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ORIGINAL ARTICLE

# Assisted dorso-lumbar instrumentation with O-arm neuronavegation and minimally invasive surgery: clinical-surgical outcome

## *Instrumentación dorso-lumbar asistida con neuronavegación O-arm y cirugía mínimamente invasiva: resultados clínico-quirúrgicos*

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## Abstract

**Objective:** *To evaluate the clinical-surgical outcomes after dorso-lumbar instrumentation using O-arm assisted neuronavigation and minimally invasive surgery.* **Method:** *In this retrospective cohort, 104 patients who underwent dorso-lumbar instrumentation with the use of O-arm from September 2013 to May 2020 were studied. Variables investigated included: symptoms, number of screws, levels approached, bleeding, surgical time, hospital stay, complications and clinical improvement after the surgical procedure.* **Results:** *The most frequent symptoms were: unilateral or bilateral radiculopathy of the pelvic extremities, paresthesia, mechanical low back pain and progressive decrease in strength. A total of 542 screws were placed, with the lumbar spine being the site with the highest prevalence. The average bleeding, surgical time, and hospital stay was: 50 ml, 160 minutes, and 24 hours, respectively. The most frequent complications were: Residual neuropathy, dura mater tear and surgical site infection. Clinical improvement at 24 hours, 4 weeks and 6 months was achieved in: 77.3%, 86.5% y 94.8% of the patients, respectively.* **Conclusions:** *Neuronavigation with the use of O-arm along with mini-open surgery approach results in good clinical-surgical outcomes in the correction of complex disorders of the dorso-lumbar spine.*

***Keywords:*** *Neuronavigation. Minimally invasive surgery. O-arm. Instrumentation. Dorso-lumbar.*

## Resumen

**Objetivo:** *Evaluar los resultados clínico-quirúrgicos de la instrumentación dorso-lumbar mediante neuronavegación asistida con O-arm y cirugía mínimamente invasiva.* **Método:** *En esta cohorte retrospectiva se estudiaron 104 pacientes sometidos a instrumentación dorso-lumbar con uso de O-arm, operados entre septiembre de 2013 y mayo de 2020. Las variables investigadas fueron sintomatología, cantidad de tornillos, niveles abordados, sangrado, tiempo quirúrgico, estancia hospitalaria, complicaciones y mejoría clínica posterior al procedimiento quirúrgico.* **Resultados:** *La sintomatología más frecuente fue radiculopatía unilateral o bilateral de extremidades pélvicas, parestesias, lumbalgia mecánica y disminución progresiva de la fuerza. Se utilizaron en total 542 tornillos, siendo la columna lumbar el sitio de mayor prevalencia. Los promedios de sangrado, tiempo quirúrgico y estancia hospitalaria fueron de 50 ml, 160 minutos y 24 horas, respectivamente. Las complicaciones*

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Date of reception: 18-07-2020
Date of acceptance: 24-10-2020
DOI: 10.24875/CIRUE.M23000292

Cir Cir (Eng). 2021;89(5):582-589
Contents available at PubMed
www.cirugiaycirujanos.com

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*más frecuentes fueron neuropatía residual, rasgadura de la duramadre e infección del sitio quirúrgico. La mejoría clínica a las 24 horas, 4 semanas y 6 meses se logró en el 77.3%, el 86.5% y el 94.8% de los pacientes, respectivamente.* **Conclusiones:** *La neuronavegación con O-arm junto con el abordaje quirúrgico de tipo mini-open permite buenos resultados clínico-quirúrgicos en la corrección de los trastornos complejos de la columna dorso-lumbar.*

***Palabras clave:*** *Neuronavegación. Cirugía mínimamente invasiva. O-arm. Instrumentación. Dorso-lumbar.*

## Introduction

The pathologies that most frequently involve a degenerative lumbar disease are primarily the disc herniation, lumbar canal stenosis and spondylolisthesis[1]. For years, vertebral instrumentation with placement of transpedicular screws has been the preferred technique to achieve the stabilization of any segment of the spine[1-3]. Espondylolisthesis, which is the abnormal "misalignment" of a vertebra over another, whether anterior, lateral, or posterior, is one of the main indications for the placement of transpedicular screws[4]. There are different types of spondylolisthesis, among which the most common are congenital, isthmic (result of a previous vertebral fracture that destabilizes the bone segment), traumatic, pathological (secondary to osteoporosis, infection, or tumor), postsurgical and degenerative (wearing of the intervertebral disc that becomes less capable of resisting the mobility of vertebral segments, conditioning the progressive intervertebral slipping). This last type of spondylolisthesis is the most common and the one which is most frequently subject to surgical intervention Spondylolisthesis is classified according to the percentage of slipping compared to the adjacent vertebral segment. It is classified as level I when the slippage is lower than 25%, level II when 25-50%, level III when 50-75%, and level IV when over 75%. The most common area affected by spondylolisthesis is the region of the lumbosacral joint, followed by the middle lumbar spine, the cervical spine, and very rarely the thoracic column[4]. Patients with spondylolisthesis history show a significant improvement of lumbosciatic symptoms when decompression surgery is performed, arthrodesis, and posterior lumbar instrumentation[1,4]. The objectives of any spinal procedure are to achieve medular decompression, prevent, or correct any deformities, and the spinal fixation through the placement of transpedicular screws with conventional transoperative imaging techniques, such as X rays or fluoroscopy[2,5]. In the last few years, imaging platforms, such as 3D fluoroscopy and tomography or magnetic resonance have been used more frequently in the transoperative period. They have facilitated the placement of transpedicular screws, a more accurate location of the placement site, and a lower dose of radiation for the surgeon[5]. With the standard placement of screws with X rays or fluoroscopy (bidimensional images [2D]), the rate of incorrect placement has been reported in ranges between 14% and 55%, and 7% of these cases result with some neurological injury[6].

Spinal neuronavigation was introduced in 1995 with the purpose of improving the accuracy in the placement of transpedicular screws, and in this way decreasing the percentage of neurovascular injuries and improving functional results[2,6]. Imaging systems that use threedimensional (3D) technology offer projections of the surgical field and the instrumentation in real time and three planes. This allows to identify the anatomy of the region subject to the surgical procedure in relation to surgical instrument, providing more accuracy when handling the instrument, and reducing the risk of complications[2]. The incorrect placement of transpedicular screws can result in important neurological and functional consequences that negatively impact the morbidity of the patient. Penetration in the sagittal plane can cause damage to the neural root, while the medial penetration can cause a dura mater tear or spinal damage[3]. Several studies have shown that precision in placing transpedicular screws assisted by O-arm navigation is better when instrumented visually without navigation, and, additionally, that surgical time is significantly reduced.[3,6]

The O-arm (Medtronic®, Inc., Minneapolis, Minnesota, USA) is an O-shaped device that offers X-ray images. It combines traditional fluoroscopy (C-arm) with 2-D scanner, and a computerized tomography scanner in 3D (Figs. 1 and 2). In elderly patients it is very useful when there is degeneration in three levels, need for medular decompression or tumoral injury resection[1,3,7]. With O-arm neuronavigation, different anatomical references can be obtained in a multiplanar manner and in real time. The spinous process, the apex pf the transverse process, or the iliac crest are used as reference points, in such a way that, with the O-arm system, the anatomical structure is correlated and the trajectory of surgical instruments that are visualized in the monitor can be seen, being able to determine the position of the instrument in relation to the vertebral anatomy. The purpose of this study is to evaluate the clinical-surgical outcomes after dorso-lumbar instrumentation using O-arm assisted neuronavigation and minimally invasive surgery.

## Method

In this retrospective cohort study, 104 patients subject to dorsolumbar instrumentation with a combined O-arm neuronavigation and minimally invasive surgery approach were analyzed (Figs. 1 and 2). All patients were intervened by the same surgical team in the period between September 2013 and May 2020. The variables researched were gender, age, most recurrent symptoms, location of instrumentation, amount of transpedicular screws used, average bleeding, average surgery time, postsurgical complications, average hospital stay, and clinical improvement at time intervals in the postoperative period of unilateral or bilateral radiculopathy, unilateral or bilateral paresthesias, mechanical lumbalgia, and decrease in strength. All patients received anti-inflammatory, anti-neuritic, and adjuvent drugs for neural regeneration after surgery, and were referred to physical therapy 2 weeks after surgery, which was indicated for 5 weeks. The physical rehabilitation consisted of ultrasound therapy, thermal therapy, and placement of electrodes in the dorso-lumbar region. For patients that manifested decrease in strength, in addition to the therapy previously indicated, resistance and muscle strengthening exercises were added.

**Figure 1.** *System O-arm Stealth Navigation 7.*

**Figure 2.** *Presurgical tomography scanner with O-arm.*

### *Neuronavigation integration*

All patients were subject to regional block surgery Once the patient is placed in ventral decubitus, a first scan is performed with the O-arm (Fig. 2). Afterward, a fluoroscopic image is recorded which locates the extension of the surgical site to act on. A local anesthetic is then provided (lidocaine 2%) over the middle line, and the mini-open approach is started (see below). Once the anatomical area to work on is exposed, a guide instrument is placed over the spinous process which automatically calibrates the instrument with the O-arm antenna by means of an optic camera, which is an image receptor. At the same time, it emits and detects an infrared light reflected continuously by means of diode spheres located on the surgical instruments; in this way, the O-arm calibration is achieved with vertebral anatomy. The neuronavigation is incorporated in this way (Fig. 3). The surgical procedure is then completed with the placement of transpedicular screws, and the need for additional procedures is evaluated (e.g., laminectomy). After doing this, a final scan is performed with the O-arm in order to verify the correct placement of transpedicular screws and the surgical site is repaired.

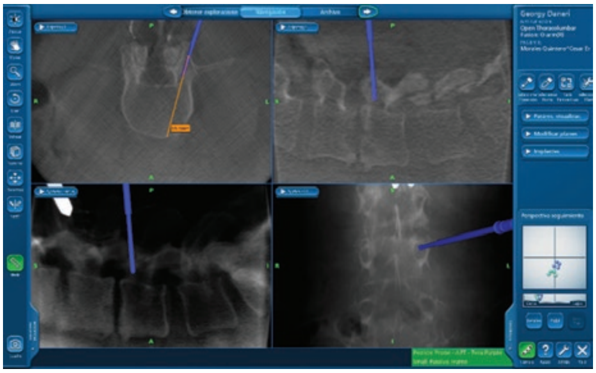

**Figure 3.** *Multiplanar projection of the vertebral level where the guide instrument is seen over the vertebral pedicle to instrument, performing an adequate calibration with the screen of the O-arm, and marking the digital trajectory in the vertebral body.*

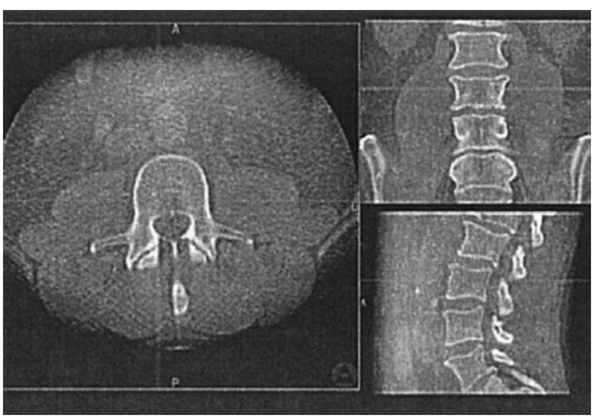

**Figure 4.** *Digital result of the first presurgical vertebral scanner done with the O-arm, where the vertebral level to instrument will be instrumented in the axial, coronal, and sagittal planes.*

## *Approach with the O-arm neuronavigator*

This approach has already been described previously by Ao, et al.[8]. Briefly, the first scan with the O-arm system provides a 3D image of the entire spine (Fig. 4). Images are automatically transferred to the Stealth Station navigation system. Subsequently, the surgeon can obtain a visualization of the multiplanar reconstruction, both in the sagittal and axial planes, anteroposterior and lateral, and even a 3D image of the dorso-lumbar spine. The last step of the neuronavigation preparation is the recording of the surgical instruments, which are monitored by the O-arm system continuously during the entire surgery, and in this way, the stereotactic navigation in a transoperative manner.

**Table 1. Variables analyzed in our sample of patients**

| Variables | Number of patients |
|---|---|
| Gender | |
| Men | 48 (46.1%) |
| Women | 56 (53.8%) |
| Most frequent age | |
| Men (54 year) | 14 (13.46%) |
| Woman (58 years) | 19 (18.2%) |
| Most frequent symptoms | |
| Radiculopahy | 57 (54.8%) |
| Paresthesias | 24 (23%) |
| Mechanical lumbalgia | 16 (15.3%) |
| Decrease in strength | 7 (6.7%) |
| Duration of procedure | |
| < 160 minutes | 71 (68.2%) |
| 160-240 minutes | 33 (31.7%) |
| Surgical complications | |
| Residual neuropathy | 10 (9.6%) |
| Dura mater tear | 2 (1.9%) |
| Wound infection | 1 (0.96%) |
| Hospital stay | |
| 24 hours | 98 (94.2%) |
| 24-72 hours | 6 (5.7%) |

## *Minimally invasive approach (mini-open)*

This approach was originally described by Skovrlj, et al.[9]. Briefly, an incision is made on the middle line of an average length of 5 cm, depending on the number of screws to place. Then, the subcutaneous cell tissue is separated, the thoracolumbar fascia is dissecated, and the paravertebral longissimus and multifidus muscles in a subperiosteal and bilateral manner, until the spinous process, the vertebral lamina, and the lateral wall of the facet joint are exposed. Then, the internal retractors are placed in order to maintain an adequate visualization of the pedicle to instrument with the previously calibrated surgical instruments. The surgical field is ready for the placement of transpedicular screws.

## Results

Out of 104 patients, 56 were women (53.8%) and 48 were men (46.1%). The mean age was 58 years for women and 54 years for men. In the total sample, the age range was 46 to 85 years, with an average of 65 years. The main identified symptoms, by order of frequency, was the unilateral or bilateral radiculopathy in

**Table 2. Dorsolumbar instrumentation levels approached and number of screws used**

| Placement site (total levels) | Total patients | Total screws placed |
|---|---|---|
| Dorsal spine | 8 (7.6%) | 64 |
| Lumbar spine | 96 (92.3%) | 478 |
| One level | 50 (48%) | 200 |
| Two levels | 46 (44.2%) | 276 |
| Three or more levels | 8 (7.6%) | 66 |

**Table 3. Complete clinical improvement after dorso-lumbar instrumentation with neuronavigation**

| Clinical variables | Patients with clinical improvement according to postsurgical time | | |
|---|---|---|---|
| | 24 hours | 4 weeks | 6 months |
| Radiculopahy | 46 (80.7%) | 51 (89.4%) | 55 (96.4%) |
| Paresthesias | 17 (70.8%) | 19 (79.1%) | 22 (91.6%) |
| Mechanical lumbalgia | 12 (75%) | 14 (87.5%) | 15 (93.7%) |
| Decrease in strength | 4 (57.1%) | 5 (71.4%) | 6 (85.7%) |

pelvic extremities (n = 57, 54.8%), paresthesias in the distal region of pelvic extremities (n = 24, 23%), posterior mechanical lumbalgia, or when performing the extension of the lumbar spine (n = 16, 15.3%), and progressive decrease of the strength of pelvic extremities that limited function and stability of movement (n = 7, 6.7%) (Table 1).

The average surgical time was 160 ± 80 minutes. In 92.3% (n = 96) of patients an additional procedure was required as coadjuvent treatment to instrumentation; the variation in surgical times depended on this. Average bleeding was 50 ml. An average of 6 screws ± 2 per patient was used, which represented a total of 542 screws places (Table 2). In the postsurgical tomographic control two screws were found violating more than 2 mm of the pedicle wall in one patient, and for this reason they were relocated. Another patient showed foraminal radicular compression with manifestation of unilateral radiculopathy, and for this reason the screw was removed after surgery.

The activities conducted by the patients intervened were heavy machinery or load vehicle operation (n = 19, 18.2%) and office work or housework (n = 67, 64.4%); the rest of patients were retired (n = 18, 17.3%). At the end of physical rehabilitation, all patients resumed normal activities.

Among the complications present, it was seen that, in first place of frequency was neuropathy (n = 10, 9.6%), which was successfully reduced with relative rest time, non-steroidal anti-inflammatories, antineuritics, and physical therapy sessions, and in most cases, they were resolved 6 months after the surgical procedure. The second complication in order of frequency was the dura mater tear (n = 2, 1.9%), which was resolved in a transurgical manner with suture stitches and subsequent sealing with muscular tissue and application of biological seal (Tissucol Duo S®, Baxter. Valencia, Spain). These patients were monitored and kept in absolute rest, and their symptoms were resolved and improved completely a week after the procedure, verified with use of Doppler ultrasound of the lumbar region, and ruling out collection of cerebrospinal fluid. The third and last complication presented in the series of cases was infection of the surgical wound (n = 1, 0.96%), which occurred in an elderly patients with a history of diabetes *mellitus,* who stated that she had not taken care of the wound. The infection was resolved successfully in 2 weeks, requiring three surgical cleanings and wide spectrum antibiotics therapy.

The average hospital stay time in patients subjected to dorso-lumbar instrumentation was only 24 hours. Only six patients (5.7%) were hospitalized for 3 days due to surgical site pain, need for absolute rest due to dura mater tear or presence of a residual peripheral neuropathy which required longer rest time and medical treatment in the hospital. In three cases (0.96%), outpatient hospitalization was required due to surgical wound infection.

Symptom remission was achieved in 77.3% (n = 75) of patients 24 hours after surgery in regard to radiculopathy (unilateral or bilateral), paresthesias (unilateral or bilateral), and mechanical lumbalgia. Complete clinical improvement was achieved, for these same symptoms, up to 94.8% (n = 92) of cases 6 months after O-arm assisted neuronavigation and mini-open approach. Strength recovery was achieved in 85.7% (n = 6) of cases 6 months after surgery with the help of rehabilitation. In table 3 the average clinical recovery times by symptoms and different time intervals are shown.

## Discussion

Degenerative diseases of the lumbar spine, such as degenerative scoliosis, narrow lumbar canal, and spondylolisthesis, are common causes of lumbalgia and pain in pelvic extremities in elderly patients, which significantly affects their quality of life[3]. The introduction of minimally invasive surgery in the spine with the placement of transpedicular screws has shown more benefits compared to other traditional surgical techniques where a larger muscular dissection was needed in order to visualize the anatomy, and consequently, more damage is caused to soft tissues. Among the benefits of minimal invasion we find reduction of postsurgical pain, shortening of hospital stay, minimal disruption of the posterior structures that stabilize the spine, decrease in the risk of infection, and shorter surgical time[8,10-13].

As reported by Singh and Haldar[14], spinal surgical intervention, when performed in a conventional manner with a wide dissection of the subcutaneous tissue, the adjacent muscles and ligaments, is a procedure that causes a disabling pain for the first 3 days after surgery. In our series of cases, 94.2% (n = 98) of patients were discharged 24 hours after surgical treatment, due to the fact that the pain was minimal at the surgical site, it was not disabling, ceased with the administration of analgesics, and particularly, there was a substantial improvement of the main symptoms. Our results are in contrast with some reports found in the literature that esttablished average hospital stays of 5 days[10,11]. A short hospital stay favor early ambulation, decreases the risk of thrombosis and nosocomial infections, and favors an early return to normal life and work, which is difficult to achieve with the conventional open approach[5].

The placement of transpedicular screws is performed more frequently on the lumbar spine, where vertebral non-traumatic pathology and degenerative arthritis appear more frequently, which explains the higher number of patients in the series required instrumentation and some radicular release approach at this level. Our report matches other series of cases published by other authors, such as Tajsic, et al.[13], which reported similarly that the lumbar spine was the location with the highest incidence of vertebral pathology, and the region subject to instrumentation more frequently.

On the other hand, the dorsal spine, despite having lower incidence of pathology, is the location with the highest rate of complications due to a more complex anatomy and the decrease in size of the pedicle, especially in levels T4 to T6, which makes this vertebral area more prone to violations on the vertebral wall, and therefore, a highest number of complications in vasculature and adjacent organs[15,16].

Concern for the use of incorrect instrumentation in anatomically complex vertebrae and exposure to excessive radiation in the surgical team with conventional fluoroscopy have motivated the evolution and adaptation of new intraoperative imaging modalities[3,17,18]. The use of 3D guided images, which facilitate vertebral anatomical visualization and the trajectory of the screw in multiple dimensions, has resulted in a more accurate placement of the screws on the thoracic spine[8,15]. The use of O-arm neuronavigation has allowed for a better real time visualization of the vertebral pedicle by presenting a multiplanar (axial, coronal, and sagittal) and simultaneous image of the spinal anatomy, and similarly, it shows the trajectory of any surgical treatment in relation to the regenerative anatomy in the computer screen in real time, and with this, the risk of transurgical complications has been reduced[3,10].

In minimally invasive surgery, visual access to the bone structure, especially in the axial plane, is naturally reduced by the size of the incision performed, which could increase the error rate during placement of the screw. However, if used in conjunction with O-arm neuronavigation, which provides real-time virtual images and offers a deep visualization of the vertebral anatomy, the accuracy of the screw placement is increase significantly, offering, in most cases, a minimum probability of inaccurate placement in the pedicle[5,19]. With the use of the O-arm system, a statistically significant decrease in the rate of perforation of the pedicle wall has been reported, around 12.8-29% using fluoroscopy, 30% with hands-free technique, and only 2.7-3% with O-arm[13,20,21]. Therefore, this combination of approaches is very useful in complex cases, such as obese patients, women with dorsal pathology or level 3 spondylolisthesis[16].

In a prospective study that evaluates cases that presented complications after a vertebral instrumentation, it was defined that the main cause of complications is an incorrect placing of the screws, which creates a neurological deficit in one of the pelvic extremities. It is considered that, up to 50% of neurological complications could be avoided with robotic guides that facilitate a more accurate visualization of the site to be instrumented[22]. In this series of cases, fortunately, the complications presented were minimal and completely reversible (residual neuropathy, dura mater tear and infection of the surgical wound). There was no significant neurological deficit or vascular damage in any case.

Additionally, a significant reduction in the number and degree of complications with the use of O-arm neuronavigation, guided instrumentations with this system

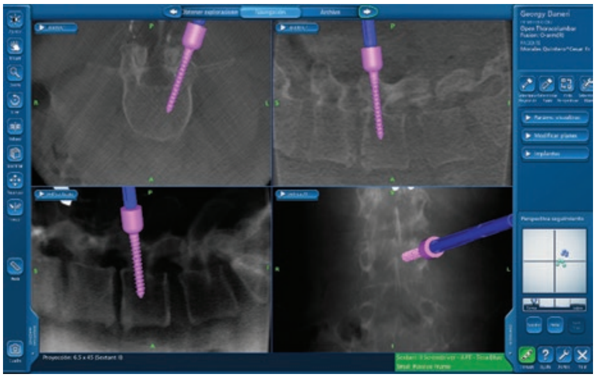

**Figure 5.** *Multiplanar projection of the vertebral level where the transpedicular screw can be seen adequately entering the vertebral body, following the trajectory delimited by the guide instrument.*

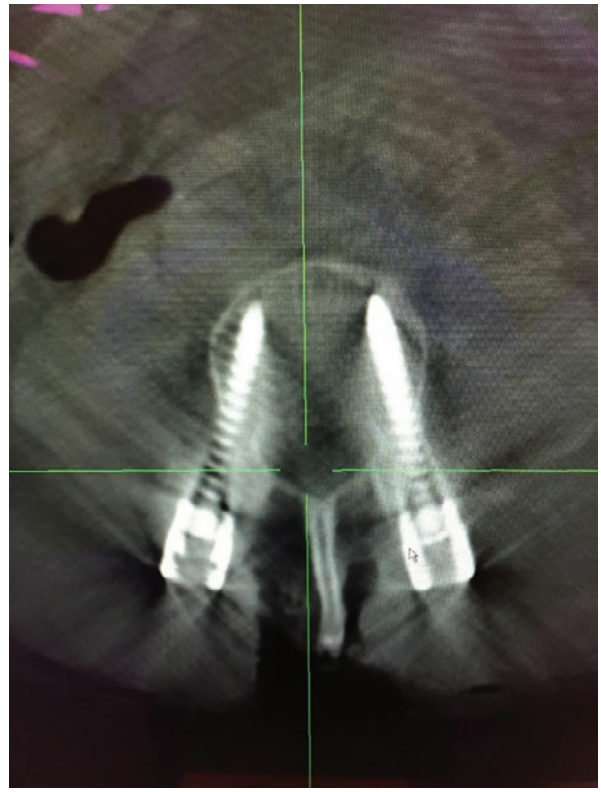

**Figure 6.** *Transurgical control tomographic scanner with O-arm showing adequate placement of transpedicular screws in the dorsal vertebra.*

achieve a significant reduction in surgical time compared to conventional techniques, as several anteroposterior and lateral projection cases are prevented with conventional fluoroscopy. In this series of cases, average surgical time in most cases was less than 160 minutes, while other reports in the literature refer an average time of 222 minutes with O-arm and 255 minutes with hands-free technique[3]. Variations in surgical time are generally due to the difference in the number of screws used and the experience of the neurosurgeon. It has been stated that, with the use of an O-arm, surgical time could be reduced up to 50% compared to conventional techniques, as long as the procedure is performed by an experienced neurosurgeon[10,20].

Different meta-analysis describe a rate of success of 89-96% for the placement of screws within the corresponding pedicle without injuring any nervous structure or arterial plexus and without penetrating the pedicle more than 2 mm with the use of O-arm neuronavigation. It has also been defined that, with assisted neuronavigation, the risk or surgical re-intervention is reduced in the future up to 50% compared with hands-free strategies or fluoroscopy[11,23]. This series of cases obtained a success rate of 95.7% with an adequate placement of the transpedicular screws through neuronavigation from the first attempt, without violating any structure of the vertebral anatomy, and without need for reaccommodation (Figs. 5 and 6).

Perhaps one of the biggest challenges in our study, which has to do with the methodological design, is the lack of a comparative cohort. Even though it is a retrospective cohort, the same approach performed by another group could provide a must robust combined procedure with neuronavigation and mini-open surgery. That is, a study of cases and controls, or two prospective cohorts would adequately confront the evidence presented in this work. Even more, an open clinical trial that compares our approach with a conventional technique would provide a more robust methodology.

## Conclusions

This work shows that neuronavigation assisted with O-arm plus the use of a minimally invase approach allow a safe instrumentation of complex disorders of the dorso-lumbar spine, with shorter surgical times, less bleeding, correction of symptoms, less complications and shorter hospital stays.

## Ethical disclosures

**Protection of People and Animals.** The authors state that no experiments have been conducted in humans or animals for this research.

**Data Confidentiality.** The authors state that the protocols of their work center regarding the publication of patient data have been followed.

**Right to privacy and informed consent.** The authors have obtained informed consent from the patients and/or subjects mentioned in the article. This document is owned by the corresponding author.

## Conflicts of interest

The authors declare that they have no conflicts of interest.

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