Modified transcorporeal anterior cervical microforaminotomy assisted by O-arm-based navigation: a technical case report

Jin-Sung Kim · Sang Soo Eun · Nicolas Prada ·
Gun Choi · Sang-Ho Lee

Received: 29 December 2009 / Revised: 16 March 2010 / Accepted: 9 May 2010 / Published online: 21 May 2010
© Springer-Verlag 2010

Abstract This study was done to present our surgical experience of modified transcorporeal anterior cervical microforaminotomy (MTACM) assisted by the O-arm-based navigation system for the treatment of cervical disc herniation. We present eight patients with foraminal disc herniations at the C5–C6, C6–C7, and C7–T1 levels. All patients had unilateral radicular arm pain and motor weakness. The inclusion criteria for the patients were the presence of single-level unilateral foraminal cervical disc herniation manifesting persistent radiculopathy despite conservative treatment. Hard disc herniation, down-migrated disc herniation, concomitant moderate to severe bony spur and foraminal stenosis were excluded. We performed MTACM to expose the foraminal area of the cervical disc and removed the herniated disc fragments successfully using O-arm-based navigation. Postoperatively, the patients' symptoms improved and there was no instability during the follow-up period. MTACM assisted by O-arm-based navigation is an effective, safe, and precise minimally invasive procedure that tends to preserve non-degenerated structures as much as possible while providing a complete removal of ruptured disc fragments in the cervical spine.

Keywords Cervical disc herniation · Modified transcorporeal anterior cervical microforaminotomy · Minimally invasive · Navigation · O-arm

Introduction

Cervical radiculopathy is mainly a disease of the anterior relations of the cervical nerve root, with disc herniation and uncovertebral osteophytes accounting for the majority of cases. Since the introduction of anterior cervical discectomy and fusion (ACDF) for the surgical treatment of degenerated cervical disc diseases by Smith and Robinson [12] and then Cloward [4] in the 1950s, it has become a well-established treatment for single and multiple level degenerative cervical spine disease.

There were some disadvantages of instrumented fusion surgeries. Fusion was seen to reduce the motion of the segment, which result in further degeneration of the adjacent segments [5, 8].

Thus, the need arose for minimally invasive techniques that would address the underlying pathology without requiring fusion and which would have a minimal effect on the biomechanics of the spine.

The transcorporeal anterior microforaminotomy is one such technique. The advantage of this technique is that it provides direct decompression of the pathology with minimal violation of the disc space, thereby maintaining the integrity of the disc [2, 7]. It also decreases tissue damage associated with open techniques and shortens hospital stay and the speed of recovery [3].

The extensive use of 2D and 3D dimensional navigation systems during the last decade has assisted spinal surgeon to perform complex surgeries in a safer and less aggressive manner [9, 10]. New intraoperative techniques such as O-arm-based navigation guidance would have an impact on these procedures [13]. This type of image-guided technology provides an enormous amount of anatomic information, particularly in minimally invasive techniques. Aided by the computer imagery, surgeon's can more safely

J.-S. Kim (✉) · G. Choi · S.-H. Lee
Department of Neurosurgery, Wooridul Spine Hospital,
47-4 Chungdam-dong, Gangnam-gu, Seoul 135-100, Korea
e-mail: mddavidk@dreamwiz.com

S. S. Eun · N. Prada
Department of Orthopaedic surgery, Wooridul Spine Hospital,
Seoul, Korea

navigate complex anatomy, and more accurately complete the procedure making this technology particularly helpful for accurate cervical decompression.

At present, there are no reports in the literature of transcorporeal cervical microforaminotomy using intraoperative O-arm-based navigation. However, the applicability and safety of this system has been shown in pedicle screw application [10].

The authors report the results of eight patients with foraminal disc herniations at C5–C6, C6–C7, and C7–T1 who underwent modified transcorporeal anterior cervical microforaminotomy (MTACM) assisted by the O-arm-based navigation system and describe the surgical technique used. The present study was conducted to evaluate the technical feasibility and the efficacy of the intraoperative O-arm-based navigation system for transcorporeal cervical foraminotomy. This technique allows the removal of ruptured disc fragments while preserving the endplate of the disc and uncinete process. It also reduces both the surgeon's and patient's exposure to radiation from intraoperative imaging during spinal procedures.

Case report

Case 1

A 51-year-old woman presented with a chief complaint of left upper extremity pain radiating to the third and fourth fingers for 1 month. She could not sleep well due to severe pain and also complained of chronic neck pain. Her physical examination demonstrated left elbow extension of grade 3 and left wrist extension of grade 4–. On radiological investigation, magnetic resonance imaging (MRI) revealed

a herniated disc at the C6–C7 left foramen (Fig. 1). The computed tomography (CT) scan showed a soft disc herniation. We decided to perform MTACM assisted by O-arm-based navigation. Postoperatively, the patient's feeling of radiating pain was diminishing. Postoperative radiological scans showed no instability and good decompression (Fig. 1). At the latest follow-up, VAS score for arm pain and ODI were improved from 10 and 68.89% preoperatively to 1 and 14% at the 12-month follow-up.

Case 2

A 69-year-old man presented with radiating pain in his right arm and positive Hoffmann's sign. Radiological investigations revealed a right foraminal herniated disc at the C6–C7 level (Fig. 2). Similar to the first case, we performed the surgery with the aid of navigation and O-arm. Postoperatively, his symptoms improved significantly and his postoperative MRI showed a good decompression (Fig. 2).

We treated six more cases and their demographics are presented in Table 1. All patients showed improved VAS scores for neck and arm pain. They succeeded in returning to the previous work place and performing their daily activity. Temporary swallowing difficulty occurred in patients 3 and 7, postoperatively but these symptoms were absent by the last follow-up.

Surgical technique

The anterior microforaminotomy approach was innovated by Jho [7] in 1996 and since then, it has undergone various modifications. In his earlier procedures, Jho made his

Fig. 1 **a** Preoperative T2-weighted MR images in sagittal and axial plane show left foraminal disc herniation (white arrow). **b** Postoperative T2-weighted MR images show adequate decompression and the direction of the drill hole

Fig. 2 **a** Preoperative T2-weighted MR images in sagittal and axial plane show right foraminal disc herniation. **b** Postoperative T2-weighted MR images show adequate decompression and the direction of the drill hole

Table 1 Demographics for patients who underwent transcorporeal anterior cervical microforaminotomy assisted by O-arm-based navigation

Case number	Sex	Age	Cervical disc level	Intraoperative bleeding (cc)	Operation time (min)	Hospital stay (days)	Follow up duration (months)
1	F	51	C6–C7	50	90	4	12
2	M	69	C6–C7	100	120	2	6
3	M	69	C5–C6	90	150	6	8
4	M	70	C7–T1	100	180	2	8
5	F	45	C6–C7	100	75	3	12
6	M	56	C5–C6	150	135	5	7
7	F	50	C5–C6	190	165	6	9
8	M	61	C5–C6	200	215	4	6

approach from the uncovertebral joint of the vertebra below the affected disc, just medial to the transverse foramen, which he later modified and the entry point was made more superior due to the cephalad nature of the cervical discs. Hacker and Miller [6] reported that anterior cervical foraminotomy, which remove uncovertebral joint and partial lateral annulus showed high reoperation rate. Choi [2] presented a modified version, which involves a more medial approach than the entry point described by Jho. This MTACM has two advantages over anterior microforaminotomy. One is that the vertebral artery is not placed in jeopardy. The second is that the risk of postoperative kyphosis may be reduced.

Intraoperatively, O-arm imaging (Medtronic Sofamor Danek, Memphis, TN, USA) and navigation in the Stealth Station (Medtronic Sofamor Danek) of the cervical spine level to be operated on is obtained. O-arm is an intraoperative conebeam CT scan that provides three-dimensional visualization. The image data are transferred to the central control unit of the navigation system. The quality of the CT scans is of paramount importance. Using the planning module of the system, the spine is re-constructed and displayed in anterior-posterior, lateral and frontal views as well as a 3D image. This provides the opportunity to study the anatomy in detail and to plan the decompression.

The coordinates of three to six intraoperatively identifiable anatomical landmarks of the level to be decompressed are obtained for use in the matching procedure during the surgery. The infrared camera is positioned at the

caudal end of the operation table and the dynamic reference base is fixed to the contralateral shoulder of the patient (Fig. 3). A technician operates the system under the surgeon's orders. For the matching procedure, the intraoperatively chosen anatomic landmarks are located on the patient. Using a special algorithm, the computer then matches the “virtual world” of the CT image with the “real world” of the patient's anatomy.

An accuracy check, which is a crucial step in the procedure, is performed to verify the quality of the matching. The surgeon has to assess and decide whether the matching accuracy is acceptable for safe navigation by comparing the position of the instrument in the operative field with the displayed position of the instrument in the CT image on the monitor. If the accuracy is insufficient, the matching procedure must be repeated. This allows the surgeon to adjust the direction of the drill into the patient's anatomy and to prepare for safe and adequately directed transcorporeal drilling.

Under general anaesthesia, the patient is placed in a supine position with nerve intramuscular monitoring (NIM). The surgical approach is made ipsilateral to the affected side similar to the conventional anterior cervical discectomy except that the transverse skin incision is made at one level higher than the affected disc level as described by Choi, which is usually made 1 cm from the midline.

Once the prevertebral fascia is opened, finger dissection is done, then the Metrix tubular retractor (1.8 or 2.0 cm diameter) is positioned to expose the adequate portion of the superior to index disc level, and the medial portion of

Fig. 3 **a** Operation room setting. 1 Navigation monitor, 2 dynamic reference frame, 3 O-arm, 4 nerve intramuscular monitoring machine. **b** O-arm is scanning intraoperative CT. Operation field is draped with sterile plastic sheet. **c** Post-operative 3D CT shows drill hole

the corresponding uncinate process without violation of the longus colli (Fig. 4).

In this technique, the affected disc level is exposed but there is no need to expose the lower vertebra of the affected segment. The position of the drill hole is 4–6 mm above the lower border of the exposed vertebra (approximately mid-body level), at the level of the medial border of LCM. The trajectory of the tunnel is decided depending on the location of the target identified on intraoperative O-arm imaging and navigation in the Stealth Station (Fig. 5).

The trajectory was started from the vertebra above the herniated level, and the entry point was made 4–5 mm above the inferior endplate of the upper vertebra at the level of the medial border of the longus colli muscle. The trajectory is directed in a medial to lateral direction and downwards towards the affected disc with the end point of the trajectory ending at the foraminal level of the disc below. A 4 × 5-mm drill hole is made.

Care is taken to avoid damage to the medial wall of the transverse foramen as well as to preserve the integrity of

the underlying end plate especially in the anterior two-thirds of the disc. Due to the obliquity of the cervical disc, this trajectory leads directly to the pathological site in the foramen.

Initially, a 4-mm matchstick type diamond burr is used with a high-speed drill (Black Max, Anspach, Palm Beach Gardens, FL, USA) to start the drill hole from the desired point. Subsequently, we may need to change to a 3-mm burr tip for better visualization and fine drilling. The trajectory and depth of drilling is usually checked once by O-arm scan (Fig. 6).

Once the posterior limit of the drill hole is reached, we use the side-cutting edge of the longer burr tip to expand the hole. The posterior longitudinal ligament still acts as a protective barrier between the instruments and the neural structures. The spongy bone of the cervical vertebra acts as a visual guide for the progress of the drilling process.

When the thin, ivory white cortical shell of the posterior vertebral wall is encountered, the drilling is stopped, and gentle, careful lifting of the cortical shell is achieved with thin bone punches and a curette. At this point, if some epidural bleeding is encountered, it can be managed by using Avitene (MedChem Products, Woburn, MA, USA) for some time, but use of bipolar coagulation is to be discouraged. After opening the posterior wall of the foraminotomy hole, one can visualize the herniated disc fragment and the hypertrophied uncovertebral region, which can be gently removed with a combination of microcurettes, micro punch, and a blunt hook. Finally, the adequacy of the foraminal decompression is checked by blunt hook palpation of the superior and inferior pedicles along the course of the nerve root. The surgeon can decide to scan O-arm for final confirmation if necessary (Fig. 7). Workflow and time needed in each step is described in Table 2.

Fig. 4 **a** Metrix tubular retractor was used. **b** Length of the wound was 2.5 cm

Fig. 5 **a** Skin entry point and **b** trajectory were decided by navigation probe

Fig. 6 Intraoperative O-arm images showing depth and trajectory of drill hole, **a** drill hole has not reached posterior cortex. **b** Foraminotomy is completed with adequate width for disc removal

Fig. 7 Intraoperative O-arm images show depth of drill hole in three planes

Table 2 O-arm workflow

Procedures	Time (minutes)
Draping	3
Moving O-arm into surgical field/ensure camera visibility	6
Scanning	1
Parking O-arm	3
Uncovering sterile drape	1
Ready to go	14

Discussion

Image-guided surgery can assist significantly in the access for surgical decompression in a variety of cervical disorders. The surgeon is allowed real-time navigation of the cervical spine, with the advantage of mapping anatomic distances and trajectories without fear of neurological

injury. Image-guided surgery also defines the orientation of surgical decompression when anatomic topographic cues make a midline location difficult to appreciate [10, 11].

Computer navigation systems are based on the principle of stereotaxis. Stereotactic operation techniques have been used in brain surgery since the beginning of the century to guide the surgical instrument into a certain target area [10]. The exact coordinates of the level to decompress can be defined by a 3-D CT.

Percutaneous cervical spine interventions require adequate knowledge of tissues in and near the target site of surgery. Currently, no single imaging technology is sufficient for imaging both bone and soft tissue adequately. CT is best for visualizing bone and certain soft tissue structures and also provides superior instrument tip visualization when navigating in high risk areas, such as the cervical spine.

Accurate intraoperative visualization of spinal anatomy is a crucial element in enabling minimally invasive, percutaneous cervical spine surgery [3]. Precision is critical because of the proximity to nerve roots, the spinal cord, and vertebral artery; that is why any minimally invasive approach to the cervical spine depends on high quality images so the surgeon can work within this complex anatomy when the surgical exposure is very small. However, accurate knowledge of spinal anatomy is totally dependent on the surgeon's experience and the ability to visualize anatomic structures three dimensionally.

Navigation in the Stealth Station (Medtronic Sofamor Danek) is a combination of specialized surgical hardware and image-guidance software that allows tracking of the position of a surgical instrument in the operating room, and to continuously update this position within one or more images (coronal, transaxial, and sagittal planes) acquired from intraoperative O-arm imaging (Medtronic Sofamor Danek). The advantages of this “virtual” navigation over conventional fluoroscopic navigation include the ability to navigate using multiple CT views simultaneously and a significant reduction in the amount of radiation exposure [9, 13]. In order to have optimal information about the surgical field and to assure maximum accuracy in minimally invasive cervical spine decompressions, it is essential to determine the location of instruments and anatomical structures. Intraoperative CT provides the surgeon with means to evaluate the spinal anatomy, correct the surgical path, and to assess for correct instrument placing. The accuracy of tip definition with new generation O-arms is considered sufficiently accurate for surgical planning and intraoperative targeting [1]. During transcorporeal foraminotomy, localization of the correct surgical level, and surgical margin to be decompressed is checked by intraoperative O-arm-based navigation. Navigation facilitates identification of an appropriate skin entry point, which is

very important since the whole procedure depends on a narrow ranged trajectory made by Metrix tubular retractor. If the starting point is far apart from the right trajectory, it will be cumbersome work to reach the target. Using intraoperative O-arm-based navigation also decreases the size of the skin incision and drill hole compared to procedures without it. Our skin incision was 2–2.5 cm, and the drill hole size was 4–5 mm when compared with 3–4 cm and 6–7 mm in Choi's method, respectively.

O-arm allows the surgeon to check how deep the drill trajectory has been made and whether it is heading in the right direction. The images provide feedback intraoperatively. Moreover, if the position of patient has been changed, navigation reregistration is feasible and fast when using O-arm.

Even though the operation time may be longer than with conventional procedures, the efficacy and safety of this technique compensate the longer operation time.

As with any other technique, there is a learning curve in using the MTACM assisted by computed tomography-based navigation system. Surgeons have to practice the use of the planning module, i.e., interpretation of unfamiliar CT image projections and identification of anatomic landmarks in the CT as well as in the operative field. Moreover, they have to learn to judge the quality of the accuracy check, in order to decide whether to proceed with the navigation process or to perform a new matching procedure. The navigation system is no substitute for intensive training in spinal surgery. Furthermore, the surgeon has to have the experience to recognize possible problems with the system and to perform the procedure with a conventional technique if necessary. Adequate training and critical awareness of the problems are key for the successful and safe use of MTACM assisted by the computed tomography-based navigation system. There are some drawbacks to the current report that deserve mentioning; the study had small case series, uncontrolled review of the clinical outcomes achieved during a short follow-up period.

Conclusion

The potential to improve the accuracy of anterior cervical decompression, as well as to perform minimally invasive procedures is an attractive feature of image guidance spinal surgery. Spine navigation is also invaluable in defining the orientation of surgical decompression when anatomic topographic cues make the location difficult to appreciate. MTACM assisted by a computed tomography-based

navigation system is a good, safe, and effective option for the treatment of cervical radiculopathy and preserves non-degenerated structures.

Acknowledgments The authors wish to thank Je Min Son and In-Sook Cho for their assistance with this study. This study was supported by a grant from the Wooridul Spine Hospital.

Conflict of interest statement None of the authors has any potential conflict of interest.

References

1. Bucholz RD, Ho HW, Rubin JP (1993) Variables affecting the accuracy of stereotactic localization using computerized tomography. *J Neurosurg* 79:667–673
2. Choi G, Lee SH, Bhanot A, Chae YS, Jung B, Lee S (2007) Modified transcorporeal anterior cervical microforaminotomy for cervical radiculopathy: a technical note and early results. *Eur Spine J* 16:1387–1393
3. Cleary K, Clifford M, Stoianovici D, Freedman M, Mun SK, Watson V (2002) Technology improvements for image-guided and minimally invasive spine procedures. *IEEE Trans Inf Technol Biomed* 6:249–261
4. Cloward RB (2007) The anterior approach for removal of ruptured cervical disks. 1958. *J Neurosurg Spine* 6:496–511
5. Eck JC, Humphreys SC, Lim TH, Jeong ST, Kim JG, Hodges SD, An HS (2002) Biomechanical study on the effect of cervical spine fusion on adjacent-level intradiscal pressure and segmental motion. *Spine* 27:2431–2434
6. Hacker RJ, Miller CG (2003) Failed anterior cervical foraminotomy. *J Neurosurg* 98:126–130
7. Jho HD, Kim WK, Kim MH (2002) Anterior microforaminotomy for treatment of cervical radiculopathy: part 1—disc-preserving “functional cervical disc surgery”. *Neurosurgery* 51(Suppl 5):S46–S53
8. Lopez-Espina CG, Amirouche F, Havalad V (2006) Multilevel cervical fusion and its effect on disc degeneration and osteophyte formation. *Spine* 31:972–978
9. Nolte LP, Slomczykowski MA, Berlemann U, Strauss MJ, Hofstetter R, Schlenzka D, Laine T, Lund T (2000) A new approach to computer-aided spine surgery: fluoroscopy-based surgical navigation. *Eur Spine J* 9(Suppl 1):S78–S88
10. Schlenzka D, Laine T, Lund T (2000) Computer-assisted spine surgery. *Eur Spine J* 9:S57–S64
11. Singh K, Vaccaro AR (2003) Computer-assisted image-guided cervical spine surgery. *Tech Orthop* 17:374–381
12. Smith GW, Robinson RA (1958) The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion. *J Bone Joint Surg Am* 40:607–624
13. Smith HE, Welsch MD, Sasso RC, Vaccaro AR (2008) Comparison of radiation exposure in lumbar pedicle screw placement with fluoroscopy vs computer-assisted image guidance with intraoperative three-dimensional imaging. *J Spinal Cord Med* 31:532–537