Int J Clin Exp Med 2016;9(7):14191-14197
www.ijcem.com /ISSN:1940-5901/IJCEM0022772

Original Article

Application of spinal navigation with the intra-operative three-dimensional (3D)-imaging modality in difficult pedicle screw fixation

Feng-Xian Wang, Xing Yu, Lian-Yong Bi, Ji-Zhou Yang, Yong Jiao, Lin Xu

Department of Orthopaedics, Dongzhimen Hospital Affiliated to Beijing University of Chinese Medicine, Beijing 100700, China

Received December 27, 2015; Accepted May 18, 2016; Epub July 15, 2016; Published July 30, 2016

Abstract: The aim of this study was to evaluate the efficacy and safety of an application using spinal navigation with the intra-operative three-dimensional (3D)-imaging modality in difficult pedicle screw fixation. 78 patients with congenital deformity of spinal column and spinal cord (41 cases) or spinal instability after laminectomy or semi-laminectomy (37 cases) were instrumented with pedicle screw system by spinal navigation with the intra-operative 3D-imaging system from September 2004 to September 2014 in our orthopedic department. The position of pedicle screw was assessed by intra-operative 3D-imaging system. The excellent rate of pedicle screw position, mean time of pedicle screw implanted, operating time, blood loss, post-operative complication were recorded. The excellent rate of pedicle screw position was 96% in these cases. The mean time of pedicle screw implanted, operating time and blood loss were 3.90±0.87 minutes, 147±65 minutes and 312±185 ml, respectively. There was no implant-related complication that occurred during operation. With spinal navigation combined with the intra-operative 3D-imaging modality, implantation of difficult pedicle screw in patients with congenital spinal deformity or spinal instability after laminectomy or semi-laminectomy is more simplified, more accurate, safer, and shorter time-consuming.

Keywords: Spinal navigation, 3D-imaging, pedicle screw, spinal deformity, revision

Introduction

Since popularized by Roy Camille, pedicle screws are widely used in combination with rods or plates (internal fixator) for spinal fixation in the treatment of spinal deformities, tumors, inflammation, trauma and degenerative diseases [1]. The pedicle adjacent to spinal cord, nerve roots, large blood vessels and internal organs and other important structures, once implanted deviations can lead to serious consequences [2]. How to improve the accuracy and safety of pedicle screw implantation has been the focus of the spine surgeons. Spinal deformity correction and revision after laminectomy spinal instability, due to anatomical variation or absence, make the pedicle screw fixation face greater difficulty and risk [3, 4]. With conventional X-ray fluoroscopy, positioning or guiding in the surgery, doctors and patients will increase the X-ray exposure [5, 6], moreover, it is difficult to ensure the accuracy of operation.

Since image navigation technique is applied in the spinal surgery, clinical practice has confirmed the image navigation system can significantly improve the accuracy and safety of pedicle screw implantation [7-9], especially in recent years, intraoperative three-dimensional (3D)-imaging navigation technology has its superiority [10, 11].

In September 2003, we started intraoperative 3D imaging navigation in the spine pedicle screw fixation, which is now routinely used to all kinds of spinal pedicle screw implantation, more than two thousands cases of intraoperative 3D imaging-guided surgery have been completed until September 2014, including complex implants such as pedicle screw spinal cord deformity, spinal instability after laminectomy of revision surgery in 58 cases, the application results and experience will now be reported as follows.

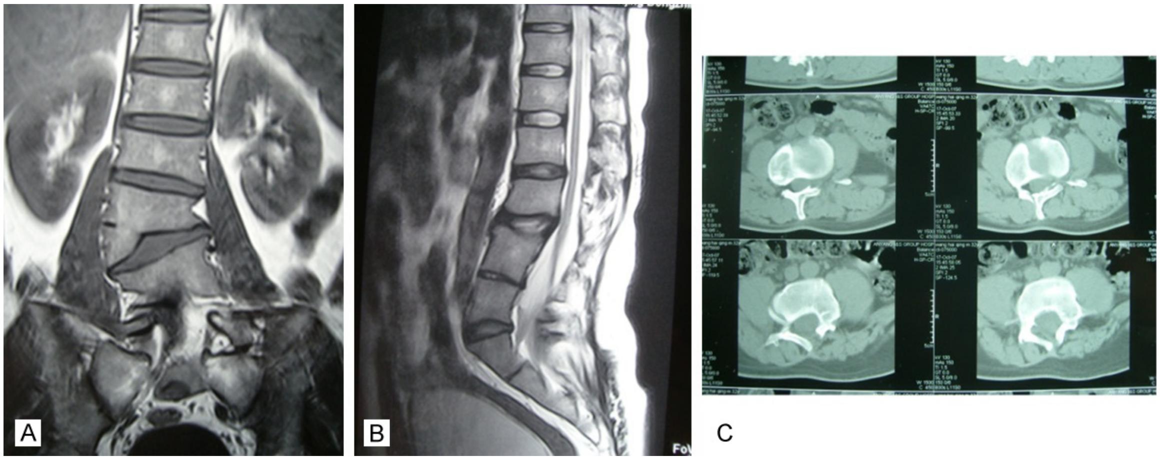

Figure 1. Congenital scoliosis, tethered cord syndrome in a typical case (male, 32 years old). A: Preoperative coronal MRI shows that, the right part of L3 vertebral body with L4 semi vertebral fusion, right part of the L5 vertebral body dysplasia, and sacral structure confusion. B: Preoperative sagittal MRI shows that, the position of conus medullaris is low (L4 level), with thickened filum terminale. C: Preoperative CT shows that L4 vertebral dysplasia.

Methods

General clinical data

From September 2003 to September 2014, we used pedicle screw fixation in 58 patients with spinal deformity, spinal instability after laminectomy surgery. Spinal deformity in which 31 cases: 20 males and 11 females, aged 14-55 years (mean 28.6 years). Including congenital scoliosis and (or) kyphosis due to semi vertebral deformities or butterfly vertebrae, vertebral lamina section or incomplete pedicle dysplasia, two of the spinal cord, tethered cord, etc. (**Figure 1**). Thoracolumbar 12 cases, 19 cases of lumbosacral, 262 pedicle screws were implanted. Laminectomy spinal instability 27 cases: 15 males and 12 females, aged 34-85 years (mean age: 67.4 years old). Laminectomy 19 cases, semi-laminectomy or windows 8 cases, 6 cases of single segment, double or multi-segment 21 cases, 5 cases of thoracolumbar, lumbar or lumbosacral 22 cases of vertebral implants pedicle screw 164. In all cases, pedicle screws were implanted under the guidance of 3D imaging of spine navigation system. Internal fixation system adopts the Sofamo-Danek company Tenor, Texas Scottish Rite Hospital (TSRH), TSRH-3D, M8 pedicle screw fixation system. This study was conducted in accordance with the declaration of Helsinki. This study was conducted with approval from the Ethics Committee of Dongzhimen Hospital affiliated to Beijing University of Chinese Medicine. Written informed consent was obtained from all participants.

Operation process

Operation bed and posture mat can pass through X-ray, navigation infrared camera on the operating table headed; workstation is placed opposite the surgeon. Preoperative, intraoperative 3D-imaging systems and spinal navigation system is connected, and to working state. According to the traditional posterior middle approach to expose the posterior spinal structures, the navigation reference base to be fixed for pedicle screw fixation segments of the head end of a vertebral spinous process (If this spinous agenesis may apply to head-end fixed, fixation must be exact). Then regional Spinal surgery 3D data are collected followed by three-dimensional imaging system (Automatic center rotate 190 degrees, such as image acquisition 256 frames two-dimensional image, 3D image reconstruction, a total of 2 minutes, 3D imaging system software upgrade later reduced to 1 minute). The data is transferred to the spine navigation system workstation after image acquisition is completed (1 minute). According to the navigation monitor real time dynamic display, surgeons determine the most ideal pedicle screw trajectories (**Figure 2**), the pedicle open device placed in the desired trajectory screws into the needle point, according to the monitor display on track in turn into pedicle probes and tapping, according to the image

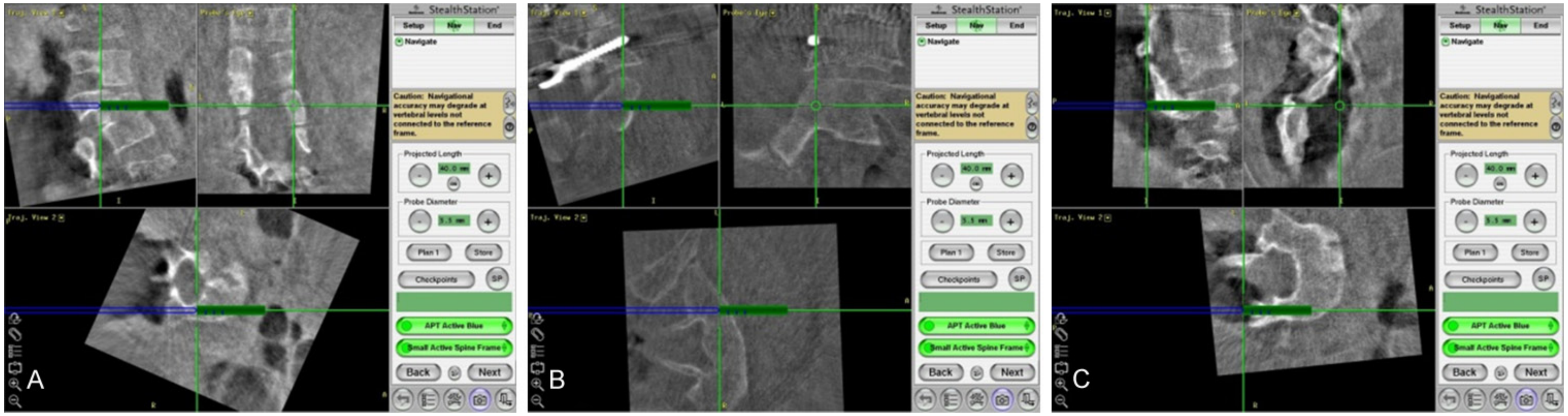

Figure 2. The result of the navigation monitor real time dynamic display. A: According to the navigation monitor real time dynamic display, one side of L3 pedicle screw was implanted. Green column shows screw desired trajectory, hollow blue column shows real-time line of display device or screw. B: One side of S1 pedicle screw was implanted. It's visible that the position of L5 pedicle screw is accurate. C: One side of L4 pedicle screw was implanted.

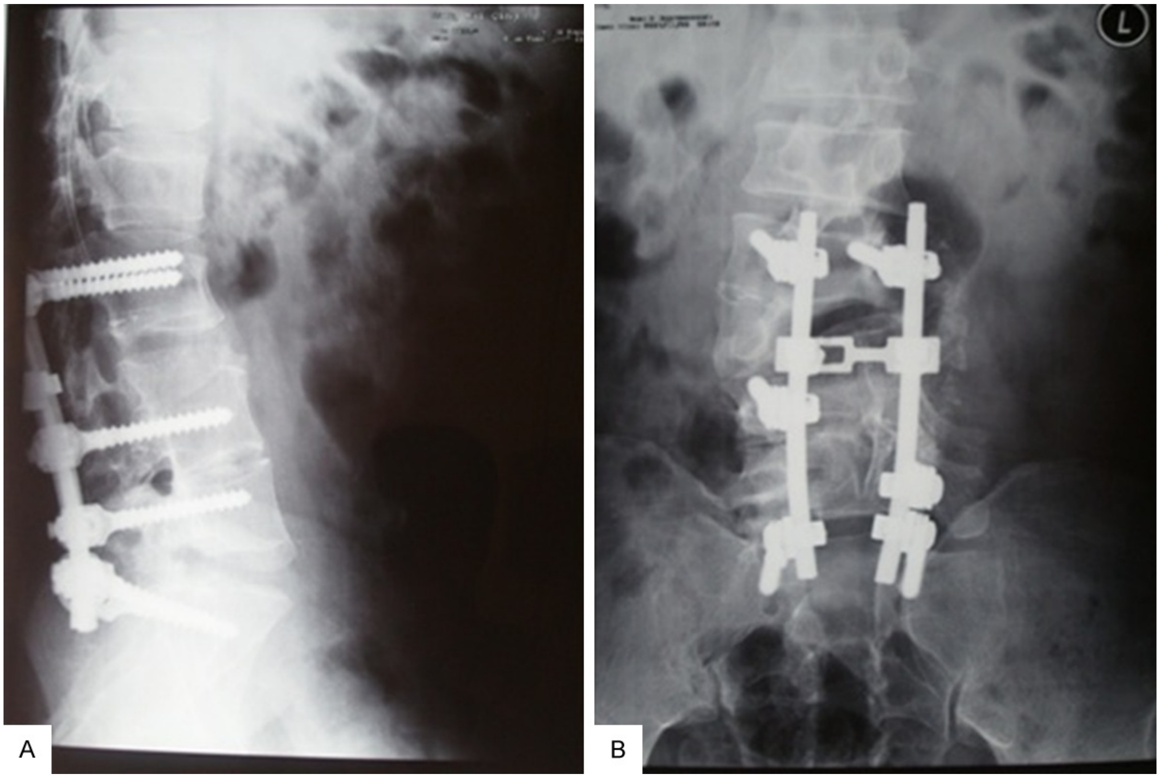

Figure 3. The result of postoperative X-ray. Postoperative X-ray shows that the L3-S1 implantation of 6 pedicle screws is accurate.

display, select the appropriate thickness, the length of the pedicle screw, along the open good pedicle screw into the channel (**Figure 2**). After all screws inserted instantly using intraoperative 3D imaging system to scan and evaluate. Adjust if 3D image screws penetrated pedicle cortex and > 2.0 mm or deviate from the pedicle or screw through the anterior edge of > 2.0 mm.

Intraoperative considerations

Pay attention to whether navigation spines reference base is loose, tighten any loose nuts. If the reference base with fixed spinous process displacement, you need to fix them exactly, then transfer the re-scanned image data; Avoid open device installed in the pedicle, probes, and tapping on the dynamic reference base loosened, tighten if loose at any time, otherwise navigation monitor real-time dynamic display pedicle screw trajectory will drift, resulting in misleading; Gentle operation, press the track displayed on the monitor for any operation, the operator scans the local position of the spine to maintain shape.

Scan evaluation

To not pass through the pedicle wall, constant depth over vertebrae 2/3 but did not penetrate the leading edge were assessed as excellent. The rest is just the deviation, including the inner deviation and outer deviation, cephalad deviation, caudal deviation and front deviation, and measure the distance corresponding deviation.

Records of each screw fixation time (minutes)

The same patients each screw placement time = total screws placement time/the number of screws. Screw placement total time: from 3D imaging system collecting data to 3D imaging system satisfaction evaluation of screw position. Record the total blood loss and time, record postoperative complications.

Results

Accuracy of pedicle screw

58 cases were implanted in 426 pedicle screws, 409 of them were assessed as excel-

lent position (excellent rate of 96%), 17 screws perforated pedicle cortex, of which cephalad deviation 7, the outer deviation 6, the caudal deviation 2, the inner deviation 2 and the front deviation 1, but the distance deviation is < 2.0 mm, not adjusted. Postoperative X-ray shows the location of pedicle screw is satisfied (**Figure 3**).

Pedicle screw placement time and total blood loss and screw related complications

This group of cases per pedicle screws implantation time was 3.90±0.87 minutes, operation time was 147±65 minutes, the blood loss was 312±185 ml. No screw implant related complications were found. We have another group of lumbar degenerative disease pedicle screw fixation cases of 352 cases, 2062 pedicle screws were implanted, the average pedicle screws implantation time was 3.70±0.65 minutes (another paper published). The average pedicle screw placement time of the two groups were compared, no significant difference, t=0.095, *P*=0.925 > 0.05.

Discussion

Pedicle screw fixation, because of its strong three-column fixation, good biomechanical properties, has been widely accepted by scholars all over the world, and through the improvement and development of more than half a century, has been widely used in the treatment of spinal diseases.

Based on anatomical characteristics of the pedicle, adjacent to the spinal cord, nerve roots, organs and large blood vessels, it's important to implant the pedicle screws correctly. Method now widely used is based on the anatomical location (such as the Roy-Camille method, Weinstein method, etc.) and the intraoperative C arm fluoroscopy monitoring. Even so, the reports of pedicle screw implantation related complications still appear constantly [12]. For pedicle screw fixation of congenital spinal deformity surgery and postoperative spinal instability in the revision, the difficulty and risks increase exponentially. Doctors can only ensure accurate screw placement through repeated fluoroscopy. The image of spinal navigation technology provides the possibility for these complex fast and accurate pedicle screw implants [13, 14]. In brief, spinal navigation system can match the preoperative or intraoperative image data with the patient's anatomy [15-17], and the location of surgical instruments on the navigation screen in the form of a virtual probe real-time display, so that doctors can figure out the relationship between surgical instruments and patient's anatomical structures, thereby increasing the safety of spinal surgery. Clinical effects were compared between spinal navigation and traditional methods on 100 T9-S1 pedicle screw patients by Laine et al [18], the result was, navigation group of pedicle screw perforation rate was 4.1%, while the traditional technology of perforation rate was 15.9%. My result is that navigation group pedicle screw perforation rate was 3.1%, perforation were less than 2 mm, do not need to re-adjust; while the traditional technique perforation rate of 14.4%, of which 6.5% the screw perforation were greater than 2 mm, need to re-adjust. In this study, 409 of 426 pedicle screws were in good locations, the excellent rate was 96%, compared with the normal anatomy of navigation guided lumbar pedicle screw implantation, there was no difference in excellent rate and average each screw fixation time. This shows not only the accuracy of three-dimensional spinal navigation surgery in pedicle screw implantation, but also a more advantage than traditional methods in the complex case, such as anatomical variation or deficiency.

Currently there are three methods, including preoperative CT imaging navigation, C arm fluoroscopy image navigation and intraoperative 3D imaging navigation [19]. Preoperative CT image guidance requires detailed preoperative CT scan data, furthermore, because of the preoperative and intraoperative different position, in order to avoid the error between the virtual image data and actual anatomical structure caused by postures, breathing or operative changes, matching process must be in operation (point matching and surface matching). This not only requires the patient with a complete spinal lamina structure (spinal instability after laminectomy refurbishment cases has been limited), but also requires the surgeon must be familiar with the use of program modules, and can accurately determine the operative field in CT and anatomical landmarks. The matching process takes a long time, matching the high failure rate. Its advantages are high image quality, especially in the thoracic or cervical spine where the effects of image 3D reconstruction are easily affected. C-arm fluoroscopy imaging navigation system is also known as a "virtual X-ray scanning system", is a major development in the preoperative image navigation technology based on CT. Automatic registration process of perspective in the matching process, avoid the time-consuming. Surgeons are very familiar with the process of intraoperative fluoroscopy, short learning curve process, easy to operate. The disadvantage is the lack of tomographic images, three-dimensional operations with reference to two images, there will be some geometric errors. In addition, for the cervical and upper thoracic spine and severe spinal flexion rotation deformity patients, the application is limited. Intraoperative 3-D image guidance technology is a further development based on the intraoperative X-ray image guidance technology [20, 21], has the advantages of two kinds of navigation, only one scanning process; there is no position error, without matching process, without requirement for spinal posterior structure integrity. The more complex spinal deformity, and anatomical structure is not clear, the more superiority of intraoperative 3D image navigation systems can be reflected. Drawback is expensive equipment, widespread difficulties. It was reported that there is drift navigation, but I think that, after summarizing thousands of cases of navigation experience, most of the drift is man-made, can be avoided. Of course, navigation technology, even the most advanced 3D image-guided surgery, it is only a kind of auxiliary means. Performer of mastery of spinal anatomy, biomechanics and other basic knowledge and traditional operation experience are still the most important.

In short, intraoperative 3-D image navigation in thoracolumbar spinal deformity correction and spinal instability after laminectomy overhaul pedicle screw implantation surgery, can obviously improve the accuracy of pedicle screw implantation, reduce screw implant related complications, shorten the operation time, has obvious superiority compared with traditional X-ray perspective.

Disclosure of conflict of interest

None.

Address correspondence to: Xing Yu, Department of Orthopaedics, Dongzhimen Hospital Affiliated to Beijing University of Chinese Medicine, Beijing 100700, China. Tel: +86 10 84013134; Fax: +86 10 84013364; E-mail: yxdoccn@163.com

References

[1] Sanborn MR, Thawani JP, Whitmore RG, Shmulevich M, Hardy B, Benedetto C, Malhotra NR, Marcotte P, Welch WC, Dante S and Stein SC. Cost effectiveness of confirmatory techniques for placement of pedicle screws. Neurosurgical Focus 2012; 33: E12.

[2] Lonner BS, Auerbach JD, Estreicher MB and Kean KE. Thoracic pedicle screw instrumentation: the learning curve and evolution in technique in the treatment of adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 2009; 34: 2158-2164.

[3] Samdani AF, Ranade A, Saldanha V and Yondorf MZ. Learning curve for placement of thoracic pedicle screws in the deformed spine. Neurosurgery 2010; 66: 290-294.

[4] Smorgick Y, Millgram MA, Anekstein Y, Floman Y and Mirovsky Y. Accuracy and safety of thoracic pedicle screw placement in spinal deformities. J Spinal Disord Tech 2005; 18: 522-526.

[5] Abdullah KG, Bishop FS, Lubelski D, Steinmetz MP, Benzel EC and Mroz TE. Radiation exposure to the spine surgeon in lumbar and thoracolumbar fusions with the use of an intraoperative computed tomographic 3-Dimensional imaging system. Spine (Phila Pa 1976) 2012; 37: e1074-e1078.

[6] Kim CW, Lee YP, Taylor W, Oygar A and Kim WK. Use of navigation-assisted fluoroscopy to decrease radiation exposure during minimally invasive spine surgery. Spine J 2008; 8: 584-590.

[7] Holly LT and Foley KT. Intraoperative spinal navigation. Spine (Phila Pa 1976) 2003; 28: S54-S61.

[8] Gelalis ID, Paschos NK, Pakos EE, Politis AN, Arnaoutoglou CM, Karageorgos AC, Ploumis A and Xenakis TA. Accuracy of pedicle screw placement: a systematic review of prospective in vivo studies comparing free hand, fluoroscopy guidance and navigation techniques. Eur Spine J 2012; 21: 247-255.

[9] Shin BJ, James AR, Njoku IU and Härtl R. Pedicle screw navigation: a systematic review and meta-analysis of perforation risk for computer-navigated versus freehand insertion. J Neurosurg Spine 2012; 17: 113-122.

[10] Wood M and Mannion R. A comparison of CT-based navigation techniques for minimally in-

vasive lumbar pedicle screw placement. J Spinal Disord Tech 2011; 24: E1-E5.
[11] Yu X, Xu L and Bi LY. Spinal navigation with intra-operative 3D-imaging modality in lumbar pedicle screw fixation. Zhonghua Yi Xue Za Zhi 2008; 88: 1905-1908.
[12] Fisher CG, Sahajpal V, Keynan O, Boyd M, Graeb D, Bailey C, Panagiotopoulos K and Dvorak MF. Accuracy and safety of pedicle screw fixation in thoracic spine trauma. J Neurosurg Spine 2006; 5: 520-526.
[13] Amato V, Giannachi L, Irace C and Corona C. Accuracy of pedicle screw placement in the lumbosacral spine using conventional technique: computed tomography postoperative assessment in 102 consecutive patients. J Neurosurg Spine 2010; 12: 306-313.
[14] Ughwanogho E, Patel NM, Baldwin KD, Sampson NR and Flynn JM. Computed tomography-guided navigation of thoracic pedicle screws for adolescent idiopathic scoliosis results in more accurate placement and less screw removal. Spine (Phila Pa 1976) 2012; 37: E473-E478.
[15] Cho JY, Chan CK, Lee SH and Lee HY. The accuracy of 3D image navigation with a cutaneously fixed dynamic reference frame in minimally invasive transforaminal lumbar interbody fusion. Comput Aided Surg 2012; 17: 300-309.
[16] Waschke A, Walter J, Duenisch P, Reichart R, Kalff R and Ewald C. CT-navigation versus fluoroscopy-guided placement of pedicle screws at the thoracolumbar spine: single center experience of 4,500 screws. Eur Spine J 2013; 22: 654-660.
[17] Hodges SD, Eck JC and Newton D. Analysis of CT-based navigation system for pedicle screw placement. Orthopedics 2012; 35: e1221-e1224.
[18] Laine T, Lund T, Ylikoski M, Lohikoski J and Schlenzka D. Accuracy of pedicle screw insertion with and without computer assistance: a randomized controlled clinical study in 100 consecutive patients. Eur Spine J 2000; 9: 235-240.
[19] Mezger U, Jendrewski C and Bartels M. Navigation in surgery. Langenbecks Arch Surg 2013; 398: 501-514.
[20] Acosta FL Jr, Thompson TL, Campbell S, Weinstein PR and Ames CP. Use of inra-operative isocentric C-arm 3-D fluoroscopy for sextant percutaneous pedicle screw placement: case report and review of the literature. Spine J 2005; 5: 339-343.
[21] Tabaraee E, Gibson AG, Karahalios DG, Potts EA, Mobasser JP and Burch S. Intraoperative cone beam-computed tomography with navigation (O-ARM) versus conventional fluoroscopy (C-ARM): a cadaveric study comparing accuracy, efficiency, and safety for spinal instrumentation. Spine (Phila Pa 1976) 2013; 38: 1953-1958.