Robotic-navigated spinal decompression procedures: the next frontier

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Cite this article:
Bone Jt Open 2024;5(9): 806–808.

DOI: 10.1302/2633-1462.59.BJO-2024-0065

In the past two decades, robotic-assisted surgery has significantly advanced its presence in orthopaedics, improving efficacy, safety, and accuracy. Currently, robotic systems can participate in surgery to varying degrees, ranging from passive systems, where the surgeon has complete control, to active systems, in which the robot operates autonomously under the surgeon's supervision with real-time guidance.[1] While the general public's acceptance of autonomous surgery may not be widespread at present, the rapid growth of the autonomous driving industry with similar safety concerns may, by parallel, yield insights. As the first automobile, the 'Benz Patent-Motorwagen' was created in 1885 by Benz. It introduced a hallmark feature: the ability to steer entirely manually. Nearly 150 years since this invention, various other capabilities have been introduced by modern cars to the masses, such as lane keeping, automatic braking, and adaptive cruise control, incorporating real-time vehicle feedback.[2,3] It is anticipated that most car companies will launch fully autonomous vehicles within the next decade.[3]

In the realm of orthopaedic surgery, robotic use in arthroplasty of the hip and knee joints currently involves active robotic navigation systems with an impressive range of applications, from cutting bone and modifying joint surfaces to verifying implant position. Within the workflow of performing a robotic total hip arthroplasty (THA), surgeons may utilize a 3D reconstruction of the patient's native hip anatomy to determine the optimal position and size of the implant.[4] Subsequently, the robotic software calculates crucial parameters, such as the depth of acetabular bone resection, proximal femoral osteotomy location and angle, and component positioning.[4] The surgeon maps out the surgical plan, and the robot executes it while providing real-time feedback with regard to bone coverage, implant inclination, implant version, offset, and leg-length correction.[4] Similar workflows can be found in knee arthroplasties, where we find systems ranging from semi-active to fully active robots, working autonomously as the surgeon supervises in a more passive physical role.[5]

Much data already supports robotic-assisted arthroplasty applications in orthopaedics, in large part due to the improved accuracy in implant positioning that it affords. For instance, a 71% acetabular positioning improvement in robotic THA compared to non-robotic THA has been shown, potentially indicating a reduction of potential manual subjective errors.[6] Additionally, better short-term clinical outcomes have been shown for robotic total knee arthroplasties, with fewer iatrogenic soft-tissue injuries than in conventional, manual techniques.[7]

More recently, robotic influences have also found applications in the field of spinal surgery. Since the first USA Food and Drug Administration approval for a spinal surgery robot in 2004, several systems have entered the market and are used as passive systems, mainly to improve the accuracy of positioning pedicle screws.[8] The advantages of robotics in spinal surgery have been supported by multiple scientific studies, with improved accuracy, safety, and efficiency in placing pedicle screws.[9,10] Additionally, robotic spine procedures have been shown to be less invasive and to involve less radiation exposure to the surgical team compared to traditional surgical approaches.[11]

Despite the rapid growth in robotic use and its large potential advantages in spinal surgery, discussions about its role and pricing have arisen, up to the colloquial critique of the robot being a costly drill guide. Currently, robotic surgery in the

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spine has been limited to the implantation of screws and cages, and has not been sufficiently adept at the more intricate and technically demanding aspects of surgical procedures, such as those involved in neurological decompression. Continuing the earlier analogy related to cars, the following comparison can help in understanding the role of robotics in spinal surgery: the insertion of screws into a bony corridor, such as a pedicle, may be likened to driving a car on the road. On the other hand, neurological decompression is potentially more complex, resembling the challenges of executing parallel parking on an incline under unstable weather conditions. To date, applications of robotic surgery have not formally extended into the realm of bony resection, partly due to the lack of developed and relevant technologies. As a result, surgeons can perform the majority of spinal procedures manually, while robotic systems play a supportive role rather than leading the surgeon. Hence, spine surgeons remain in control of the steering wheel.

Nevertheless, considering the proven capabilities of the robot in various other orthopaedic domains, with improvements in software the spinal robot appears to have expanded its repertoire. Recently developed software features now allow for meticulous planning of targeted bone resection by way of a navigated bone removal instrument. This application is capable of executing a predefined plan for the volume and trajectory of the bone to be removed and prompts stoppage at the end of the planned resection, thereby preventing injury to the surrounding structures. For the first time, the ability of robotic systems to perform bony resection in a controlled and navigated fashion represents a significant step forward. While one of the timeless challenges of traditional manual surgical decompression of the spine includes achieving an optimal balance of sufficient bone and soft-tissue removal for adequate neurological decompression without biomechanically destabilizing the motion segment, there does exist promise for the application of robotic techniques to achieve this balance more precisely and reliably.

While this advancement may seem trivial to the non-spine orthopaedist, it has the potential for widespread application in the field of spinal robotics, upgrading existing systems from passive to semi-active participants in the operation.

In the context of these recent technological advancements, the navigated robotic bone removal instrument has been adopted into surgical practice as an assistive device for robotic lumbar decompression. Consequently, a proof-of-concept study is presented to establish the first surgical technique for robotic lumbar decompression. The first phase of the study involved the use of a cadaveric model to demonstrate feasibility and accuracy. Following in vitro analysis, the technique was successfully expanded to patients with symptomatic lumbar stenosis.

This innovative technique represents a novel application of an evolving technology, and while in its nascency, we believe it offers enhanced precision and reduced risk to surrounding structures. Its usage in vitro and in vivo underscores the potential of robotic navigation assistance in lumbar decompression techniques and introduces a new era of semi-active robotics in the spine. Nonetheless, the innovation of robotic navigation in spinal surgery from a passive tool to an autonomous and collaborative system, similar to the automotive industry, seems to be on a journey that is far from completion, and with lots of runway ahead.

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Funding statement

The author(s) disclose receipt of the following financial or material support for the research, authorship, and/or publication of this article: Rama and Shashi Marda Foundation.

ICMJE COI statement

D. R. Lebl discloses grants or contracts from Rama and Shashi Marda; research support from Medtronic Sofamor Danek USA; royalties from Stryker; being a consultant and advisory board member from Choice Spine, consultant for Depuy Synthes, being a consultant and having an ownership interest in Viseon, being an advisory board and having an ownership interest in Remedy Logic, and having an ownership interest in Vestia Ventures MiRus

Investment and Woven Orthopedic Technologies, all of which are unrelated to this article.

Open access funding

The authors report that the open access funding for this manuscript was self-funded.