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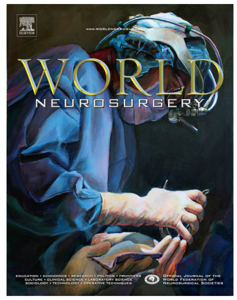

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Keywords: cortical bone trajectory; minimally invasive; robot-assisted surgery; lumbar interbody fusion

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Nicola Marengo: Conceptualization, Supervision. **Federico Pecoraro**: Conceptualization. **Enrico Lo Bue**: Methodology, Writing-Review and Editing. **Stefano Colonna**: Investigation, Writing-Review and Editing. **Flavio Panico**: Investigation, Data curation. **Alberto Morello**: Writing-Review and Editing. **Marco Ajello**: Investigation, Data curation. **Francesco Zenga**: Formal analysis, Validation. **Diego Garbossa**: Supervision, Editing. **Fabio Cofano**: Conceptualization, Supervision.

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ABSTRACT

Objectives

The robot-assisted cortical bone trajectory (CBT) screw placement is safer than the traditional fluoroscopy-assisted approach. This is the first technical note reporting a novel technique of robot-assisted CBT screws placement with a subfascial transmuscular approach.

Technical note

After a lumbar interbody cage position, the second step consists in the robot-assisted placement of CBT screws in a prone position. A median skin incision is performed, ensuring an incision as small as possible. CBT screw direction and trajectory are planned on the sterile robot touchscreen display. A navigated drill is used to breach the cortical surface of the entry point. Then, a navigated drill bit is used to complete the exposure of the screw trajectory. The screw is placed with the support of the robotic arm. In the single-position the surgical field must be prepared since the first surgical step. All the navigation references are placed on the same iliac crest. The following steps resemble the ones described for the double-position.

Conclusion

This is the first reported technical note about robot-assisted transmuscular CBT screw placement for posterior fixation in LLIF. The surgical technique proposed aims to combine the advantages of CBT screws and the use of innovative robot-assisted technology.

INTRODUCTION

Lateral lumbar interbody fusion (LLIF) is a commonly used minimally invasive procedure for arthrodesis[1,2]. This technique is commonly supplemented with posterior fixation to decrease the risk of cage subsidence and pseudoarthrosis[3]. Different strategies have been reported for posterior fixation. The cortical bone trajectory (CBT) screw technique is a recent lumbar posterior fixation strategy[4–6] following a mediolateral route in the axial plane and a caudocephalad route in the sagittal plane[7–9]. The screw placement accuracy is fundamental considering the potential complications of screw malpositioning[10,11].

In recent years, a multitude of technologies were reported to improve the accuracy of screw positioning, such as navigation software, neuromonitoring, custom-made template guides and robot-assisted surgery[7,12–14]. As recently reported by Xiaofeng et al., the robot-assisted CBT screw placement is safer than the traditional fluoroscopy-assisted approach[12]. By combining these two modern trends in spine surgery, one could be able to exalt a concrete advantage of new technology spent on minimally invasive strategies.

TECHNICAL NOTE

The first step of the surgical procedure consists in the placement of a lumbar interbody cage through a lateral transpsoas approach, as described in other previous studies[15]. The second step consists in the robot-assisted placement of CBT screws in a prone position.

After the interbody cage placement, the patient is placed prone with hands above the head on a radiolucent carbonium operating table to minimize interference with intraoperative fluoroscopy. The robotic base (ExcelsiusGPS, Globus Medical, Inc., Audubon, PA, USA) is placed on the right side of the patient, while the 3D-fluoroscope is positioned on the opposite side. After skin preparation, the robotic arm and the patient are draped, harvesting the sterile surgical field. The navigation frames like ICT (Intraoperative CT), DRB (Dynamic Reference Based), probe and surgical instruments like the drill are registered in the robot system. A 15 mm skin incision is performed above the right iliac crest to anchor the Quattro-spike to the posterior-superior iliac crest. The use of a long instrument oriented with a 45° angle to the floor facilitates the engagement with the robot camera. Similarly, a 5 mm skin incision is performed above the left iliac crest to anchor the Surveillance-marker to the posterior-superior iliac crest. It is preferable to place the Quattro-spike and the Surveillance-marker as lateral as possible on the iliac crests, in order to minimize postoperative pain and guarantee the lowest possible encumbrance of the reference system to the operative field. Adequate hemostasis is recommended to minimize the risk of postoperative hematoma. Subsequently, the DRB is anchored to the Quattro-spike on the right side of the patient, avoiding contact with the skin. Once the Quattro-spike and the DRB are secured, the ICT is finally anchored to the DRB. The ICT represents the reference for patient placement in the space, and should be placed with its arm oriented towards the midline. Surveillance-marker and DRB have a fixed distance for navigation. (Fig. 1)

Once the references are positioned and secured, a preliminary latero-lateral and antero-posterior fluoroscopic control is performed to ensure the correct visualization of the optic references. Subsequently, an intraoperative 3D scan with a 3D-fluoroscopy is performed and sent to the robotic positioning system to plan CBT screws trajectory, diameter, and length, preferentially during apnea condition. The robot system acquires the 3D reconstruction of the patient relating it to DRB, Surveillance-marker and ICT references. Once the imaging reconstruction is uploaded to the robot software, the ICT is removed and the correct correspondence of the system is verified.
Finally, CBT screw direction and trajectory are directly planned on the sterile robot touchscreen display (“drag and drop” system). (Fig. 2) During the screw planning it is preferable to avoid “sloping” entry points: if the bone surface is too steep, the drill could slip and the accuracy could be consequently compromised. It is encouraged, whenever feasible, to choose a flat bone surface for the screw entry point. The modalities of cortical bone trajectory surgical planning are available in the author's previous studies[4,7]. Screws follow a mediolateral path in the axial plane and a caudocephalad path in the sagittal plane; the entry point is usually located in the medial surface of isthmus.

Once the optic references are placed and the surgical planning is defined, the robotic arm is placed above the patient. A median skin incision is performed between the projection of the cranial screw of one side and the contralateral caudal screw, ensuring an incision as small and precise as possible. (Fig. 1) After skin incision, the fascia is exposed and then incised centrally above the spinous process. The underlying muscular layer is then gently dissected from the fascia to ensure the correct placement of the robotic arm. A transmuscular approach is then adopted to reach the planned screw entry point. Once the approach is completed, the rigid robotic arm places itself along the planned trajectory above the skin. A navigated drill is used to breach the cortical surface of the entry point, subsequently a navigated drill bit is used to complete the exposure of the screw trajectory. Finally, the screw is placed with the support of the robotic arm. (Fig. 3) During the entire procedure the robotic arm maintains a rigid trajectory to avoid undesired deviations from the preoperative planning. Rods and inner screws are then locked in a standard fashion. A final fluoroscopic control is obtained to evaluate the correct placement of the screws. (Fig. 4)
All the surgical steps are resumed in Table 1.

Single-lateral position
After the placement of the lumbar interbody cage through a lateral transpsoas approach, in the single-lateral position the patient remains in the lateral position, ensuring to completely remove the bed tilting adopted during the first surgical step. If a CBT planning is chosen for screw placement, no further adjustments of patient positioning are needed: the more medial trajectory of CBT screws compared to pedicle screws allows to keep the patient positioned at the center of the operating table, without interferences between the edge of the operative table and the robotic arm or the intraoperative imaging devices. Differently from the double-position, in the single-position the surgical field must be adequately prepared since the first surgical step. In this context, skin preparation has to cover both

the lateral and posterior surgical fields. A sterile drape is temporarily positioned to cover the posterior surgical field during the first surgical step, subsequently removed while harvesting the sterile surgical field for the second step of the procedure. (Fig 5)

Similarly to the double-position intraoperative setting, the robotic base is placed on the right side of the operating table, while the 3D-fluoroscope is placed on the contralateral side. Navigation references and surgical instruments are registered in the robot system. Differently from the double-position, in the single-position all the navigation references are placed on the same iliac crest. A 5 mm skin incision is performed on the most lateral aspect of the iliac crest to anchor the Surveillance-marker to the posterior-superior iliac crest. The Quattro-spike reference can either be positioned through a new 5 mm skin incision adjacent to the Surveillance-marker incision, or through a slight posterior extension of the previous XLIF incision. The DRB-ICT complex can be alternatively attached to the Quattro-spike or to the Surveillance-marker. In the latter case, the ICT reference can be more easily positioned perpendicular to the floor considering its more posterior position compared to the Quattro-spike reference. (Fig. 5) Once the references are positioned, the following steps resemble exactly the ones described for the double-position. (Fig. 6)

DISCUSSION

LLIF is a transpsoas retroperitoneal approach for lumbar interbody fusion used in appropriately selected patients with several lumbar pathologies, such as discarthrosis, discopathy or spondylolisthesis. This technique requires a supplemented instrumentation with either a lateral or posterior approach for screw fixation. Nevertheless, in literature there are no definite indications about the choice of instrumentation in LLIF[2]. In 2016, the group of Verga et al. suggested that posterior fixation provides higher rigidity rather than isolated lateral instrumentation[16]. In this context, significant efforts have been dedicated to advancing minimally invasive techniques in posterior spinal fixation, with the aim to reduce patient morbidity and enhance recovery outcomes. In recent years, CBT screws have emerged as an effective technique for posterior fixation, offering significant advantages in terms of tissue trauma and postoperative outcome.

CBT screw fixation was first described in 2009 by Santoni et al. with the aim to minimize the pullout resistance in osteoporotic bone[4,5,17]. The divergent trajectory of CBT screws allows more limited soft tissue dissection, ensuring a minimally invasive procedure with favorable biomechanical properties[8]. As demonstrated by the author's previous study, this trajectory allows a lower iatrogenic injury to the paraspinal muscles, resulting in a less postoperative replacement of multifidus muscle with fatty or scar tissue[14,18]. Previous in-vivo studies demonstrated an insertion torque 1.7 times higher of CBT screws compared to traditional peduncular screws, with screw entry points almost four times richer in cortical bone compared to traditional peduncular entry points[19,20]. The divergent medial-to-lateral trajectory of the screws allows to minimize muscular exposure, permitting shorter skin incision with better aesthetical results and favorable postoperative outcome in terms of pain and recovery[4]. Despite the advantages of CBT screws, the caudo-cephalad medio-lateral trajectory is associated with a narrow and often uncomfortable anatomical corridor, with a deviation rate for freehand positioned screws up to 22%[21–23]. In addition, the complexity of freehand placement of CBT screws is furtherly evident with a percutaneous approach. In 2015, Orita et al. reported the first percutaneous CBT screws insertion series in 20 patients, demonstrating comparable postoperative outcomes compared to traditional percutaneous pedicle screws[24]. In this context, significant technological advancement has been made to improve the accuracy of CBT screws positioning. The development of technologies as computer-assisted navigation systems, or robotic-assisted technologies, or patient-matched 3-dimensional (3D) targeting guides, have significantly reduced the rate of CBT screw misplacement compared to freehand techniques[12,21,25–27].

The surgical technique proposed in this study aims to combine the advantages of CBT screws, the minimally invasive transmuscular approach and the use of innovative robot-assisted technology for screw placement. As opposed to traditional percutaneous technique with multiple paramedian incisions for screws placement, in this technique a unique median incision is performed to minimize soft tissue trauma and obtain a more cosmetic wound thanks to divergent trajectory. In addition, contrary to the transfascial approach requiring the dissection of epifascial soft tissue from the muscular fascia, in our technique the screws are placed with a subfascial-transmuscular approach thus significantly reducing the risk of postoperative seroma or hematoma in the subcutaneous-epifascial space. Overall, this technique provides several advantages. Compared to CBT screws positioned with conventional open technique, the possibility to place the screws with a percutaneous transmuscular approach avoids paraspinal muscular skeletonization thus reducing intraoperative blood loss and postoperative pain. In addition, compared to traditional percutaneous techniques with paramedian incisions, a unique median approach allows unilateral decompression maneuvers such as hemilaminectomy or foraminotomy if necessary. Furthermore, in cases treated with a single lateral position technique the intraoperative time is significantly lowered compared to double position techniques. In the context of single position technique, the possibility to place divergent screws with a medial to lateral trajectory significantly facilitates the insertion process compared to traditional convergent pedicle percutaneous screws with a lateral to medial trajectory. Despite the advantages of CBT screws with single lateral position, this technique and positioning involve a higher complexity of decompressive maneuvers compared to the prone position, whether needed. Whether the surgical technique is performed in a double or single position, the use of a robot-assisted navigation system significantly contributes to improve the accuracy of screw placement. Several studies in the literature demonstrated the role of robot-assisted systems to enhance the precision of CBT screws placement[21,28].

To the best of the author's knowledge, this is the first technical note reporting combination of these surgical techniques for the abovementioned advantages. In our opinion, it represents a safe and effective alternative for posterior fixation in LLIF, that is comfortable for both senior and young surgeons.

This is a technical note that does not involve any statistical analysis of the results. The future perspectives of this preliminary work are to collect data of a large population. Then, a comparison between this technique and the traditional methods of posterior fixation after LLIF is mandatory to better understand its potential advantages, especially in terms of paravertebral muscle sparing and post-operative outcomes.

CONCLUSION

This is the first reported technical note about robot-assisted transmuscular CBT screw placement for posterior fixation in LLIF. The surgical technique proposed aims to combine the advantages of CBT screws, the percutaneous approach, and the use of innovative robot-assisted technology for screw placement.

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FIGURES

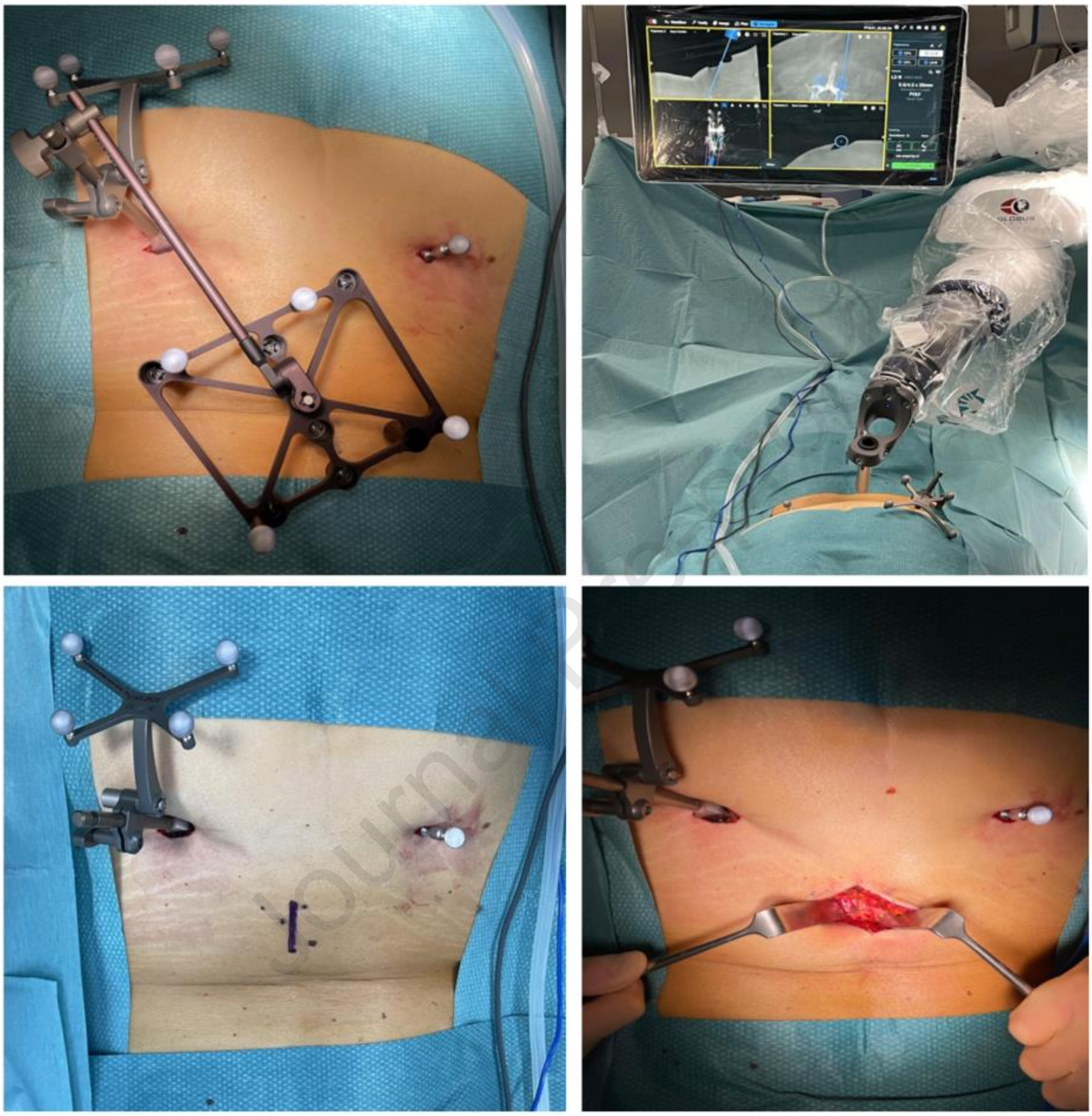

FIG. 1

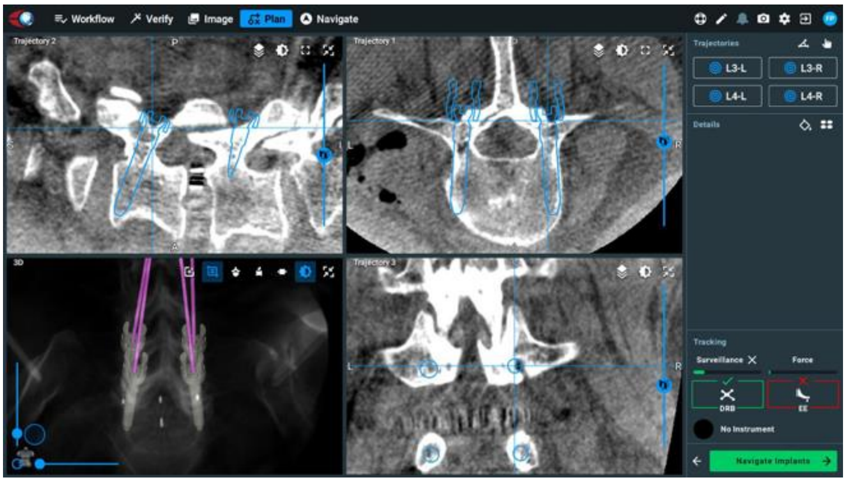
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FIG. 2

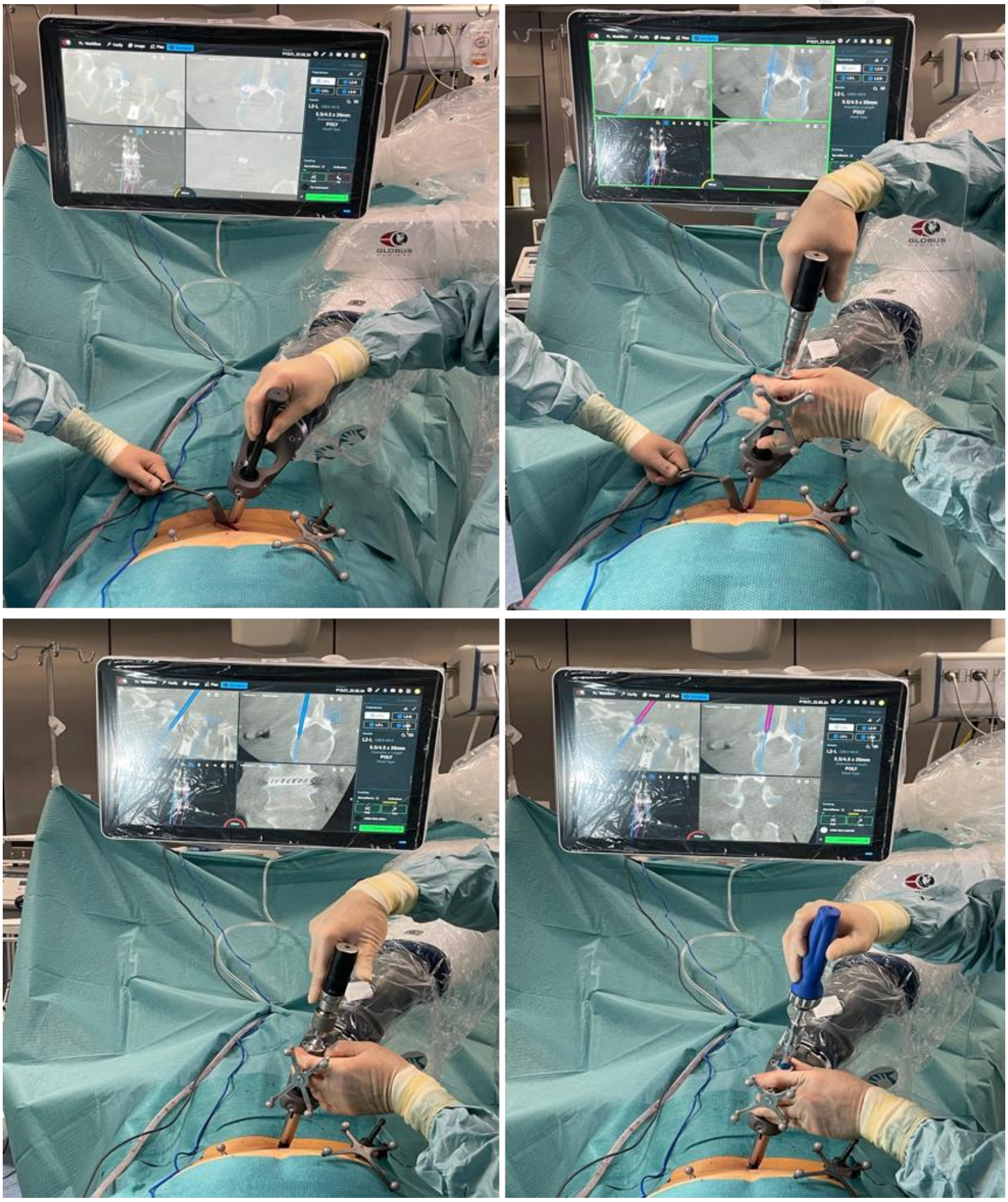

FIG. 3

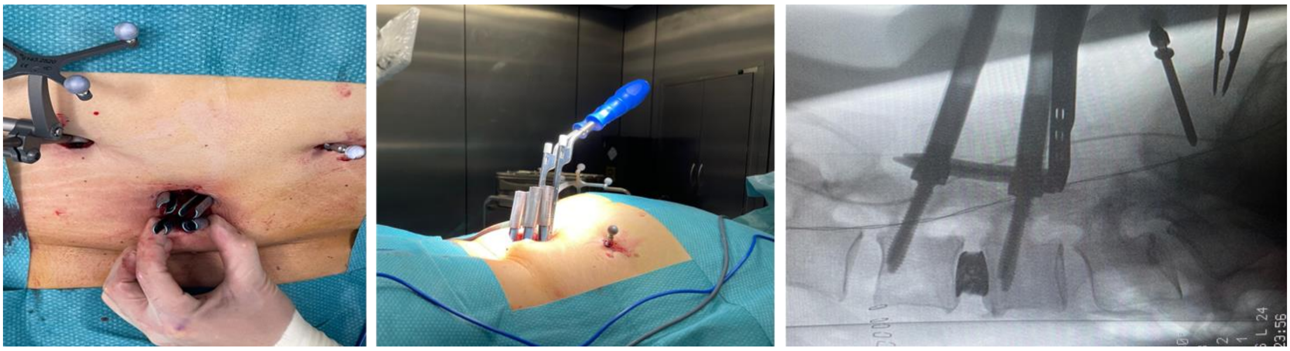

FIG. 4

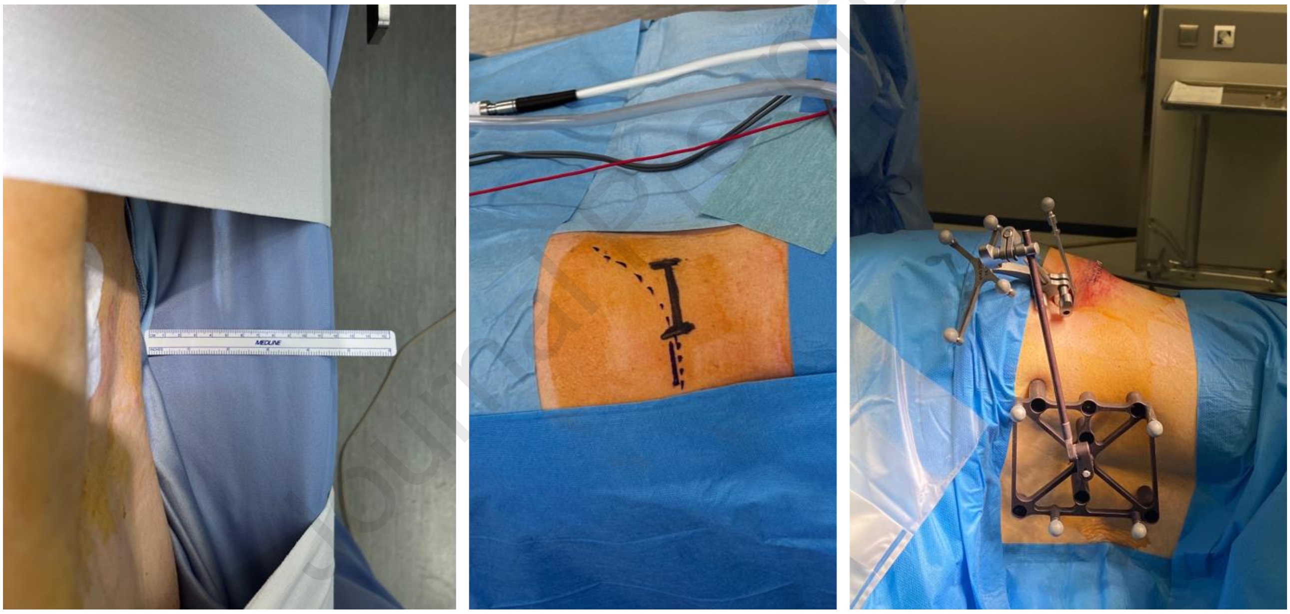

FIG. 5

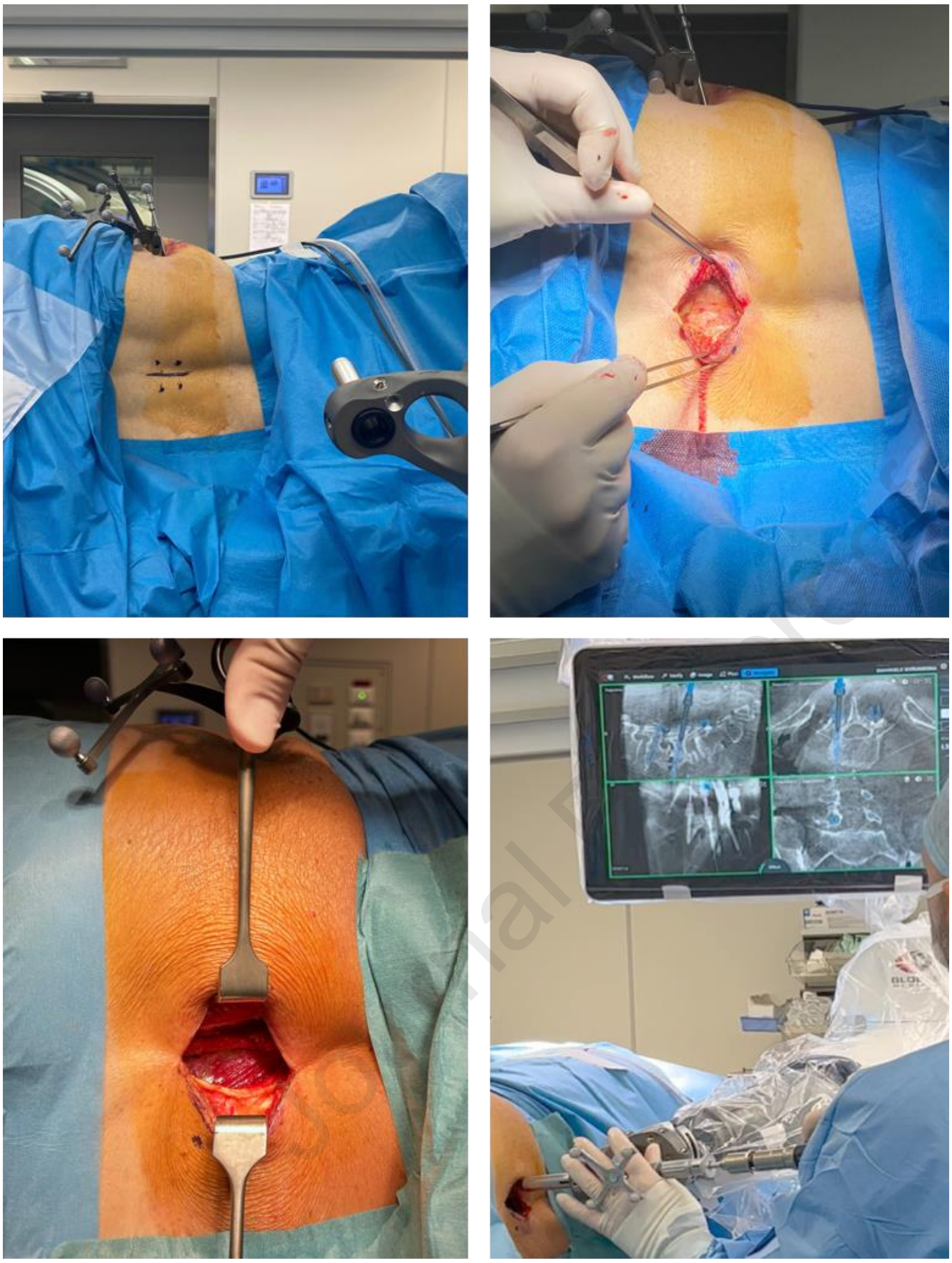

FIG. 6

FIGURE CAPTIONS

Fig. 1
Surgical planning and incision in prone position.
The optic references (Quattro-Spike, DRB and ICT on the right side, Surveillance-marker on the left side) are placed and the surgical planning is defined. The robotic arm is placed above the lumbar spine of the patient. A median skin incision is performed between the projection of the cranial screw of one side and the contralateral caudal screw, ensuring an incision as small and precise as possible.

Fig. 2
CBT screws planning.

CBT screw direction and trajectory are directly planned on the sterile robot touchscreen display with a "drag and drop" system. Screws follow a mediolateral path in the axial plane and a caudocephalad path in the sagittal plane. The entry point is usually located in the medial surface of isthmus, avoiding "sloping" entry points.

Fig. 3
Robot-assisted screws placement.
After the transmuscular approach is completed, the rigid robotic arm places itself along the planned trajectory above the skin. During the entire procedure the robotic arm maintains a rigid trajectory to avoid undesired deviations from the preoperative planning. A navigated drill is used to breach the cortical surface of the entry point. Then, a navigated drill bit is used to complete the exposure of the screw trajectory. Finally, the screw is placed with the support of the robotic arm.

Fig.4
Closure of the system and final control.
Rods and inner screws are locked in a standard fashion. A final fluoroscopic control is obtained to evaluate the correct placement of the screws.

Fig.5
Single lateral positioning.
In the single-position the surgical field must be adequately prepared since the first surgical step: skin preparation has to cover both the lateral and posterior surgical fields. A sterile drape is temporarily positioned to cover the posterior surgical field during the first surgical step, subsequently removed while harvesting the sterile surgical field for the second step of the procedure. All the navigation references are placed on the same iliac crest.

Fig.6
Robot-assisted screws placement in single lateral position.
Once the references are positioned, the following steps resemble the ones described for the double-position.

Table 1.
Surgical phases and steps of robot-assisted CBT screws placement with a transmuscular approach

PHASES	**STEPS**
Navigation phase	Registration of navigation frames
	Registration of surgical instruments
	Placement of Quattro-spike (right posterior-superior iliac crest)
	Placement of Surveillance-marker (left posterior-superior iliac crest)
	Placement of DRB anchored to Quattro-spike
	Placement of ICT anchored to ICT
	3D scan with a 3D fluoroscopy
	Robot system acquisition of 3D reconstruction
	Check of correct correspondence of navigation
Planning phase	CBT screw direction and trajectory planning
	Skin incision planning between the projection of the cranial screw of one side and the contralateral caudal screw
Surgical phase	Skin incision
	Fascia exposure and incision
	Dissection of fascia from the underlying muscular layer
	Navigated drilling of entry point
	CBT screws placement
	Rods and inner lock
	Final fluoroscopic control
	Closure

Abbreviations:

Lateral lumbar interbody fusion (LLIF), Cortical bone trajectory (CBT), Intraoperative CT (ICT), Dynamic Reference Based (DRB), 3-dimensional (3D)

Declarations of interest: None.