and 1 patient with transient dysphagia. The rate of radiographic atlantoaxial fusion was 96.8% at 6 months, with no evidence of instrumentation failure, graft dislodgement, or graft related complications.

Conclusion: We demonstrate a novel technique for C1–2 arthrodesis that is a safe and effective option for atlantoaxial fusion.

Keywords: Arthrodesis, Atlantoaxial instability, Fusion, Interlaminar bone graft, Sublaminar

INTRODUCTION

Atlantoaxial instability due to cervical spine congenital malformations, inflammatory disease, benign and malignant neoplasms, degeneration, and trauma is commonly encountered by spine surgeons. Instability in the cervical spine can lead to neck pain, cervical deformity, spinal cord injury, and disability.[1,2] Several surgical techniques for atlantoaxial fixation have been proposed over the years to treat patients with atlantoaxial instability and innovative approaches continue to emerge.[3] Here, we report our technique that secures the bone graft at C1–2 in a safe and expedient manner, facilitating fusion while minimiz-

ing complications associated with securing the bone graft.

The earliest reported approach for treating atlantoaxial instability was in 1910 when Mixter and Osgood[4] used stout braided silk to anchor the posterior arch of C1 to the spinous process of C2. Gallie[5] then expanded upon this approach in 1937 by using threaded steel wire in likewise fashion while adding an autologous iliac bone graft secured by these wires within the posterior elements of C1 and C2. Brooks and Jenkins proposed a different approach by using sublaminar wires to secure bilateral iliac crest bone grafts, in an effort to promote more robust fusion.[6] This was followed by the Sonntag approach, which involves crimping a sublaminar C1 wire to the notch in C2 process along with

a C1–2 bone graft.[7,8]

With the evolution of modern instrumentation systems, surgical fixation using various screws and rods has demonstrated excellent clinical and radiographic fusion rates. Surgeons now have more tools to obtain arthrodesis at the craniovertebral junction with less need for noninstrumented wiring bone graft techniques with external orthoses. Magerl and Seemann[9] proposed using C1–2 transarticular screws for fixation in this region. Goel and Harms then reported the use of C1 lateral mass screw placement in combination with C2 pars or pedicle screws with high fusion rates.[10,11] A variant of the Goel technique, in which an allograft spacer is placed within the C1–2 joint in addition to bilateral C1 lateral mass and C2 pedicle or pars interarticularis rods and screws fixation has also been described.[12] This approach results in higher fusion rates, but was associated with increased rates of postoperative occipital headaches and may increase the risk for vertebral artery injury. Ghostine et al.[13] also reported a similar approach in which arthrodesis along the entire C1–2 joint is used to complement instrumented fixation, but without sacrificing the C2 nerve roots, resulting in lower rates of occipital headaches in patients postoperatively. Another method of atlantoaxial fixation that obviates the need for C2 nerve root sacrifice or compression by using C2 translaminar screws in combination with C1 sublaminar cable suspension for C1–2 fusion in the setting of atlantoaxial instability has also been described.[14]

Here we report an operative nuance, which combines the Goel-Harms fixation technique with a safe and facile, modified Sonntag arthrodesis technique for securing interlaminar bone graft between C1 and C2. Our variation entails wedging an iliac crest graft, either harvested autograft or structural allograft, between C1 and C2 for interbody arthrodesis and anchoring it with a 0-Prolene suture. The curvature and low-profile nature of the needle as well as the easy handling of the 0-Prolene suture makes sublaminar passage under C1 relatively straightforward. We demonstrate the effectiveness of this technique in a series of 32 patients with atlantoaxial stability for a variety of pathologies commonly encountered in practice and confirm excellent radiographic evidence of fusion at minimum 6 months and low complication rates. Illustrations and operative video highlight the technique.

MATERIALS AND METHODS

Institutional Review Board (IRB) approval at the Massachusetts General Hospital (2015P001837) was obtained to perform a retrospective database query of a prospectively maintained spine surgery database developed by the senior author at our tertiary care academic institution. Individual patient consent was not collected given the retrospective nature of this case series and technical report. Standing postoperative plain lateral and anteroposterior radiographs were obtained prior to discharge and at 6 weeks, 3 months, 6 months, 1 year, and 2 years postoperatively. Cervical spine computed tomography (CT) was obtained at 6 months after surgery to assess the graft position and the extent of arthrodesis. Fusion was radiographically confirmed by the following criteria: (1) absence of radiographic lucency between iliac crest bone graft and C1 inferior laminar and C2 superior laminar on thin cut CT; (2) absence of dynamic motion on plain lateral and anteroposterior x-rays; (3) presence of new bone formation and remodeling across C1–2. Patients were managed in a soft collar for comfort after surgery. No halo immobilization or rigid cervical orthoses were used in the postoperative setting.

Thirty-two consecutive adult patients were identified who met the inclusion criteria for the study. Primary and metastatic tumor cases were excluded. Cases including occipital plate fixation were excluded. Patients with less than 6 months of follow-up were excluded. Data were collected on hospital stay, readmission rates, perioperative complications, patient-reported outcomes with Neck Disability Index (NDI) questionnaires, and fusion rates based on cervical CT scans.

1. Description of Technique

The patient is positioned prone on the Jackson table and a standard approach to the C1–2 region is performed. C1 lateral mass and C2 pars interarticularis screws are placed using the Goel-Harms technique. After the instrumentation is placed in the C1 lateral masses and the C2 pars interarticularis, an angled curette is used to dissect soft tissue away from superior and inferior ledges of the C1 lamina. A plane is created safely underneath the lamina so that the epidural space is free from attachment to the posterior C1 ring. Meticulous dissection is required to avoid neurologic injury and dural disruption. Dissection is continued until an adequate sublaminar corridor is obtained. For purposes of arthrodesis, either a structural iliac crest autograft or allograft can be used. In the accompanying video, iliac crest autograft is used. In many cases and in the illustrations provided, structural allograft is used.

The bone graft is sized to fit within the C1–2 interlaminar space and decortication is performed on the inferior aspect the C1 lamina and the superior aspect of the C2 spinous process
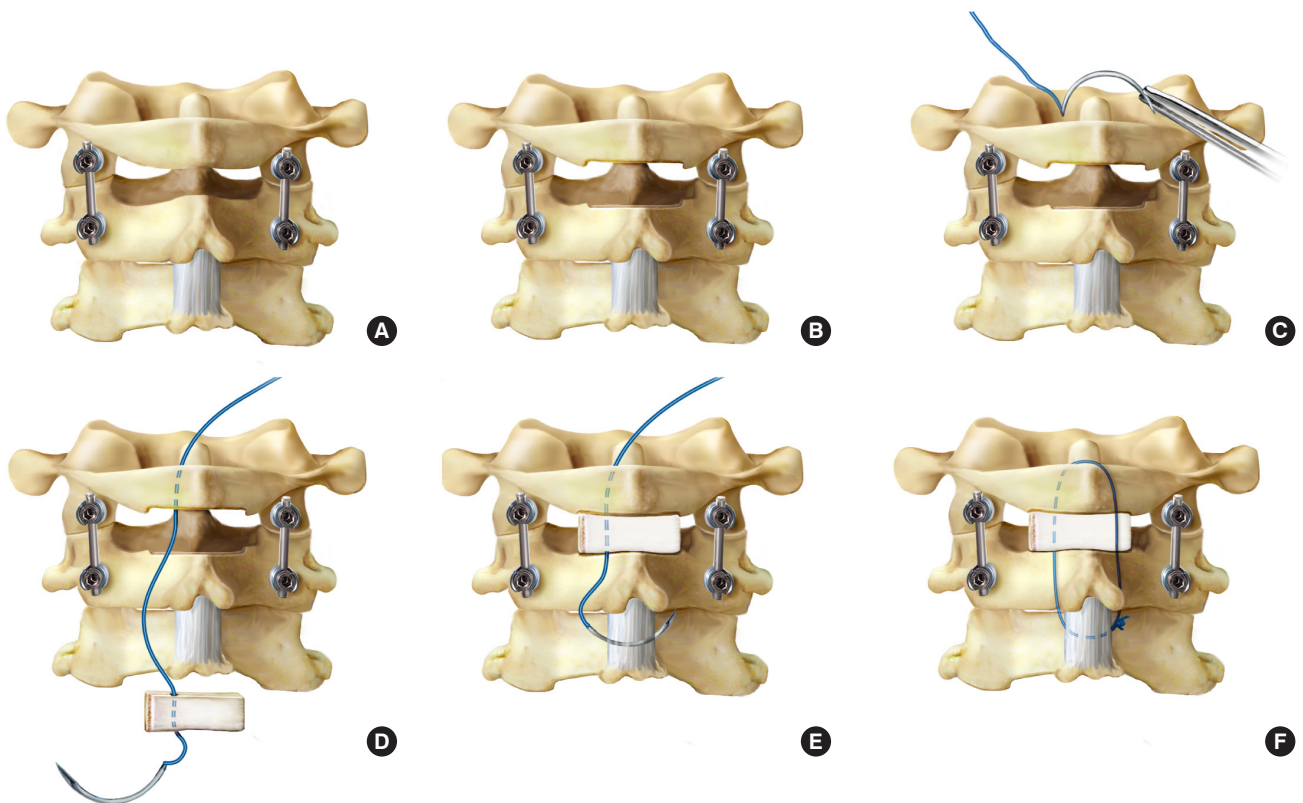
Fig. 1. Illustration of technique. Following (A) standard C1–2 instrumented fusion with C1 lateral mass and C2 pars interarticularis screws, (B) troughs for bone graft placement are drilled into the inferior aspect of the C1 lamina and the superior edge of C2 lamina. (C) 0-Prolene suture is passed with the blunt side of the needle first, underneath C1 lamina in superior-to-inferior direction with the needle holder protecting sharp needle point. (D) The 0-Prolene suture is then passed through an offset (here, to the left) drilled channel in the bone graft and (E) passed through the interspinous ligament between C2 and C3. (F) To secure the graft, the needle of the 0-Prolene is the cut and the other end of the suture is passed over (superficial to) the graft and secured by tying knots over the C2 lamina and graft.

and lamina with a high-speed drill. The C2 spinous process is preserved to allow the suture to loop around the graft before securing it with surgical knots.

Once the bone graft is sized, the high-speed drill is used to make a 2-mm hole through the iliac crest graft (Fig. 1; Supplementary video clip 1). The 0-Prolene suture is then passed underneath the C1 lamina superior to inferior, with the tip of the needle backwards. The back-handed needle is then rotated out from under the C1 lamina. It is critical that the needle is passed under the C1 lamina backwards so that the sharp tip of the needle does not tear the dura. The curvature of the 0-Prolene needle allows for passage underneath the C1 lamina without having to bend or modify the needle. The needle is then passed through the hole made through the graft and the graft is wedged into the C1–2 interlaminar gap that had been decorticated. The needle is then cut from the suture. This needle end of the suture is then looped underneath the C2 spinous process and tied to the other

end of the suture which passes over the C1 lamina and over the bone graft. Several knots are tied over the graft securing it in position. The passing of the suture through the graft and tying the knots above and around the graft help secure it sufficiently to avoid displacement (Fig. 2). In cases were subaxial fusion was need (e.g., for trauma cases resulting in fractures in C3), lateral mass screws were placed at C3 and incorporated into the hardware construct before performing the technique described above.

RESULTS

We identified 32 patients who met the study inclusion criteria. Each patient was treated with the technique described above. Patients with atlantoaxial instability due to primary tumors, malignant nerve sheath tumors, metastatic disease or vascular lesions were excluded. The average age of the cohort was 66 years,
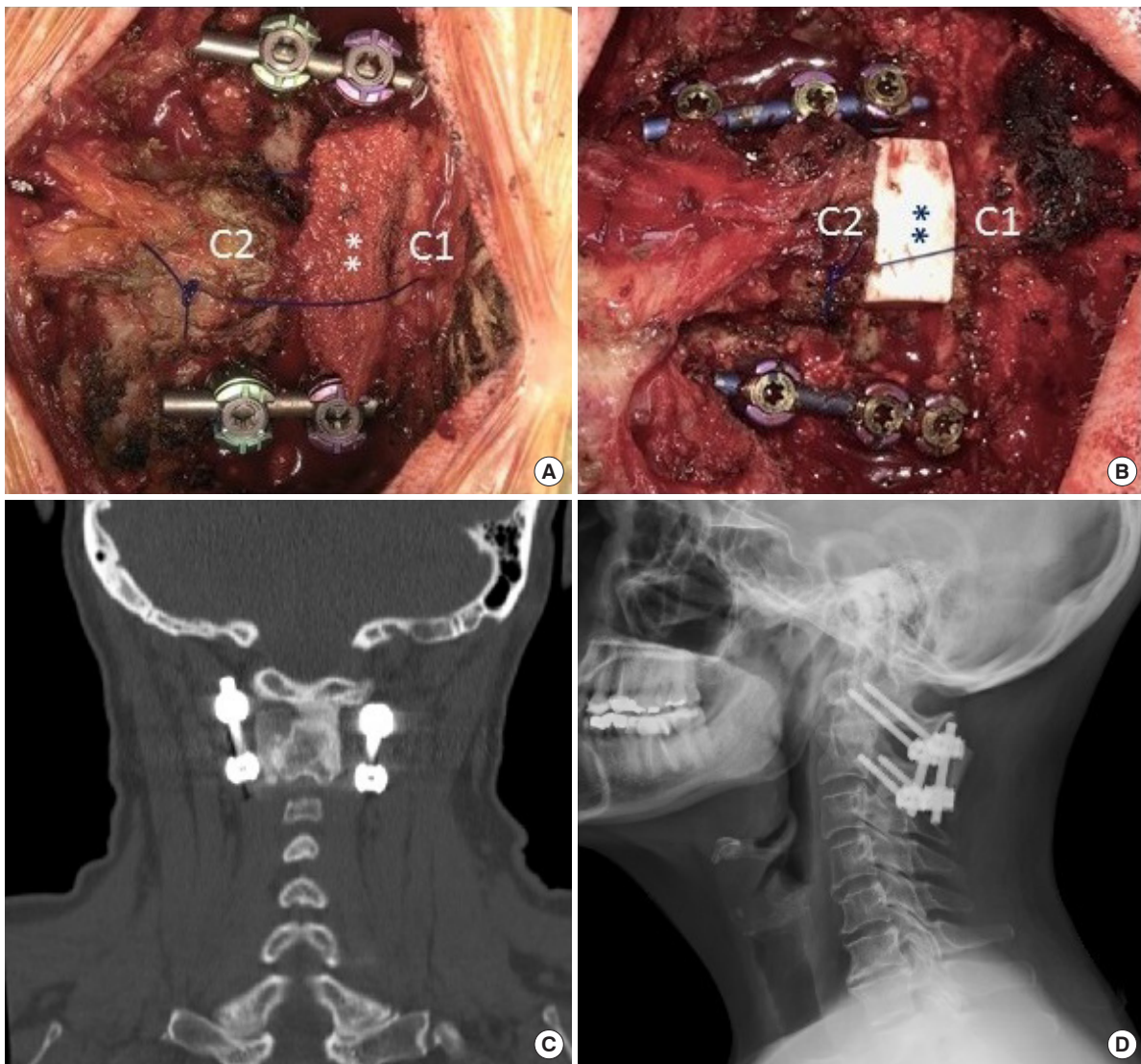
Fig. 2. Intraoperative pictures and follow-up radiographs. (A) Image showing an example in which iliac crest autograft is secured between the interlaminar space of C1 and C2. (B) Image demonstrating the use of iliac crest allograft wedged between interlaminar space of C1 and C2. (C, D) Computed tomography and plain radiographs obtained 6 months after surgery in a patient with atlantoaxial instability due to dens fracture showing fusion across C1 and C2 with bone graft in place, without instrumentation failure or graft dislodgment. This figure highlights the absence of artifacts obscuring visualization of arthrodesis, which is a problem in techniques that use cables. **The allograft or autograft in position.

with ages ranging from 22 to 91 years of age. The patients were 56% male and 44% female. The preoperative atlantodental interval ranged from 1 mm to 6 mm, with most patients demonstrating evidence of transverse ligament disruption (Table 1).

The average hospital stay was 6 days. Forty-eight percent of patients were discharged to home whereas 52% were discharged to rehabilitation centers. The follow-up period ranged from 6 to 26 months (mean, 18.2 months). The rate of readmission within 30 days after surgery was 3%. Two patients had a CSF leak related to trauma, 1 patient developed a surgical site infec-

tion requiring readmission and washout, and 1 patient developed dysphagia (Table 2).

Patient reported neck pain-related disability (as determined by NDI) improved by 60% ($p < 0.001$) with a preoperative mean score 30 (standard deviation, 8) and postoperative mean score 12 (standard deviation, 4). Pre- and postoperative NDI scores were available in 21 of the 32 patients. Preoperative questionnaires were completed within 30 days prior to surgery and at 3 months postoperatively.

Plain radiographs and CT of the cervical spine obtained at 6

Table 1. Demographic information

Variable	Value
Age (yr), mean (range)	66 (22–91)
Sex	
Male	56%
Female	44%
Indication	
Deformity (includes rheumatologic)	5%
Trauma	60%
Degeneration	35%
Iliac crest autograft	2
Iliac crest allograft	30
Total cases	32

Table 2. Clinical and radiographic outcomes

Outcome	No. of cases (%)
Readmission within 30 days	1 (3.1)
Radiographic fusion	31 (96.8)
Complications	
Dysphagia	1 (3.1)
Cerebrospinal fluid leak	2 (6.3)
Wound infection	1 (3.1)

months showed a radiographic rate of fusion of 96.8% in our patient cohort (31 of 32) (Table 2). In one case, CT imaging at 6 months demonstrated a 2-mm linear gap between the inferior edge of C1 and the top of the allograft bone without incorporation. There was otherwise complete assimilation between the graft and C2 and arthrodesis across the C1–2 joints. Overall, there was no evidence of instrumentation failure, screw pullout, screw fracture, graft fracture or graft dislodgement. No revision surgery was required.

DISCUSSION

The treatment of atlantoaxial instability due to trauma, degeneration, rheumatologic disorders and tumors is common in practice. The techniques for C1–2 fixation continue to evolve with modern instrumentation techniques. Historical approaches for achieving atlantoaxial fusion in the literature are associated with inherent risks of injuring the dura or spinal cord while performing internal fixation and securing the bone graft. Insufficient bone-on-bone apposition can lead to pseudarthrosis, instrumentation failure, and symptomatic pain.

The Gallie technique, which involves passing a steel wire sublaminar to C1 and securing a single autograft harvested from the iliac crest by wrapping the wire around the spinous process of C2, is associated with nonunion rates as high as 25%.[15] The Brooks-Jenkins fusion technique, which uses 2 separate iliac crest autografts between the lamina of C1 and C2 and securing them by passing sublaminar wires beneath C1 and C2, is associated with 7% rates of nonunion, but somewhat improves with halo immobilization.[7] The Brooks-Jenkins fusion technique is limited by the high risk of injury to the dura and spinal cord

from passage of bilateral sublaminar cables beneath both C1 and C2 compared to single passage underneath laminar of C1.[16]

The Sonntag technique further improved the fusion rates in this region with lower rates of nonunion compared to the other wire techniques. Sonntag's approach involves passing a sublaminar cable under the posterior C1 arch from inferior to superior, placing a notched iliac crest autograft between the spinous process of C2 and the posterior arch of C1, looping the cable over the iliac crest autograft into a notch created on the inferior aspect of the C2 spinous process, and then tightening and crimping the cable to secure the graft. This technique improves the rotational stability of the Gallie technique and avoids sublaminar C1–2 cable passage (unlike the Brooks-Jenkins technique), thereby decreasing the risk of neurological injury. Sonntag demonstrated fusion rates of 97% using this technique, but required patients to be immobilized in a halo for 3 months after surgery as well as use a rigid cervical collar for an additional 1 to 2 months.[7]

Despite the high fusion rates, the Sonntag approach has now largely been replaced by internal fixation using various screw and rod constructs across C1 and C2.[7,8] Fixation methods such as the Magerl approach, which utilizes C1–2 transarticular screws and rods, gained some traction earlier, but the Goel-Harms technique is now the most commonly used technique given its advantage of rigidly fixing the atlas and axis using C1 lateral mass screws in combination with the C2 pars or pedicle screws with less risk of vertebral artery injury.[9-11] Over the years, surgeons have become facile in using this technique, with reported of cases of vertebral artery injury decreasing accordingly.[11,17]

Given the importance of achieving fusion and reducing the risk of pseudarthrosis—factors that impact patient-reported outcomes after atlantoaxial instability—we feel that our technique offers the benefits of both secure interlaminar bone graft placement and C1–2 instrumented fixation using the Goel-Harms technique.

The original Sonntag approach requires using sublaminar wires, which poses some risk of durotomy and spinal cord inju-

ry.[18,19] The wires can be awkward to handle and require various tools to crimp and secure the wires. We used 0-Prolene sutures given their flexibility and lower risk of tissue or dura injury without compromising the tensile strength of securing the bone graft. By combining this approach with the C1 lateral mass and C2 pedicle or pars screws, we have found that postoperative external cervical immobilization with a halo or rigid collar is not required. This helps limit the patients' exposure to halo and collar related morbidity in the postoperative setting, especially with older patients. In our series, our fusion rates were essentially 100% with the exception of 1 patient where the superior aspect of the graft did not completely integrate with the decorticated C1 arch at 6 months. Although our cohort was not powered to statistically identify a difference in fusion rates between allograft versus autograft, the 2 patients in which iliac crest autograft was used all demonstrated excellent fusion whereas 29 out of 30 cases in which allograft was used demonstrated excellent fusion between C1 and C2.

Our technique harnesses the rotational stability provided by lateral mass C1 and C2 pars or pedicle screw placement along with a safe way to secure bone graft to promote fusion. This technique does not use cables or wires and only requires passing a 0-Prolene suture underneath the lamina of C1. While 0-Prolene suture material has less tensile biomechanical strength than sublaminar titanium wires, we found it sufficiently strong to secure bone graft without issues. By combining the C1 lateral mass and C2 pars screw-rod construct technique with our approach of securing bone graft using 0-Prolene suture, we were able to obtain nearly 100% atlantoaxial fusion rates without the need of using external immobilization postoperatively. This was true regardless of the type of iliac crest graft used, although we used autograft in only 2 out of 32 patients in our cohort, limiting statistically rigorous comparison between autograft versus allograft. The current study is clearly limited by the small sample size, less than perfect follow-up for clinical outcomes reporting (e.g., 11 out of 32 patients did not respond to NDI questionnaire postoperatively), and limited duration of follow-up.

CONCLUSION

Our intention here is primarily to highlight and illustrate our technique and provide surgeons with an alternative method for securing bone graft at C1–2 that minimizes tissue manipulation and readily secures the graft needed for arthrodesis.

CONFLICT OF INTEREST

The authors have nothing to disclose.

SUPPLEMENTARY MATERIAL

Supplementary video clip 1 can be found via https://doi.org/10.14245/ns.1938344.172.

Supplementary video clip 1: Description of technique.

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