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Research Article

Robotic-Assisted Minimally Invasive Transforaminal Interbody Fusion (TLIF) Using A New Hands-Free 3D Digital Microscope with Head-Mounted Display (HMD): Technical Note

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Abstract

Background: Looking into the eyepiece of a conventional operative microscope during minimally invasive spine surgery may result in uncomfortable or highly nonergonomic postures. Robotic systems are rapidly changing the landscape of modern surgery, offering potential benefits for both patients and surgeons. This study aims to describe potential advantages of a new high-definition hands-free robotic visualization device (RoboticScope) displaying 3D images in a head-mounted display (HMD) accessory for minimally invasive decompression and navigated transforaminal lumbar interbody fusion (TLIF).

Methods: We performed a single TLIF with prior laboratory training to assess the advantages and disadvantages of RoboticScope assistance, its integration into the operative workflow, and its qualitative appraisal in spine surgery.

Results: A senior surgeon evaluated magnification, perception of depth and robot manipulation with HMD as good. All four placed pedicle screws were assessed as grade A according to the Gertzbein-Robbins scale (GRS) No intra- or perioperative complications were experienced.

Conclusion: Maintaining ergonomic posture and hands-free control microscopy are of particular interest in minimally invasive spine surgery. Further clinical research is required to demonstrate the safety, usability and surgical outcome using the Robotic Scope.

Keywords: Smart glasses; minimally invasive surgical procedures; robotics; microscopy; spinal fusion; ergonomic.

Case Report

COVID-19: Coronavirus Disease 2019; CT: Computer Tomography; DOF: Degrees-Of-Freedom; GRS: Gertzbein-Robbins Scale; HD: High-Definition; HMD: Head-Mounted Display; MISS: Minimally Invasive Spine Surgery; OM: Operating Microscope; TLIF: Transforaminal Interbody Fusion.

Introduction

Since the 1970s, the operating microscope (OM) has been a standard tool for visualization and illumination of the surgical field during spinal microsurgery. However, some limitations have been documented, e.g., the limited movability of the binocular lenses and discomfort experienced by surgeons due to the abnormal postures required, and efforts have been made to replace the OM with exoscopic and digital systems [1]. Minimally invasive spine procedures rely mostly on good visualization, which has been proven using microscopes; however, this approach comes with a price, notably the need for repetitive movement of the microscope, a limited field of view (focus) and focal length, which lead to difficulty maintaining proper visualization when working with long instruments, such as screwdrivers [2]. Furthermore, the mandatory alignment of the microscope optics with tubular retractors and the constraint of the surgeon to look at the operative field through the binoculars results in nonergonomic postures (Figure 1A), leading to discomfort, pain and eventually work-related musculoskeletal disorders with potential disability [3-5].

Various portable head-mounted display (HMD) devices have been described in spinal surgery to superimpose valuable intraoperative information to the surgeon's field of view in the headset, such as real-time fluoroscopic images, 3D neuronavigation or augmented reality data during minimally invasive pedicle screw placement [6-8]. By keeping "eyes on the field" during the whole procedure, without need-

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ing to frequently look at the display monitors, surgeons minimize the risk of unintentional hand deviation and complications resulting from microsurgical manipulation.

A new microscope displaying high-definition binocular 3D images of the operative field onto an HMD, with hands-free control of the robotic arm carrying the camera, has been assessed in hand, plastic and otologic microsurgery [9-12]. An HMD enables the maintenance of a safe working distance, wearing adequate personal protective equipment and additional surgical draping to reduce perioperative staff contamination risk during the coronavirus disease 2019 (COVID-19) pandemic [13].

The aim of this technical note is to appraise the feasibility of using an innovative high-definition microscope (RoboticScope®, BHS Technologies GmbH, Innsbruck, Austria) with a camera head-mounted onto a controllable robotic arm linked to an HDM displaying the images of the surgical field for minimally invasive 3D-navigated TLIF (**Figure 1B-D**).

Figure 1(A-D): Transoperative images. A: Figure showing a possible position of the surgeon using a traditional microscope with integrated eyepieces, the position may not be ergonomically correct. B: Using the RoboticScope system, the surgeon shows a better ergonomic position, without forced movements, even trying to see "around the corner". C: The eyepieces can be raised automatically on the surgeon's command (by activating the virtual menu or via a foot pedal). D: the system allows seeing out of the eyepiece screens, for instance to use the navigation.

Materials and Methods

Operative Indication

A 76-year-old female patient with chronic radicular neurogenic claudication shown by L5-S1 discopathy and bilateral severe foraminal stenosis on preoperative MRI who was resistant to conservative treatment, underwent microsurgical decompression and instrumentation using minimally invasive surgery (MIS-TLIF) under general anesthesia.

Training

Two weeks prior to the procedure, the senior surgeon received a practical introduction to the RoboticScope on artificial models, including teaching on the use of its main functions such as orientation of the robotic arm to change the angle of vision and navigation through the interface to select and adjust the different parameters (Figure 2A).We recorded the surgeon's head movements for camera motion control and time taken to reach different positions of the robotic arm during training.

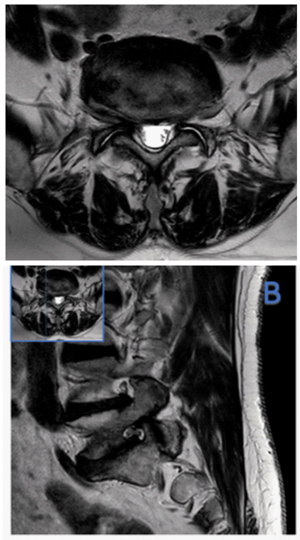

Figure 2(A-B): A: Laboratory training: a training procedure was performed to demonstrate how to control the camera via the integrated virtual menu. B: The integrated virtual menu allows controlling the eyepiece aperture, camera movement, focus, magnification, light intensity etc. Everything is done through subtle movements of the head. This makes the system very intuitive (Courtesy of BHS Technologies GmbH, Innsbruck, Austria).

Technique

The patient was positioned prone on a Jackson table (Mizuho, OSI®). After placing the spinous process clamp and reference on S1, 3D imaging was acquired by computer tomography (CT) intraoperative scan (O-arm™, Medtronic, Inc.) and was transferred to the spinal navigation system (StealthStation™, Medtronic, Inc.). A two-centimeter-long skin incision was made approximately 5 cm paramedian on the right side. Tubular retractors (MAST QUADRANT™ system, Medtronic, Inc.) were placed regarding the segment of interest under navigation, exposing all structures between pedicles L5 and S1 (facets and lamina). The RoboticScope® camera head was brought in after adjusting and calibrating the HMD on the surgeon's head (Figure 1B and C). After drilling through the inferior articular process of L5 and removing the superior articular process of S1 with the drill and Kerrison rongeurs, the dura and traversing S1 nerve were exposed and medially retracted. Annulotomy was performed, the disc material removed, and endplates prepared with different curettes.

After localization confirmation with the navigation probe, an interbody titanium cage was brought under fluoroscopic control.Four titanium percutaneous pedicular screws were inserted into L5 and S1 under computer-assisted navigation. 3D intraoperative images were then acquired to confirm the correct placement of the screws and cage (**Figure 3**).

Microscopic System: Robotic Scope

Surgical field images were captured by a high-definition (HD) dynamic camera mounted on a six degrees-of-freedom (DOF) robotic arm. Binocular digital screens fixed onto the helmet on the surgeon's head displayed the HD 3D live operative images, irrespective of the surgeon's head position (Figure 1 D).Taking off the HMD eye screens, orientation of the robotic arm and control of microscope settings were possible using light head gestures (Figure 1C) as follows. After pressing on a foot pedal to engage control mode, nodding and head turning detected by the HMD enable navigation through a visual user interface, allowing changing the perspective of sight or adjusting parameters such as the working distance (300-600 mm), magnification (absolute magnification 4.3-34.4x), and illumination (white LED technology) (Figure 2B). The RoboticScope received the European conformity (CE) certification in 2020.

This study was conducted in accordance with the local Swiss Ethics committee guidelines and the Declaration of Helsinki. Written consent for medical data collection and de-identified use for research was obtained from the patient.

Results

Training in the laboratory before the procedure was of great benefit. The first transition from one point to another in the mock surgical field took 10 seconds, but after 1 hour of training went down to 3 seconds. Focusing took 8 seconds vs 2 seconds after 1 hour of training. Control of the camera was highly intuitive, and no difficulties controlling the position and movements of the camera were encountered. During the real surgery, focusing and moving from one point to another required the same amount of time as after the 1-hour training period (**Figure 2A**).

After operation, all four placed screws were assessed as grade A according to the Gertzbein-Robbins scale (GRS), with no pedicle breach detected on the intraoperative CT scan (**Figure 3,4**) [14]. There were no intra- or perioperative complications.

Figure 3: A) Robotic arm with 3D mounted camera, surgeon in ergonomic posture looking horizontally at the microdisplays in the HMD device. B) holding the foot pedal and moving head up enables the unfolding of HMD, giving sight on the operative room's environment. C) Surgeon looking laterally at navigation data on the monitor, shifting gaze away from binocular of HMD.

Magnification, depth perception and robotic manipulation with the HMD were evaluated as comparable to the traditional microscope. The focal length was evaluated superior to our standard microscope and the available workspace under magnification when using long instruments. More workspace is due to freeing the space occupied by the traditional microscope. We can therefore conclude that the use of a new microscope with a robotic mounted camera fit in well with the established workflow of MIS-TLIF of our institution. The surgeon reported a significant reduction in muscle tension and fatigue after a procedure lasting several hours, being able to maintain an aligned and physiological spinal posture during all microsurgical steps

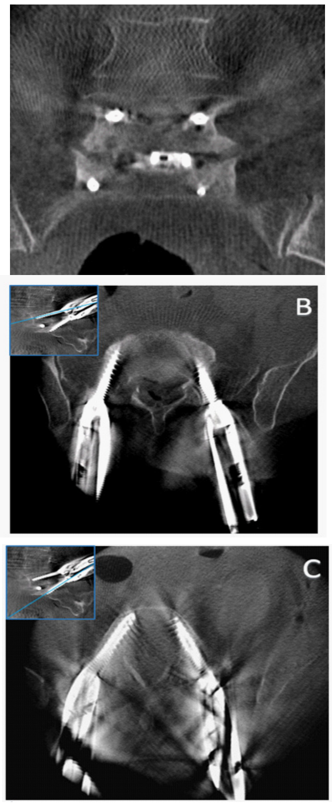

Figure 4: A coronal, B axial L5 and C axial S1 intraoperative CT scan acquisitions.

Discussion

In this technical note, we used a newly conceptualized 3D stereoscopic microscope previously tested in other conditions, with a robotic mounted camera from which surgical field images are displayed in an HMD to now test the feasibility of use for MIS-TLIF. After a relatively short training, the surgeon was ready to use the new device for a designated spine procedure. The surgery was uncomplicated, the new device integrated seamlessly and safely in the usual operative process and a significant reduction in tension and muscle fatigue following ergonomic positioning was reported by the surgeon.

Extreme angulation of tubular retractors to optimize the exposure of relevant structures in a narrow operative corridor of less than 3 cm diameter represents a current maneuver in MISS. Working independently of oculars mounted on traditional microscopes in MISS was our goal to elude the classical alignment constraint of the surgeon's eyes and eyepiece proximally to the microscope's objective and the tubular retractor distally so that the surgeon can adopt a more neutral and ergonomic posture. Use of exoscopes with tubular retractors has also been advocated for this purpose [15] but with an exoscope, surgical site observation still depends on looking at a screen with altered field depth perception. Furthermore, preoperative placement of the 3D monitors for the first operator and the assistant can sometimes be cumbersome, while for Robotic Scope, the working images permanently follow the head movements of the surgeon in the HMD [16]. In addition, notwithstanding significant technical developments in the field of digital monitoring with 3D ultrahigh-4K definition, the tridimensional image quality, depth perception and illumination of exoscopes have not yet achieved the results of classical microscopy operating or the performances that are expected to be maintained with the binocular digital microdisplay system of RoboticScope [17].

Bringing in a navigation probe or long instruments during minimally invasive spinal procedures often results in taking operative instruments out of the surgical field to remove the microscope head leading to incapacity to look at operative 3D images through the microscope eyepiece and unergonomic body movements when observing the 2D external screen. Field obstruction by a microscope prevents camera visualization of the tracking markers and causes loss of neuronavigation. In this respect, uncoupling the surgeon's eyes from a microscope eyepiece via an HMD enables maintaining 3D images of the neurological structures during critical instrumentation steps. In addition, hands-free control of the field view with head motion and the wide working distance of RoboticScope (300-600 mm) allows instruments to be kept in the operative field throughout.

Kwan et al. showed a significant increase in the incidence of scope adjustment during the same spinal procedure using a high-definition 3D exoscope compared to a classical operating microscope. therefore, by means of hands-free orientation of the microscope, an additional reduction in the incidence of scope adjustment could be foreseen using Robotic Scope. For narrow surgical corridors, especially when using tubular retractors, slight angulations of the microscope tube are sometimes useful to clear microsurgical instruments out of the line-of-sight of anatomical structures of interest. The head-controlled orbital mode of RoboticScope would permit gentle rotation around a chosen point to reveal the tip of instruments in a confined space without the need to manually orient the microscope.

Limitations

We report the first use of robotic microscopy with HMD for spinal surgery; however, a larger number of cases is needed to assess the safety and usability of the system on a regular basis in MISS. Further assessments are required to appraise the learning curve and the optimum length of preoperative training sessions. Ex-vivo tests on human cadavers could contribute first to assess feasibility and then to measure accuracy and reproducibility of the procedures with this new device. As Molina et al. mentioned in their study, a major obstacle interfering with a seamless and safe workflow of conventional computer-assisted spine navigation is attention shift. Repeatedly shifting looking at the surgical field and neuronavigation screen entails a risk of hand deviation and misplacement of screws. Moving the gaze away from the micro-display of the HMD (e.g., taking off the HMD eye screens as in Figure 1C) to assess navigation information on other display screens in the operating room could easily be prevented by embedding the navigation screens into the HMD's digital micro-display. In addition, the digital character of the HD procedural images displayed on the HMD may allow for more convenient superimposition of computer-generated data onto the patient in augmented reality than those with demanding projection techniques for overlapping supplementary images onto an optical system, such as microscope oculars [18].

We noted two possible disadvantages of Robotic Scope that could be readily addressed in the future. First, the initial delicate process of balancing the relatively heavy helmet (485 gr.) on the surgeon's head and maintaining a constant distance from the binocular screens of the HMD to the eyes are mandatory to maintain the focus during the length of the procedure. Optimizing the fit of the HMD to the surgeon's head and especially limiting its weight would help to maintain a constant distance between eyes and the HMD screens. With conventional microscopy, this distance from eyes to binoculars is not fixed, but surgeons can adapt it with slight back and forth movement of the head. Second, a double HMD is not currently available for another surgeon, hindering the same 3D visualization of the surgical field for quality operative assistance.

Conclusion

To our knowledge, this is a first report of the use of an innovative microscope, the RoboticScope® (BHS Technologies GmbH, Innsbruck, Austria), for minimally invasive spinal stabilization procedure. In contrast to conventional operating microscopy, working independently of the eyepieces allows surgeons to adopt an ergonomic posture, even in cases of extreme tubular retractor angulations. Changing the perspective of sight and working distance while keeping operative instruments and the surgeon's sight in the surgical field is made possible by hands-free control of the microscope's camera head. Further pre-clinical and clinical research is required to demonstrate safety, usability, and surgical outcomes using this new technology

Ethics approval: NA

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References

1. Oppenheimer JH, DeCastro I, McDonnell DE. Minimally invasive spine technology and minimally invasive spine surgery: A historical review. Neurosurg Focus. 2009; 27:1-15.

2. Foley KT, Smith MM, Rampersaud YR. Microendoscopic approach to far-lateral lumbar disc herniation. Neurosurg Focus. 2008;7:E7.

3. Auerbach JD, Weidner ZD, Milby AH, Diab M, Lonner BS. Musculoskeletal disorders among spine surgeons: Results of a survey of the scoliosis research society membership. Spine. 2011;36:1715-1721.

4. Lavé A, Gondar R, Demetriades AK, Meling TR. Ergonomics and musculoskeletal disorders in neurosurgery: a systematic review. Acta Neurochir (Wien). 2020;162:2213-2220.

5. Park JY, Kim KH, Kuh SU, Chin DK, Kim KS, Cho YE. Spine surgeon's kinematics during discectomy according to operating table height and the methods to visualize the surgical field. Eur Spine J. 2012; 21:2704-12.

6. Gibby JT, Swenson SA, Cvetko S, Rao R, Javan R. Head-mounted display augmented reality to guide pedicle screw placement utilizing computed tomography. Int J Comput Assist Radiol Surg. 2019;14:525-535.

7. Jang W Yoon, Robert E Chen, Phillip K Han, Phong Si, William D Freeman Stephen M. Pirris. Technical feasibility and safety of an intraoperative head-up display device during spine instrumentation. Int J Med Robot Comput Assist Surg. 2016.

8. Molina CA, Sciubba DM, Greenberg JK, Khan M, Witham T. Clinical Accuracy, Technical Precision, and Workflow of the First in Human Use of an Augmented-Reality Head-Mounted Display Stereotactic Navigation System for Spine Surgery. Oper Neurosurg. 2021;20:300-309.

9. Battiston B, Stefano A, Ciclamini D. The RoboticScope can be a Useful Tool for Hand and Microsurgical Procedures during the COVID-19 Pandemic. J Hand Microsurg. 2020;12:132-132.

10. Boehm F, Graesslin R, Theodoraki M, Schild L, Greve J, et al. Current Advances in Robotics for Head and Neck Surgery — A Systematic Review p. 2021;1-18.

11. Scaglioni M, Meroni M, Fritsche E, Linder T, Rajan G. Use of the BHS robotic scope to perform lymphovenous anastomosis. 2021;1-2.

12. Schär M, Röösli C, Huber A. Preliminary experience and feasibility test using a novel 3D virtual-reality microscope for otologic surgical procedures. Acta Otolaryngol. 2020:1-6.

13. Lavrysen E, Gilles A, Mertens G, Saki N, Vanderveken OM, Rompaey V Van, et al. Elective otological healthcare under COVID-19 contaminations risks. B-ENT. 2020;16:73-80.

14. Gertzbein SD, Robbins SE. Accuracy of Pedicular Screw Placement In Vivo. Spine (Phila Pa 1976) 1990;15.

15. Hisam M, Ariffin M, Ibrahim K, Baharudin A, Tamil AM. Early Experience, Setup, Learning Curve, Benefits, and Complications Associated with Exoscope and Three-Dimensional 4K Hybrid Digital Visualizations in Minimally Invasive Spine Surgery. Asian Spine J. 2020;14(1):59-65.

16. Kwan K, Schneider JR, Du V, Falting L, Boockvar JA, Oren J, et al. Lessons Learned Using a High-Definition 3-Dimensional Exoscope for Spinal Surgery. Oper Neurosurg. 2019;16:619-25.

17. Siller S, Zoellner C, Fuetsch M, Trabold R, Tonn J-C, Zausinger S. A high-definition 3D exoscope as an alternative to the operating microscope in spinal microsurgery. J Neurosurg Spine. 2020;33:705-14.

18. Elmi-Terander A, Burström G, Nachabé R, Fagerlund M, Ståhl F, et al. Augmented reality navigation with intraoperative 3D imaging vs fluoroscopy-assisted free-hand surgery for spine fixation surgery: a matched-control study comparing accuracy. Sci Rep. 2020;10:707.