Eur Spine J
DOI 10.1007/s00586-015-4165-x

IDEAS AND TECHNICAL INNOVATIONS

Use of intraoperative fluoroscopy for the safe placement of C2 laminar screws: technical note

John A. Engler[1,2] · Michael L. Smith[1]

Received: 9 February 2015 / Revised: 23 July 2015 / Accepted: 23 July 2015

Abstract
Introduction Rigid fixation of the atlantoaxial joint can be quite challenging due to complex anatomic variants. Numerous techniques have evolved over time, improving the surgeon's adaptability. The recent advent of C2 laminar screws adds to the surgeon's armamentarium, but is not without its own set of limitations. Risk of ventral laminar breach with possible spinal cord injury, CSF leak, or poor bony fixation have led some to recommend prefabricated models or expensive intraoperative spinal navigation to aid screw placement. The purpose of this report is to detail how the use of intraoperative fluoroscopy can be used to aid in the safe placement of C2 laminar screws.
Methods One patient with rheumatoid arthritis and progressive cervical myelopathy from C1–2 instability underwent C1–2 fixation using C2 laminar screws. Intraoperative fluoroscopy was used to guide and confirm safe laminar screw placement.
Results Immediate and 6-month postoperative imaging demonstrated excellent placement of C2 laminar screws without ventral breach. At 6 months, the patient noted significant improvement of her preoperative symptoms.
Conclusion Use of intraoperative fluoroscopy is an easy and safe method for the placement of C2 laminar screws. Given its use of readily available equipment, this method can be implemented without significant pre-planning, or as an impromptu salvage maneuver.

Keywords C1–2 fixation · C2 laminar screw · Fluoroscopy

Introduction

Techniques to achieve rigid fixation of the atlantoaxial complex have continuously evolved since their inception. Brooks and Gallie first introduced the concept of sublaminar wiring with placement of structural autologous bone graft in the 1960s. This technique requires adjuvant external immobilization with a halo or Minerva brace and is associated with a high rate of pseudoarthrosis [2, 3]. Jeanneret and Magerl improved the fixation techniques with the advent of transarticular screws for C1–2 fixation, which provided greater rates of arthrodesis without the need for prolonged external immobilization. The development of C1 lateral mass, C2 pedicle and C2 pars screws has largely supplanted the use of transarticular screws due to the technically demanding nature of C1–2 transarticular screw placement and risk of vertebral artery injury. However, pedicle screw placement carries similar risk of vertebral artery injury with cadaveric series reporting up to 26 % [8] of patients with vertebral artery anatomy precluding pedicle screw placement and clinical series reporting 2–8 % incidence of vertebral artery injury [7]. Recently, Wright [15] developed a C2 laminar screw technique which obviates the risk of vertebral artery injury by pedicle or transarticular screw placement. Taking advantage of the capacious C2 lamina, crossing C2 laminar screws are often placed by a freehand technique, visualizing the slope of the lamina and directing the laminar

✉ John A. Engler
john.engler@alumni.med.nyu.edu

1 Department of Neurosurgery, New York University School of Medicine, New York, NY, USA

2 Department of Neurosurgery, Naval Medical Center Portsmouth, 620 John Paul Jones Circle, Portsmouth, VA 23708, USA

screw along that trajectory. Ventral breaches can be difficult to recognize, however, and can lead to neurologic injury from damage to the upper cervical spinal cord, construct failure due to poor bony fixation, and wound healing problems from cerebrospinal fluid leaks. We describe here a simple technique using intraoperative fluoroscopy to visualize the trajectory of the lamina, and confirm by direct fluoroscopic visualization, intralaminar screw placement without a ventral breach.

Illustrative case

62-year-old female with known history of rheumatoid arthritis and progressive evidence of cervical myelopathy, manifested as diffuse weakness of all four extremities, bilateral hand clumsiness and progressive gait ataxia. MRI showed pannus formation at C1–2 with spinal cord compression. Cervical spine X-rays showed reduction of C1–2 anterolisthesis in extension (not pictured) and CT showed a unilateral high-riding vertebral artery, precluding safe placement of a C2 pedicle screw on that side (Fig. 1). Patient was taken to the operating room for C1–2 instrumentation and arthrodesis, using iliac crest bone graft to enhance probability of arthrodesis in the face of disease-modifying rheumatology medications. Using intraoperative fluoroscopy, C2 laminar screws were safely placed. 6 months postoperatively, patient with significant improvement in preoperative myelopathy symptoms and X-rays show a durable construct without hardware loosening or recurrence of C1–2 anterolisthesis.

Surgical technique

Patient is positioned prone on gel rolls, with the head rigidly secured to the bed using Mayfield head holder. A standard subperiosteal exposure of the C1 and C2 posterior elements is performed. C1 lateral mass screw placement by freehand technique is performed as described by Harms. For placement of C2 laminar screws, the fluoroscopy machine was brought into the operating field from over the top of the head. Prior to the operation, the angle of the lamina from the horizontal was measured on the preoperative CT and the arc of the C-arm is then adjusted to that same angle until a view down the "eye" of the lamina is obtained (Fig. 2). Screw placement then proceeds using a 1-mm-high speed bur to create the pilot hole for the laminar screw. A 2.4-mm drill is then used to create the trajectory for laminar screw placement, followed by placement of the 4 mm × 32 mm laminar screw. X-ray can be used during all steps of laminar screw placement to visualize the ventral margin of the lamina and confirm appropriate placement within the lamina (Fig. 3). After

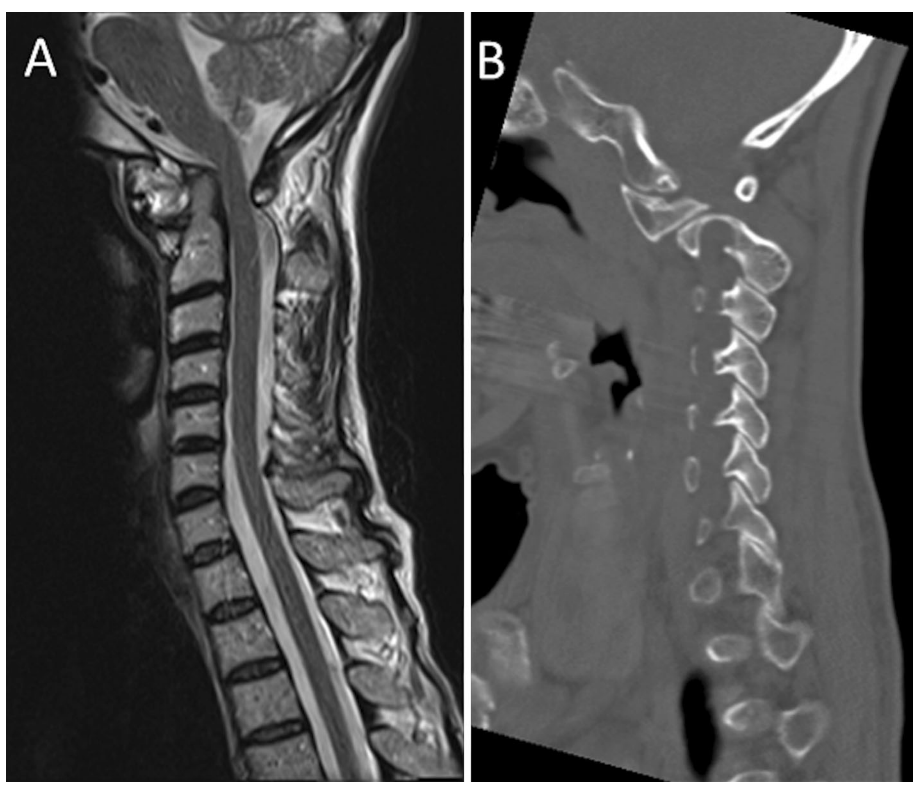

Fig. 1 Preoperative MRI (**a**) and CT (**b**) showing ventral spinal cord compression with C1–2 pannus and anomalous course of vertebral artery

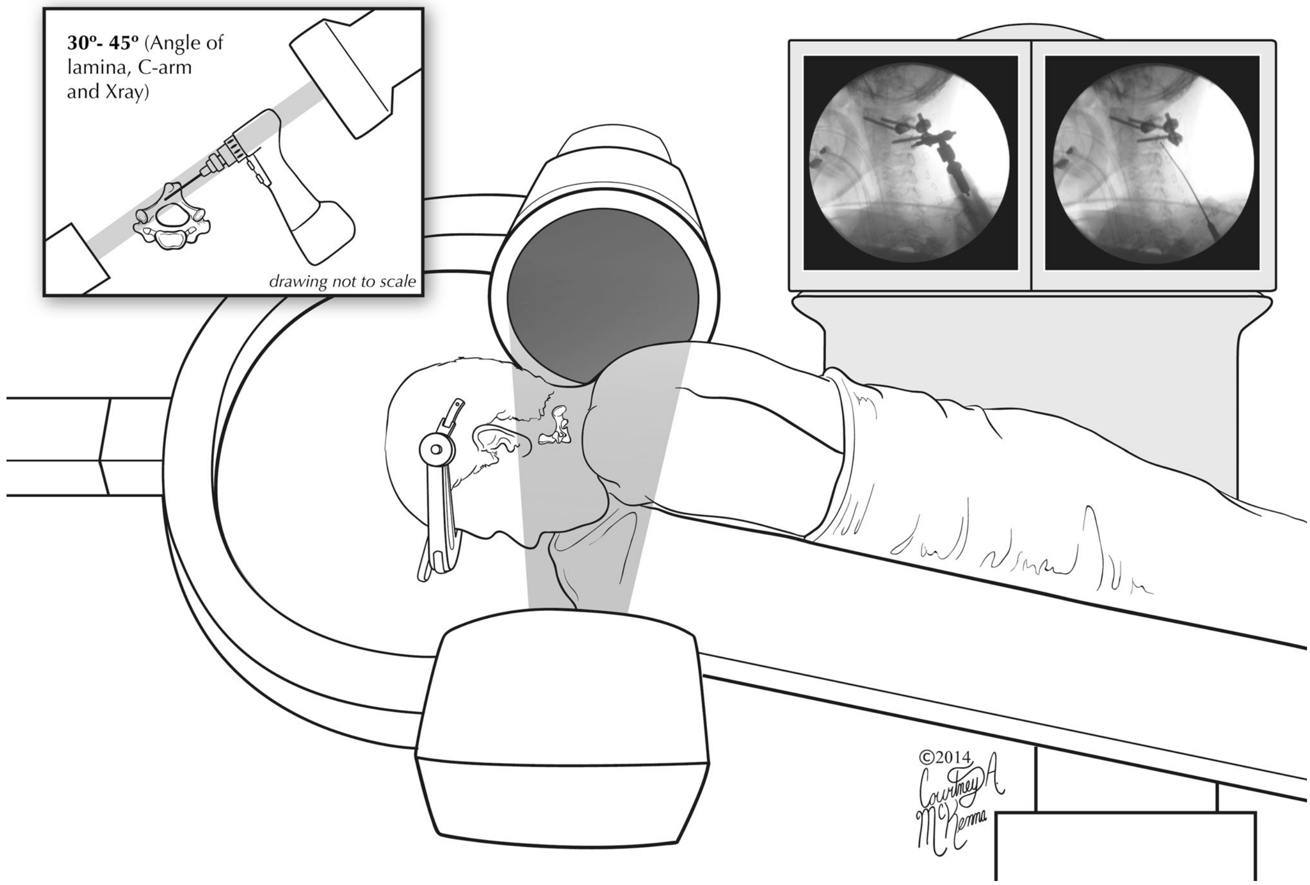

Fig. 2 Artist rendition of set-up and placement of translaminar screw using fluoroscopic guidance. *Inset* angulation of C-arm to correspond to the angle of the lamina and provide the "eye of the lamina" view

successful placement of the first laminar screw, the arc of the C-arm is rotated to obtain a view down the eye of the contralateral lamina, and the process is repeated. Postoperative CT scan shows successful placement of bilateral C2 laminar screws without ventral breach.

Discussion

Rigid fixation of the atlantoaxial construct can be challenging due to anatomic variants that are unique to the C1–2 complex. Congenital anomalies such as os odontoideum, hypoplastic C2 pedicles and significant vertebral artery asymmetry increase the risks associated with C2 instrumentation and in some cases, altogether precludes the placement of C1–2 transarticular and C2 pedicle screws. Sairyo et al. [13] recommend a minimum C2 pedicle diameter of 3.5 mm for safe placement of C2 pedicle screws and Meng et al. [8] recommend a minimum diameter of 5.5 mm, further limiting the patient population in which C2 pedicle screws are feasible. In their radiographic study of C2 anatomy in os odontoideum patients, Meng et al. [8] show 14 of 29 patients have C2 pedicles of less than 3.5 mm in diameter and 20 of 29 patients had C2 pedicles under 5.5 mm diameter. C2 laminar screws offer a safe alternative for rigid C1–2 fixation without risk of vertebral artery injury. In the case of our patient, the pedicles measured 4.1 mm on the right and 2.8 mm on the left. Additionally, preoperative imaging shows a high-riding vertebral artery on the left. Both pedicle size and anomalous vertebral artery position factored into the decision to use translaminar rather than transpedicular C2 fixation.

Since Wright [15] developed bilateral crossing C2 laminar screws, several series have been published documenting their efficacy. However, despite the relative ease of C2 laminar screw placement, several published series have reported ventral laminar breaches that required reoperation for revision (Table 1). Ventral laminar breaches can occasionally be detected by direct palpation under the C2 lamina; however, this technique is likely to detect only the most egregious breaches and does little to prevent the damage that can be caused by errant screw placement into the upper cervical spinal canal. Similarly, direct

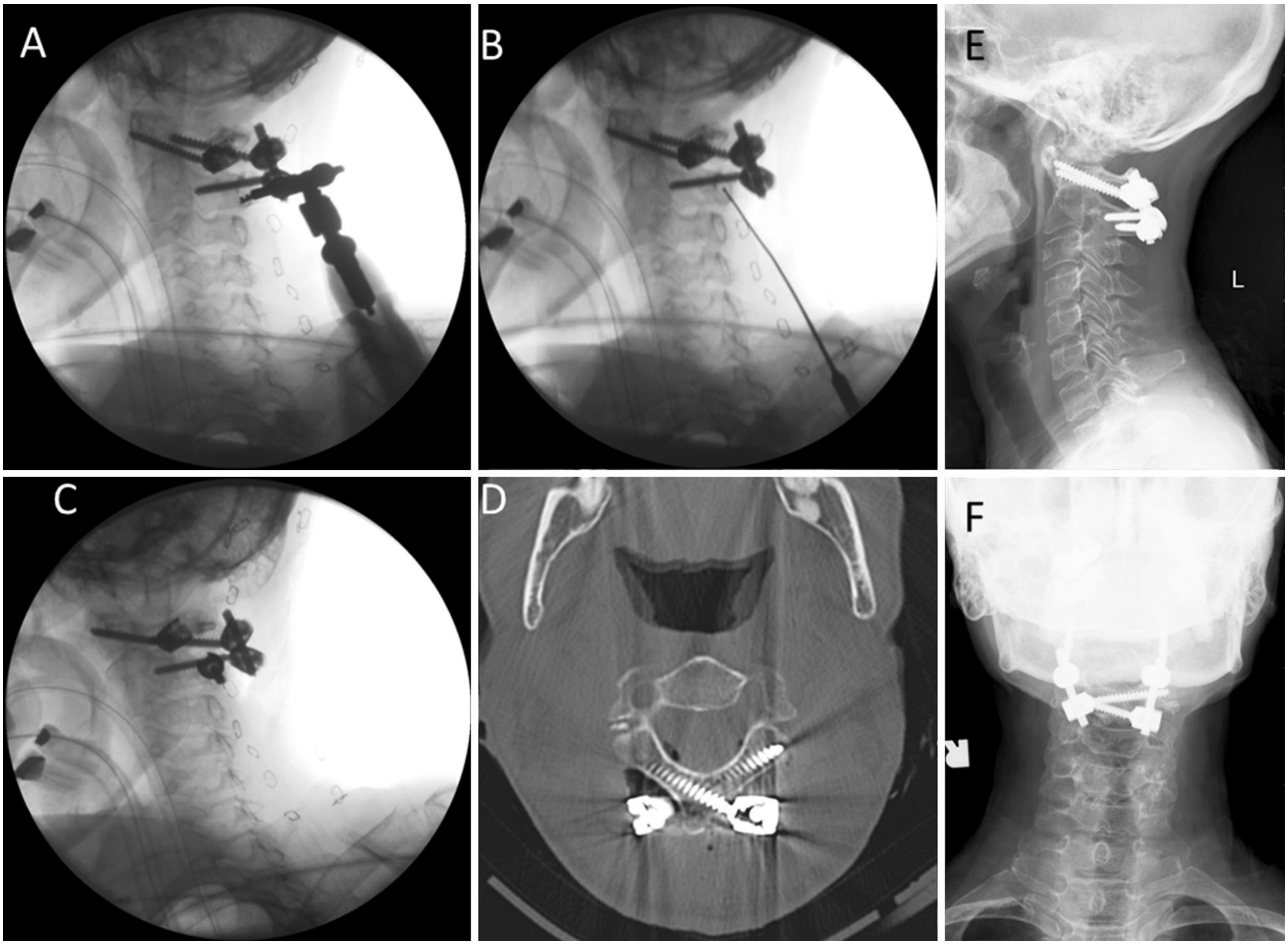

Fig. 3 Intraoperative fluoroscopy and postoperative imaging. **a–c** Images taken sequentially during placement of a screw in the oblique plane. Note well-defined ventral aspect of lamina marked with *bold black line*. **a** Use of 2.4-mm drill to create trajectory. **b** Palpation of tract with pedicle probe. **c** Final image after screw placement. **d** Postoperative CT scan confirming intralaminar placement without ventral breach. **e** Lateral postoperative X-rays. **f** AP Postoperative X-rays

Table 1 Review of C2 laminar screw placement

Authors	# of translaminar screws	Ventral breach	Comments
Bransford et al. [2]	63	4	Partial ventral breach—not revised
Hu et al. [3]	20	0	No postop/periop complications
Parker et al. [11]	152	2	One screw required acute revision
Wang [14]	59	1	Required revision
Ma et al. [7]	68	0	Ten patients with dorsal laminar breach—not revised
Park et al. [10]	26	0	No postop/periop complications

palpation may not recognize partial ventral breaches that are noted on postoperative imaging and lend themselves to poor bony fixation of the construct and delayed sequelae of pseudoarthrosis. In cadaveric studies, plain radiographs have limited sensitivity (68.8–77.4 % reported) to detect ventral breaches [5].

Concerns over the difficulties in placing upper cervical hardware as well the infrequency in which many spine surgeons perform the operations have prompted the development of navigation techniques to insure accurate screw placement. Lu et al. [6] developed a computer-generated spine template used intraoperatively to guide laminar screw placement and prevent misplaced hardware. This system requires production of a computer-generated spine model and template for each patient and significant preoperative planning for the laminar screw placement.

Table 2 Comparison of radiation exposures for upper cervical spine hardware placement

Surgery	Exposure time (s)	Cumulative area dose product
C2 translaminar screw	14	46.67 $cGycm^2$
Odontoid screw (biplanar fluoro)	17	155.72 $cGycm^2$
C1–2 fusion with C2 pedicle screws	26	57.80 $cGycm^2$

Technical difficulties can be encountered if the soft tissues are not sufficiently dissected from the lamina, thereby preventing proper seating of the cast to the lamina. Rajasekaran et al. [12] and Nottmeier and Foy [9] advocate the use of intraoperative spinal navigation for the safe placement of C2 laminar screws. Both authors note difficulty with intraoperative registration using point to point registration due to the complex anatomy of C1–2 and the need for advanced fluoroscopic imaging using an isocentric 3-D C-arm. The technique we describe does not require advanced production of computer-generated models nor the use of expensive 3-D navigation, which may not be available in all clinical practices. Using a standard C-arm, available in most clinical practices, we were able to visualize the ventral border of the lamina and confirm safe laminar screw placement. Additionally, the ability to visualize the inner diameter of the lamina allows bilateral screw placement with entry point modifications made to adjust to the unique anatomy of each patients' upper cervical spine. For surgeons that prefer the freehand placement of C2 translaminar screws, our technique could also be utilized as an intraoperative control to confirm the appropriate screw position prior to leaving the operating room.

Many surgeons may be concerned about the increased radiation exposure related to our technique. By measuring the angle of the lamina from the horizontal on the preoperative CT and using this angle to orient the C-arm in the correct plane, radiation exposures can be limited. Furthermore, comparing our technique with a recent C1–2 fusion and odontoid screw placement performed by the senior author shows comparable or reduced radiation exposure times (Table 2).

Our proposed technique uses resources available in most clinical practices, and can readily be used without significant preoperative planning. This allows for the impromptu use of laminar screws as a salvage maneuver for C2 pedicle and pars screws even by experienced surgeons, or as a safety guard against errant screw placement by the occasional surgeon. As further advances in translaminar screws develop, including the lower cervical levels [1, 4, 16] where the canal is less capacious, modifications to our technique may help promote the safe placement of screws at these additional levels.

Compliance with ethical standards

Conflict of interest No conflict of interest exists.

References

1. Alvin MD, Abdullah KG, Steinmetz MP, Lubelski D, Nowacki AS, Benzel EC, Mroz TE (2012) Translaminar screw fixation in the subaxial cervical spine: quantitative laminar analysis and feasibility of unilateral and bilateral translaminar virtual screw placement. Spine 37(12):E745–E751
2. Bransford RJ, Russo AJ, Freeborn M, Nguyen Q, Lee MJ, Chapman JR, Bellabarba C (2011) Posterior C2 instrumentation: accuracy and complications associated with the four techniques. Spine 36(14):E936–E943
3. Hu Y, Gu Y, Ye P, Ma W, Xu R, He X (2010) Posterior cervical spine arthrodesis incorporating C2 laminar screw fixation in the treatment of cervical spine injury. Orthop Surg 2(1):32–37
4. Kretzer RM, Hu N, Kikkawa J, Garonzik IM, Jallo GI, Tortolani PJ, McAfee PC, Cunningham BW (2010) Surgical management of two- versus three-column injuries of the cervicothoracic junction: biomechanical comparison of translaminar screw and pedicle screw fixation using a cadaveric model. Spine 35(19):E948–E954
5. Lehman RA, Sasso RC, Helgeson MD, Dmitriev AE, Gill NW, Rosner MR, Riew KD (2007) Accuracy of intraoperative plain radiographs to detect violations of intralaminar screws placed into the C2 vertebrae. A reliability study. Spine 32(26):3036–3040
6. Lu S, Xu YQ, Zhang YZ, Guo H, Li DP (2009) A novel computer-assisted drill guide template for placement of c2 laminar screws. Eur Spine J 18:1379–1385
7. Ma W, Feng L, Xu R, Liu X, Lee AH, Sun S, Zhao L, Hu Y, Liu G (2010) Clinical application of C2 laminar screw technique. Eur Spine J 19:1312–1317
8. Meng XZ, Xu JX (2011) The options of C2 fixation for os odontoideum: a radiographic study for the c2 pedicle and lamina anatomy. Eur Spine J 20:1921–1927
9. Nottmeier EW, Foy AB (2008) Placement of C2 laminar screws using three-dimensional fluoroscopy-based image guidance. Eur Spine J 17:610–615
10. Park JS, Cho DC, Sung JK (2012) Feasibility of C2 translaminar screw as an alternative or salvage of C2 pedicle screws in atlantoaxial instability. J Spinal Disord Tech 25(5):254–258
11. Parker SL, McGirt MJ, Garces-Ambrossi GL, Mehta VA, Sciubba DM, Witham TF, Gokasfan ZL, Wolinsky JP (2009) Translaminar versus pedicle screw fixation of C2: Comparison of surgical morbidity and accuracy of 313 consecutive screws. Oper Neurosurg 64(2):343–349
12. Rajasekaran S, Avadhani A, Shetty A (2011) Axial translaminar screw placement using three-dimensional fluoroscopy-based navigation. Singapore Med J 52(1):15–18
13. Sairyo K, Sakai T, Higashino K, Tamura T, Katoh S, Yasui N (2009) Cervical and upper thoracic screwing for spinal fusion: strategy for its safe insertion to avoid major complications. Arch Ortho Trauma Surg 129:1447–1452
14. Wang MY (2007) Cervical crossing laminar screws: early clinical results and complications. Oper Neurosurg 2:311–316
15. Wright N (2004) Posterior C2 fixation using bilateral, crossing C2 laminar screws. J Spinal Disord Tech 17:158–162
16. Yusof MI, Shamsi SS (2012) Translaminar screw fixation of the cervical spine in Asian population: feasibility and safety consideration based on computerized tomography measurements. Surg Radiol Anat 34(3):203–207