Robots have been gradually introduced into medical practice in the recent years in order to improve the quality of various procedures and surgical interventions, to shorten their duration, and to assist the surgeon during surgery. Robots are produced not only to perform surgical manipulations but also to provide assistance to the patient during the recuperation period. According to the Robotic Institute of America, a robot is re-programmable multi-functional manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

Medical robots are divided into four groups [5, 9, 11, 12, 21—23, 25—27].
1. Remote manipulators (telesurgery);
2. Passive robots: surgical manipulations are guided by the surgeon;
3. Semi-active robots: certain stages of an operation are performed by the surgeon, some manipulations are performed by a robot;
4. Active robots that perform complete surgical intervention under control of a computer.

The majority of neurosurgical operations are performed using a microscope and require a high accuracy and utmost care with respect to the nervous structures. Various studies have been carried out recently on the use of robots in specific branches of neurosurgery such as epilepsy surgery, stereotactic surgery, and stabilizing interventions (transpedicular fixations) [5, 6, 9, 22].

In 2004, a SpineAssist spinal robot was developed and clinically tested in Israel (Mazor Surgical Technologies, Caesarea, Israel). This is the first robotic system approved by the Food and Drug Administration for the use in spine surgery [18]. SpineAssist belongs to the group of passive robots [16, 22, 24]. One of the main objectives taken into account during design of the robot was the necessity for a robot to be firmly fixed within the operative field during surgery. The robot is fixed by mounting a platform (bridge) to a bony (spinous) process within the operative field using a special clip in the case of open intervention or a Kirschner’s wire in the case of transcutaneous interventions; in addition, the platform (bridge) is externally fixed by metal rods to the patient’s iliac spines. This approach is particularly relevant when placing transpedicular systems.

The robotic assistance system consists of a Windows-based workstation, used for preoperative planning on the basis on CT scans (in the DICOM format), and the robot itself. Movements of the robot are controlled by the workstation. The robotic arm has six degrees of freedom. The arm itself is a rigid steel stem. During surgery, the surgeon and the robot work together; the robot indicates the trajectory for introduction of an instrument, while the surgeon drills the holes for placing implants. The course of surgery is controlled by stage-by-stage X-ray, but in general, operative intervention occurs under the ultimate surgeon’s control [2, 3, 20].

The use of the SpineAssist robot has demonstrated a high accuracy of transcutaneous operative interventions using hardware [10, 19, 22]. Also, open surgeries have been performed using SpineAssist for placing transpedicular systems [2, 3, 7]; under the control of SpineAssist, the placement accuracy is almost perfect both in transcutaneous and in open modes [14]. SpineAssist is used for vertebroplasty of vertebral bodies in the case of their fractures or hemangiomas. The main advantage of SpineAssist is its high accuracy. The main disadvantage of the system is the high cost of the robot [13, 15].

The use of the SpineAssist robot

Between 2011 and 2013, 77 surgeries (39 males and 38 females, the mean age of 56.1±2 years) were performed using the SpineAssist robot.
All the patients were divided into four groups based on the pathology and the type of surgery (Table 1):

— Group 1 included patients with degenerative spinal stenosis and spondylolisthesis at the level of one spinal segment who underwent fusion using the GO-LIF procedure with or without bilateral decompression of the vertebral canal;

— Group 2 included patients with degenerative stenosis, spondylolisthesis, and lesion of two or more spinal segments who underwent fusion using classical transpedicular systems (Viper, Romeo);

— Group 3 included patients with the vertebral body changes of various origin (hemangioma, fractures, and deformities) who underwent vertebroplasty;

— Group 4 included patients who underwent biopsy of the altered vertebral body tissue.

Group 1 consisted of 36 patients who, if necessary, underwent bilateral decompression with or without interbody fusion followed by transcutaneous transpedicular interdisc fusion using the GO-LIF (Guided Oblique Lumbar Interbody Fusion) procedure as the main stage (Fig. 1). Interbody fusion was performed using different type cages, including cages filled with bone autograft.

Good results were obtained in 35 (97.22%) patients (Fig. 2), and an unsatisfactory result was obtained in 1 (2.78%) patient, which is associated with pathoanatomical features at the operative level (exostoses and facet joint hypertrophy) and vertebral body osteoporosis, which hampered the proper screw fixation. The system was removed, and bilateral decompression was performed.

Both the pain syndrome and neurological symptoms regressed during the postoperative period.

The L5—S1 level was most commonly affected (Fig. 3).

The advantage of the GO-LIF procedure is its minimal invasiveness; the lack of injury to the facet joints and minimal injury to soft tissues; a possibility to fuse a spinal segment with two screws, which are placed through the pedicle of a subjacent vertebra to the body of a superjacent one.

Table 1. Summary of patients’ groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Pathology</th>
<th>Type of surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, n=36 (46.75%)</td>
<td>Spinal stenosis, grade I—III spondylolisthesis, one affected level</td>
<td>GO-LIF fusion with or without bilateral decompression</td>
</tr>
<tr>
<td>Males — 17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females — 19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2, n=14 (18.18%)</td>
<td>Spinal stenosis, vertebral body fracture, two or more affected levels</td>
<td>Fusion with classical transpedicular systems (Viper, Romeo)</td>
</tr>
<tr>
<td>Males — 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females — 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3, n=16 (20.78%)</td>
<td>Hemangiomas, vertebral body fractures</td>
<td>Vertebroplasty of vertebral bodies</td>
</tr>
<tr>
<td>Males — 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females — 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4, n=11 (14.29%)</td>
<td>Vertebral body mass lesions</td>
<td>Biopsy</td>
</tr>
<tr>
<td>Males — 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Females — 7</td>
<td></td>
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</tbody>
</table>

Fig. 1. The SpineAssist robot in the operative field with an attached “arm” and guides for the subsequent placement of screws.

Fig. 2. CT control. The GO-LIF procedure is performed at the L4—L5 level.
Application of the GO-LIF fusion procedure requires the use of the SpineAssist robotic-guided system.

Indications for fusion using the GO-LIF procedure include:
- grade I—III spondylolisthesis;
- spinal stenosis;
- degenerative spine diseases.

Contraindications to fusion with the GO-LIF procedure include:
- lumbar hyperlordosis;
- abnormal sacral development;
- infectious spine diseases (osteomyelitis);
- osteoporosis (T-score less than 2.5);
- obesity (body mass index over 40).

Group 2 consisted of 14 patients with multilevel spinal lesions (Fig. 4) such as spinal stenosis and vertebral body compression fractures.

All the patients underwent robotic-assisted implantation of the Viper or Romeo transpedicular fixation system: for vertebral body fracture (3 cases) and for degenerative multilevel stenosis (11). In all cases, fusion was performed transcutaneously (Fig. 5). All the patients also underwent bilateral decompression.
Regression in the pain syndrome and neurological symptoms were observed in the early postoperative period. Patients were activated on the 2nd day after the operation.

The results of interventions were positive in all cases. Group 3 consisted of 16 patients with various changes in the vertebral bodies (hemangiomas, fractures); in one case, multiple vertebral body hemangiomas in the lumbar spine were present (Fig. 6). Robotic-assisted vertebroplasty was performed in all cases.

According to the clinical presentation, all hemangiomas were symptomatic and non-aggressive [1, 4, 8, 17]. The use of the SpineAssist robotic system allowed introduction of the filling material directly into the affected vertebral bodies with good results in all patients (Fig. 7).

Group 4 consisted of 11 patients in whom the SpineAssist robot was used to perform biopsy of vertebral body mass lesions (Table 2).

The use of robotic assistance allowed safe, reliable, and qualitative biopsy sampling from hard-to-reach regions of the vertebral bodies (Fig. 8).

Clinical case

A 30-year-old male N, diagnosed with a “L4 body defect of unknown origin” was hospitalized with complaints of gnawing pain in the lumbar spine that was in-
increased upon moving (Fig. 9). Biopsy was performed to determine nature of the process in the vertebral body cavity. The material was taken for the histological examination. No pathological tissue was detected (probably, the cavity was due to previous spondylodiscitis). At the second stage, vertebroplasty of a vertebral body defect was performed (Fig. 10).

**Conclusion**

The use of the SpineAssist robotic system enables minimally invasive, transcutaneous transpedicular interventions with safety and a high accuracy of screw placement. The GO-LIF fusion procedure can be combined with microdisectomy and decompression of the spinal canal. Fusion of spinal segments using the GO-LIF procedure is impossible without the SpineAssist robotic system. Vertebroplasty using the SpineAssist robotic system allows introduction of the filling material directly into the hemangioma cavity and in the vertebral body fracture region. Biopsy from hard-to-reach regions of the vertebral bodies by means of robotic assistance allows sampling the histological examination material using the optimal and safe trajectory.

Therefore, the use of the spinal robotic assistance system makes it possible to perform high-technology surgical interventions with high accuracy, safety, and efficiency.

**REFERENCES**

This article describes current issues in spine and spinal cord surgery such as improving the efficiency and accuracy of operations through the use of modern intraoperative navigation systems. The SpineAssist system is a combination of the navigation system and manipulation robot that defines the trajectory for insertion and determines the location of spinal fusion implants or biopsy and vertebroplasty needles. The paper presents the data on the application of SpineAssist in 77 patients. All the patients were divided into four groups based on the type of intervention.

Group 1 consisted of patients who underwent fusion of the affected segment with the GO-LIF procedure; Group 2 included patients who underwent fusion of the affected segments using a transpedicular system; Group 3 included patients who underwent vertebroplasty of the vertebral bodies; Group 4 consisted of patients who underwent biopsy of the vertebral bodies. The article describes the use of the SpineAssist system in degenerative pathologies, trauma, and tumors of the spine.

The groups the patients were divided can not be compared to each other. To our opinion, the article title should be expanded to “Results of using the SpineAssist robot in surgical treatment of spine disorders”. When describing the surgical stages in Group 1, the authors did not indicate that the trajectory in the subjacent vertebra is drilled first, and then decompression of the spinal canal and placement of an autologous bone or BiCalPhos interbody implant are performed. The next step is drilling the screw trajectory in the superjacent vertebra. The operation is then completed with fusion of a segment by placement of the GO-LIF screw.

In general, the article is modern scientific work devoted to the state-of-art technologies in spine surgery. Promotion of the robotic assistance method will expand the knowledge of spine surgeons. Undoubtedly, the technologies, such as navigation and robotic assistance, will be available in all specialized clinics in the near future, so it is necessary to learn how to use them right now.

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