Aus der Klinik für Neurochirurgie
der Medizinischen Fakultät Charité – Universitätsmedizin Berlin

DISSERTATION

Freihändige Einstellung des Mikroskops in der Mikroneurochirurgie

Hands free adjustment of the microscope in Microneurosurgery

zur Erlangung des akademischen Grades
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von

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aus

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OPMI	Operationsmikroskop
VR	Virtual Reality
BMBF	Bundesministerium für Bildung und Forschung
3D	Three dimensional
HTC	High Tech Computer Corporation
NASA-TLX	National Aeronautics and Space Adminstration - Task Load Index
2D	Two dimensional
LED	Light Emitting Diode
FOV	Field of Vision

Abstract- English

A wide array of medical errors plague the healthcare system. The repercussions of those errors are more palpable in healthcare and more so in the operative microsurgical theater. The surgical microscope, although a key element within it, has a high propensity for errors.

The two communication approaches evaluated in this study took advantage of the natural physiology of the human body by tracking and utilizing eye movements and body gestures to execute tasks that would typically require manual interaction with the microscope. Independent trials at the Charité Hospital in Berlin were conducted, and different technological tools like Virtual Reality were utilized to evaluate them. Specialized tasks were created for both of the trials. The results showed us that these body tracking approaches (body gestures and gaze) were almost 30% and 20% faster than the contemporary alternative.

In the last 20 years, the diffusion of technology within medicine has been enormous, these new patient-oriented technological approaches could be revolutionary in controlling an existing critical element within the microsurgical theater.

Zusammenfassung – Deutsch

Das Gesundheitssystem wird von einer Vielzahl medizinischer Fehler geplagt. Die Auswirkungen dieser Fehler sind im Gesundheitswesen und insbesondere im mikrochirurgischen Operationssaal am deutlichsten spürbar. Das Operationsmikroskop ist zwar ein Schlüsselelement in diesem Bereich, aber dennoch sehr fehleranfällig.

Die beiden in dieser Studie untersuchten Kommunikationsansätze verwenden die natürliche Physiologie des menschlichen Körpers, indem sie Augenbewegungen und Körpergesten verfolgen und nutzen, um Aufgaben auszuführen, die normalerweise eine manuelle Interaktion mit dem Mikroskop erfordern würden. In der Charité in Berlin wurden separate Trials durchgeführt und verschiedene technische Hilfsmittel wie Virtual Reality eingesetzt, um sie zu bewerten. Für beide Trials wurden spezielle Aufgaben erstellt.

Die Ergebnisse zeigten uns, dass diese Body-Tracking-Ansätze (Körpergesten und Blicke) fast 30 % bzw. 20 % schneller waren als der aktuelle Stand der Technik.

In den letzten 20 Jahren hat die Technologie in der Medizin eine enorme Verbreitung erfahren; diese neuen patientenorientierten technologischen Ansätze könnten bei der

Kontrolle eines bestehenden kritischen Elements im mikrochirurgischen Bereich revolutionär sein.

1.Introduction

This paper examines two hands-free interaction concepts utilizing 1) Gaze Tracking 2) Head Movement as a means to navigate the intraoperative Microscope.

This research was supported by the German Ministry of Education and Research (BMBF).

1.1 Microsurgery

The Intraoperative Microscope was introduced into the operating table to magnify the operator's field of view to make fine anatomical landmarks of the human body more visually accessible. This added another dimension to the operating table, where earlier relatively impossible facets of the operatory challenges became easier to navigate. A succinct example of the current times is the operation of a patient with a painful lumbar herniated disc. This disease modality is managed operatively with a procedure known as Microdiscectomy, or Microlumbar Discectomy (MLD), where the surgeon visualizes the disc herniation utilizing the surgical Microscope utilizing specialized instruments removes the herniated disc material.

An interesting case where the intraoperative Microscope allowed for timely and otherwise non-operable access was a Schwannoma of the S1 Dural Sleeve as reported by Kobayashi et. Al. This case report demonstrated how with the help of the intraoperative Microscope, the surrounding nerve Fibers were preserved using the microsurgical technique and is further discussed below.

A Schwanomma is mostly a benign tumor composed of Schwann cells affecting the peripheral nerves. The clinical manifestations arise as the tumor, which usually lies outside the nerve, induces pressure on the affected nerve or the skeletal structure.

A 32-year older adult presented with clinical symptoms of pain in the lumbar vertebral region along with right-sided radicular leg pain from the past 18 months. The initial diagnosis was of a lumbar disc herniation that was managed conservatively. The patient presented himself again at the author's hospital with persistent symptoms.

The author's hospital further conducted different radiological examinations, which involved an MRI and a Myelography. After a thorough clinical and radiological examination, the conclusive diagnosis was a tumor at the S1 dural sleeve.

30-40% of all spinal cord tumors were reported to be Schwanommas.(1) A Schwannoma found in the nerve root at an extradural site and to be diagnosed at an early stage is relatively rare. (2)
As reported by the authors, the tumor was visualized after incision of the dura mater, which was done with the help of the operating microscope. The dura mater is the external cover that covers the nerve root and fibers. Careful management and visualization is critical at such parts of the operation as this being a sensitive area, is more prone to extreme consequences if an error occurs (for example, damage to the spinal cord or the nerve roots surrounding it). Microsurgery utilizing the intraoperative microscope allowed for precise visual magnification incision of the dura mater, which lead to clear visualization and excision of the tumor with maximal preservation of function, and minimal impairment from incision of nerve fibers in the nerve root. (3)

As the name suggests, microsurgery is the type of surgery that requires the utilization of high magnification to visualize the anatomical structures to execute the operation. Different fields of surgery utilize the microscope regularly.
Different surgical specialties with standard procedures utilizing the surgical microscope are listed below.

- Cochlear implantation in otolaryngology
- Cataract surgery in Ophthalmology
- Neurovascular surgical procedures in Neurosurgery
- Free tissue transfer for Reconstructive Breast Surgery in Plastic Surgery
- Surgical management of herniated discs in Orthopaedic surgery

1.2 Surgeon and machine (microscope) interaction

A multitude of commands as directed by the operator can be executed with the microscopic setup of today. In the current microsurgical setup, the operator uses both their hands to operate on the anatomical site of the patient and interrupts the operation very briefly to optimize the field of view using ancillary functions of the microscope. This is done with the help of appendages that are part of the microscope (for example, the handles that are part of the Zeiss OPMI Pentero 800 Microscope). The intraoperative microscope of today provides illumination of the surgical site, heightened magnification, with some of them even having an autofocus feature and ability to project the operation and record it on a live screen for the other participants to view the microsurgical operation within the operating theater as well. With this wide array of functionality that the operator utilizes, this inevitably brings us into the spectrum of Human-machine Interaction.

The reciprocity between the machine and the human user with the help of a human-machine interface is what defines as Human-machine interaction. In this context, the intra-operative microscope and the operator. This has been widely applied in different domains like industrial, transportation, medical and entertainment systems. (4) The task in this context can be divided into two parts. The prescribed task is supported by the machine, and the executed task is the part done by the user. (5) The seamless interplay within them is critical, especially in working conditions that are highly inclined to automation and digitalization like currently in the industrial, medical settings. (6)

In the highly stressed and increasingly complex operating room of the current, various disruptions can cause an interruption of the operating flow. (7) The ones pertinent to the context of the “human-microscope interaction” are listed below

- Poor instrument (machine) design (8)
- Lack of minimal distance between the operator and the instrument (machine)(9)
- Minimal freedom of movement (10)
- Operator fatigue
- Intraoperative manipulation to carry out ancillary tasks

One common disruption is the intraoperative manipulation of the microscope to carry out tasks like changing the optical axis and adjusting the zoom. These manipulations are traditionally carried with the operating microscope by the handles that are a component of the entire microscope. Touchless alternatives were presented to execute these manipulations. They come with their drawbacks which are further discussed further below.

1.3 Current touchless interaction concepts for the microscope

The dimensions of the operating microscope, with its ability to adjust the focus and general workability, have continually presented challenges. (11) In the recent past, there have been attempts at creating alternative additions to the intraoperative microscope to navigate the entire microsurgical setup. They come with certain limitations, which are discussed below.

1. Foot Pedal
2. Mouthpiece

Foot Pedal

A foot pedal is a device that is operated with the user's foot. It provides the ability for the user to completely utilize both hands on the task and execute other additional tasks using the feet. Automobile, Medical, and Agriculture are amongst many industries that have utilized this technology in recent years.In this, Basic mechanisms of levers are utilized to create leverage which helps to trade off forces against movement to create an advantage.

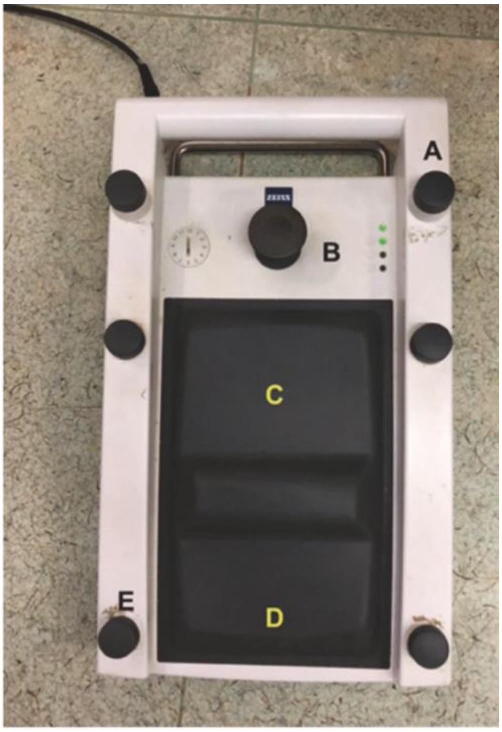

Figure 1 : Foot pedal. "(*A*) Illumination intensity adjustment tab; (*B*) X-Y joystick; (*C*) focus tab; (*D*) zoom tab; light on-off " (Dogra M., Singh M., Ichhpujani P. (2019) Basic Operating Room Machines. In: Ichhpujani P., Singh M. (eds) *Ophthalmic Instruments and Surgical Tools.* Current Practices in Ophthalmology. Springer, Singapore.)

Various studies have pointed out specific critical points regarding this appendage. The most obvious is that in the already pre-existing microscopic set-up, an addition of another foot pedal to execute a function increases the risks of hitting the wrong pedal and triggering a wrong task in the bargain (12). Schurr et al. also pointed out that surgeons did not prefer this due to its limitations on movements for the surgeon and its general unergonomic nature.

The study conducted by Veelen et al. showed that occasionally the wrong switch was pushed by 75% of the surgeons, leading the operation into a precarious situation for the patient. Obstruction of freedom, risk of activating certain functions occasionally, lack of comfort while operating were amongst the other disadvantages also discussed in the study.

Mouthpiece

Another addition that has been in utility in the market is the mouthpiece, a whistle-shaped tool maneuvered by the operator's lips or teeth to execute specific tasks. Clear, crisp, and vital inter personnel communication is vital intraoperatively, and this device limits the ability to do so for the operator as the device itself is either close or inside the mouth while using it (13).

This was further highlighted by Afkari et al., where the authors explain a practical problem while using this in the context of Microneurosurgery. An operator has the surgical mask on at all times during the operation. They pointed out that utilizing this appendage on top of that would only further magnify the verbal communication problems that could arise between the operator and the other essential participants in the operating theater. Other limitations of this are discussed in the original publication by Khakhar et al.; (2021).

Figure 2 : Mouthpiece integrated within the operating microscope (Aaron Cohen-Gadol, C 2020, The Neurosurgical Atlas.)

The apparent drawbacks made it difficult for these alternatives to be seamlessly adapted and utilized regularly as a gold standard addition. These alternatives also did not tap into maximizing utilizing all the possible movements of the microscope.

The examples highlighted above show that Integration and further technological advancements within the microscope set-up did not necessarily streamline the entire process but rather increased the complexity of handling the microscope and thereby increased the possibility of avoidable errors.

1.4 Aim of the study

“Errors in the operation related to handling or visualization of the surgical microscope can lead to severe complications that can have devastating consequences for the patient. Therefore, the undisturbed interplay between neurosurgeon, assistant, surgical nurse, and the surgical microscope is central to these interventions.”(Khakhar et al., 2021)

The focus of this study has been on optimizing the human-machine (operating microscope) interaction in the operating room by applying other technical additions within it to minimize intraoperative disruptions and maximize patient safety. Nowadays, the optimization of human-machine interaction in dynamic technical systems (such as modern intraoperative neurosurgery microscopes) has been recognized as critical for process safety, quality, and efficiency.

We have reached an era of constant updates within the operational setup, where orchestral coordination with militarized regulatory processes is frequently a prerequisite for a seamless course of the entire intraoperative process. In the microsurgical operation, our focus lies on the errors/fault lines that can come across by navigating one of the most critical elements (the intraoperative microscope) of this set-up and providing testable alternatives to mitigate that. We envision a microsurgical setup where the microscope is seamlessly harmonious with the operator and so intuitive that the part of navigating the microscope is as automated and unnoticeable as a Respiratory cycle of an average-bodied, healthy adult.

We assessed two innovative touchless interaction concepts to navigate the adjustments of the intraoperative microscope so that operators can focus and channelize their energies on what matters the most, the operation itself and nothing else.

In the future, for microsurgery, we envision the surgeon controlling the robotic microscope with these hands-free interaction concepts, wearing a head-worn visualization system for displaying all the pertinent information, and with a virtual display delivering the intraoperative information via the head-worn Visualization system.

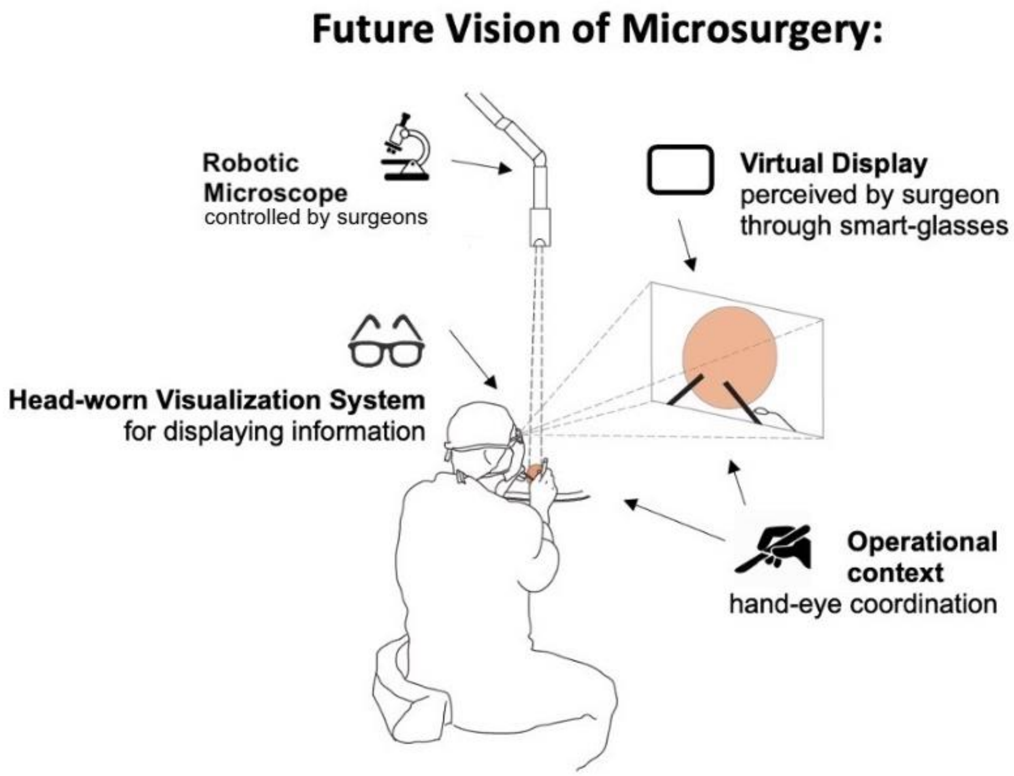

Figure 3. Pictorial depiction of all the pertinent information for the future vision of Microsurgery. (Khakhar R, Fang Y, Picht T & Dobbelstein D,2020)

2. Methodology

2.1 Overview of the methodology

In order to evaluate the interaction concepts, a user study was conceptualized and carried out. Eleven neurosurgeons (four attendings, seven residents) from the Department of Neurosurgery at the Charité Hospital in Berlin were recruited as candidates for this study. They were selected as the study participants as they are the target audience and their feedback about the interaction concept provided essential ideas for discussion and future work. In order to validate the viability of the interaction concepts, two different trials were conducted. In both trials, the same tasks were performed by the participants.

The first trial was conducted utilizing Virtual Reality, and the second trial used a 3D printed target probe. Virtual Reality was used to simulate the concepts of hands-free interaction, and then as a baseline comparison, the manual repositioning of the microscope handle was carried out with a surgical microscope (Carl Zeiss Pentero 900, Carl Zeiss AG, Oberkochen, Germany) and a 3D printed target probe. A systematic user study protocol was designed to measure the outcomes of both trials accurately.

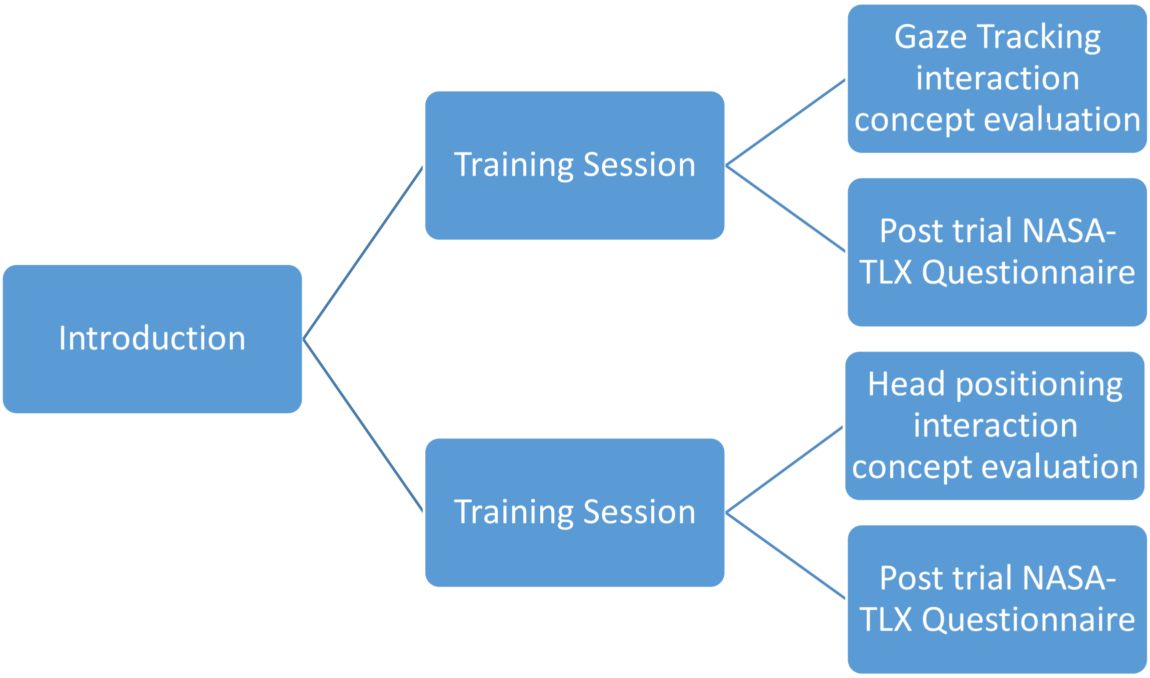

Figure 4 : Protocol implemented for the trial in VR (Khakhar R,2021)

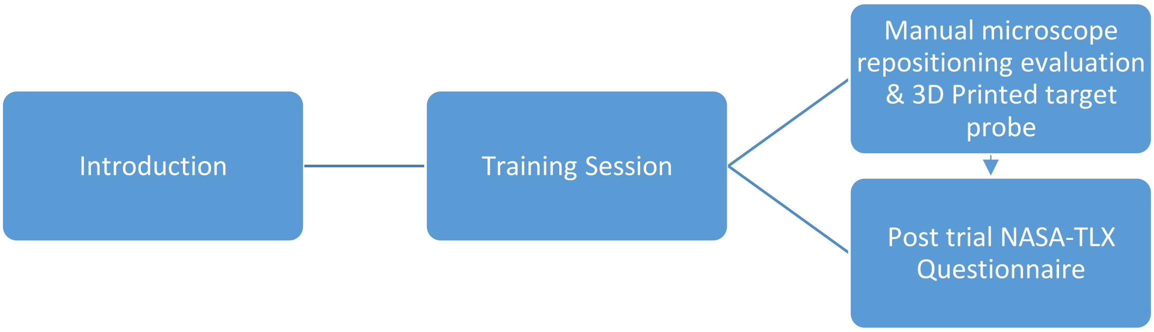

Figure 5 : Protocol implemented for the trial using the surgical microscope and the 3D printed target probe. (Khakhar R, 2021)

2.2 Study protocols

Specific study protocols were designed and followed for both trials. Before the beginning of every trial, the study's definitive objectives were explained to the participants. After that, a consent form was filled by every participant, which permitted the evaluation of all the data obtained during the trials. It was followed by a brief training session for each of the interaction concepts in the first trial. This was done to familiarize the participants with the interaction concepts. In the second trial, the training session was utilized to familiarize the participants with the 3D printed target probe. A maximum of five minutes was designated for both the training sessions. This was followed by the final part of the trial, where each of the interaction concepts was evaluated by all the participants by performing the pre-determined target selection tasks. Immediately after both trials, at the same time points, the NASA Task Load Index questionnaire (14) was used to assess participant workload.

2.3 Study set up

A specialized room was developed and utilized to test the interaction concepts in VR. The participants were provided with an operating chair and surgical wrist rest to mimic the operative environment. Technical instruments utilized for this trial were the HTC Vive Pro (Xindian, Taiwan), The VP Reveal, version 1.5 running on a computer with an Intel® Core™ I7-8700 central processing unit (3.20GHz), and a Display Adaptor with NVIDIA GeForce GTX 1080 graphics card.

The operating room at the Charité Hospital in Berlin Mitte was utilized while evaluating the manual microscope calibration. Technical equipment utilized for this trial was the Zeiss OPMI Pentero 900 and a 3D Printed target probe.

2.4 Data collection

In the VR Trial, data logging was optimized by the engineers, which allowed us to measure the time required to complete the tasks accurately using the VP reveal software. In the second trial, an Arduino microcontroller was embedded within the 3D printed target probe, which allowed us to do the same. Additional data were also obtained in audio and video recordings along with review protocols and detailed questionnaires.

2.5 Virtual Reality Simulation

"*Virtual reality (VR) is defined as developing simulated expertise that is somewhat similar to the real-time situation. The majorly employed constituents for the development of virtual reality are the input tools, output devices, and the graphical interface software*" (Singh RP, Javaid M, Kataria R, et al., 2020). (15)

The simulated immersive environment in Virtual Reality was designed to mimic the operative environment. The microscope setup was the main object for both of the interactions. The HTC Vive Pro headset was utilized to realize that.

Few of the technical specifications of the headset are as follows:

- 90 Hz refresh rate (16)
- 110 ° field of view (17)
- 1080×1200 pixel resolution (18)
- The real-time localization in space via infrared sensors (19)

A simulated microscope, which contained its field of view (FoV), and a stereo camera was set up. Configurational settings were optimized within the Head Mounted Display for the specifications of the study with the engineers so that the virtual display within the HMD directly corresponded to the Field of Vision (FoV) of the simulated visualization system. The virtual display within the HMD acted as the interface providing the view to the virtual screen, which was voice-controlled to activate the interactions. Within the VR simulation, a virtual surgical site on the skull was designed to mimic the actual operation. The tasks were executed on that site using both of the interaction concepts. The HTC Vive Pro controller was used as the surgical instrument.

2.6 The tasks

The tasks developed for the trials were intended to mimic the nuances of the operator's cognitive demands and physical movements. After several discussions within the team, a set of activities requiring objective acquisition and modification of the visualization system were established. In the first trial in VR, a target area within the surgical site (*as shown in Figure 9*) with 25 targets was created.

Each participant had to individually select the randomized sequenced 25 targets using both the interaction concepts. The tasks were designed in a way that required a minimum orientation tweaking of up to at least 57 degrees. The team of engineers calibrated the positioning of the x and y-axis accordingly to realize that. After successfully selecting the individual target with the virtual surgical instrument, a randomized sequenced target would be illuminated within the virtual screen, guiding the participant to carry out the tasks until all the 25 targets were selected.

In the second trial, a 3D heptagonal target probe was created with the same structural integrity for the targets. Further information on the technical specifications of the 3D printed target probe is provided in the original publication by Khakhar et al., 2021. The visualization system adjustment was made utilizing the handles of the operating microscope, and a surgical instrument was used to select each target manually. Neurosurgeons from the Charité Hospital in Berlin took part in the optimization of both the study trials. They did not participate in the Final study.

Figure 6: Study set up for the first Trial (Image Guidance Lab, Berlin,2020)

Figure 7: Study set up for the second trial.(Image Guidance Lab, Berlin,2020)

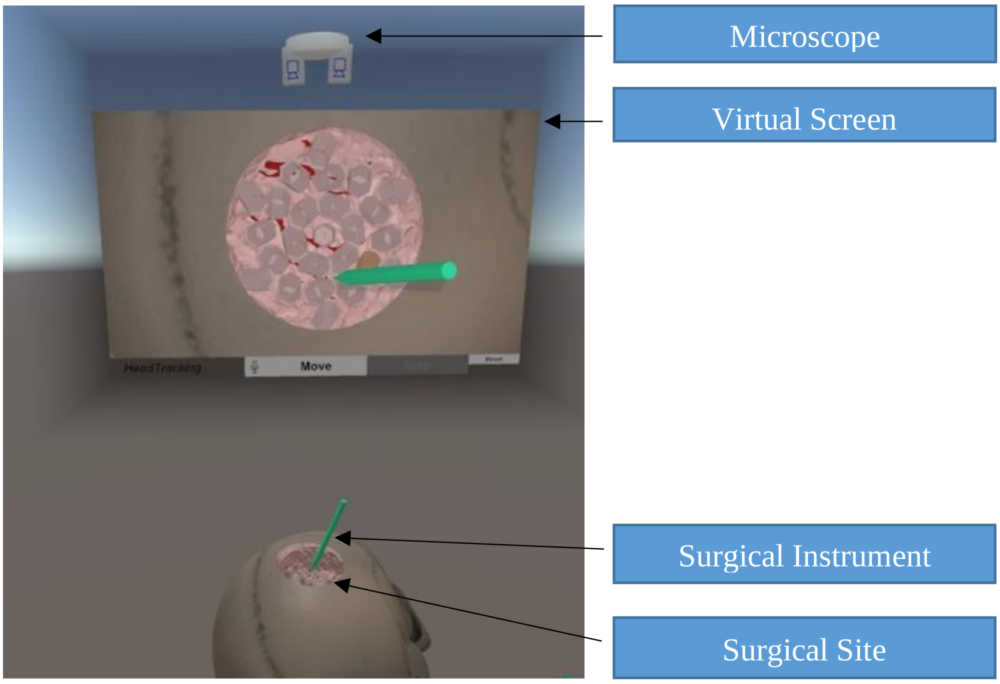

Figure 8 : The Virtual Reality simulation designed for the trial (Image Guidance Lab, Berlin,2020)

Figure 9 : The designed tasks in Vitual Reality (left) and on a physical prototype. (Image Guidance Lab, Berlin, 2020

2.7 Interaction concepts

Further information on the specifications of the technical details can be found in the original publication (Khakhar et al.,2021). Here the generalized details will be summarized.

2.8 Head Positioning Interaction

"*The concept of head positioning Interaction follows the basic principle of forward and backward to manually change and adjust the visual perspective of the user on the virtual screen in 6D.*" (Khakhar et al., 2021)

The integrated sensor within the HMD allows the track of the head movement of the participant in real-time. In this interaction concept, the participant can control the virtual microscope with six degrees of freedom, combining functions like zoom, focus, and rotate whilst utilizing the X, Y & Z planes of movement of the head to execute them.

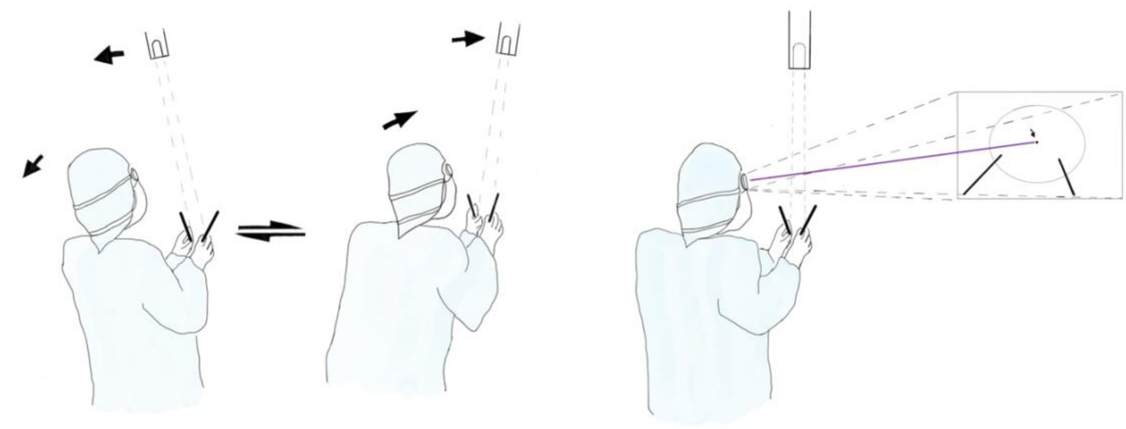

Figure 10.1: “Pivot Movement Figure (left) 10.2: Perspective adjustment (right)” (Khakhar et. al., 2020)

2.9 Gaze Tracking Interaction

“*Gaze-tracking is a process that estimates and tracks the line of sight in the 3D space of a person or simply where a person is looking*” (Khakhar et al., 2021)

Motion tracking and the positioning of the user's eye are executed at the same time utilizing the gaze tracker (20). A specialized gaze tracking system from Pupil Labs (Berlin,Germany) was integrated within the Head Mounted Display. Without needing to move the participant's head, this integrated system focused and magnified the user's view within the virtual screen. Control functions like the zoom of the virtual microscope are executed by head rotation. Minimal vocal orders were applied to centralize the focus.

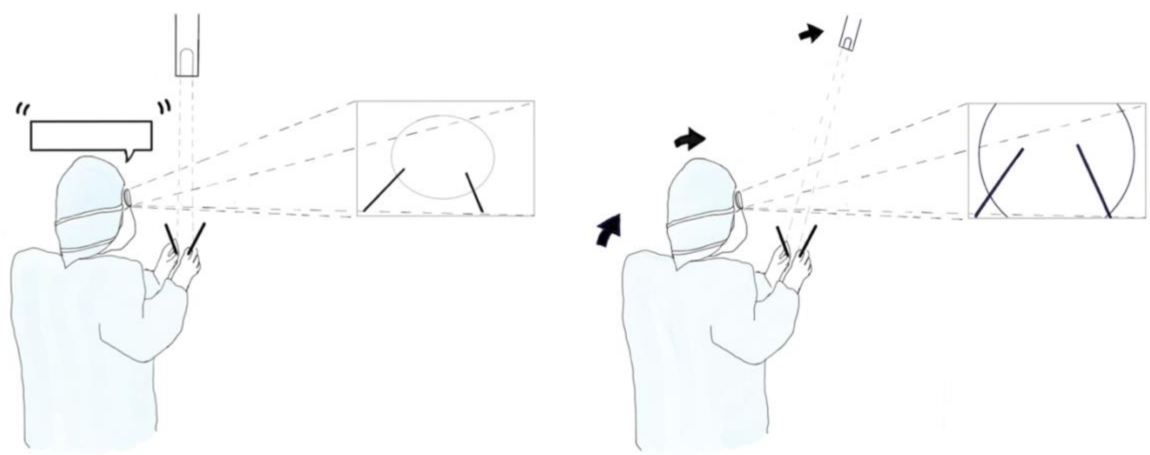

Figure 11.1: “Voice Command Figure (left) 11.2: Pivot Movement with focus adjustment (right)”(Khakhar et. al.,2020)

2.10 Manual Interaction

The manual Interaction evaluated in the second trial was utilized as the baseline as that is how surgeons are traditionally trained. The participants would have to adjust the conventional operating microscope with the microscope handles and calibrate the microscope to the specific target every time while completing the task. Further details on the tasks are provided in the Tasks section above. It is the exact scenario that a surgeon would be in a while utilizing the conventional microscope and adjusting the microscope while operating.

3. Results

3.1 Time measurements

The time required to execute the tasks was a critical parameter to evaluate the efficiency of the interaction concepts. Estimating the time required to perform tasks is an essential skill that individuals use almost daily (21). An accurate estimation of these interaction concepts with time measurements would provide vital information as 8% of the intraoperative time during surgery is spent in the operator's interaction with the microscope (22). The overall procedure to complete the task involved the following steps – 1) Evaluating the visibility of the target point 2) Activation of the interaction concept to position the microscope 3) Calibrating the vision of the participant using the zoom function to get a clearer view 4) Touching the target point with the instrument. Time on task was calculated as the amount of time required to complete all the steps mentioned above, including the minor interruptions involved within the steps like readjusting the zoom to focus on the target.

The average time required by the participants to complete the tasks with head positioning interaction was 6.79s (SD = 2.35s), while the gaze-tracking interaction was 7.84s (SD = 2.76s). Participants would wait for a brief moment for the translation movement of the microscope to the gaze point, after which the participants could pivot the microscope to find the optimal suitable angle. This could be the reason for the relatively long time required for the gaze-tracking interaction. The head positioning interaction on the other hand was faster, as the participants would be able to control the microscope's movement directly. The mean time required to complete the tasks for different groups is illustrated in Figure 12 below.

The participants were 29% faster utilizing the head positioning interaction concept than the manual readjustment of the microscope via handles, whereas 18% faster with the gaze tracking interaction concept.

The Wilcoxon Signed-Rank Test was applied to test the significance of the interaction concepts. A p-value of 0.0024 showed the statistical difference between the interaction concepts. This, combined with the mean value results, showed that the head positioning interaction concept was more efficient than gaze tracking.

In the first trial, the time required by each participant to complete the tasks using the interaction concepts was measured. The surgical simulation setup assembled for it was optimized in a way that allowed us to measure and log the time for each participant using the Unity 3D software. In the second trial, an Arduino microcontroller was implanted within the physical prototype which helped in the data and time logging.

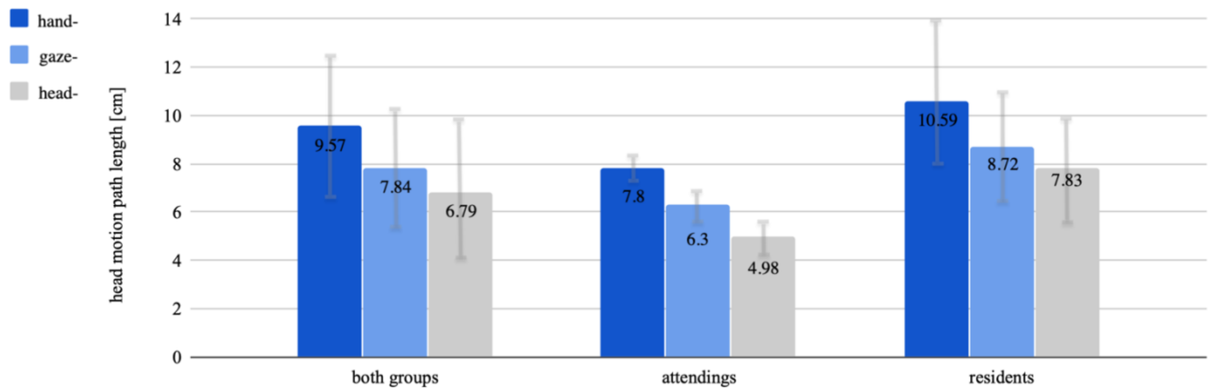

Figure 12. “Objective acquisition was 29% faster applying the head-movement concept in comparison to the current position control of the microscope using handles.” (Khakhar et. al., 2021)

3.2 Head movement

“The efficiency in the movement was measured by integrating the path length of head translation distance (m)” (Khakhar et al., 2021). The Head movement was an essential parameter while evaluating both the concepts. Both of the interaction concepts utilized the head movement to control the virtual microscope. The Head Mounted Display allowed to track and deduce the participant’s head movement. During the gaze tracking interaction concept, the pivot function utilized the rotatory motion of the head to

manipulate the simulated microscope, and the head-positioning interaction utilized all six degrees of freedom of the head movement for the same. As illustrated in Figure 13 below, the head positioning interaction concept utilized more head movement m=35.2cm (SD= 24.2cm), while the gaze tracking required relatively more minor m=16cm (SD=11.9cm).

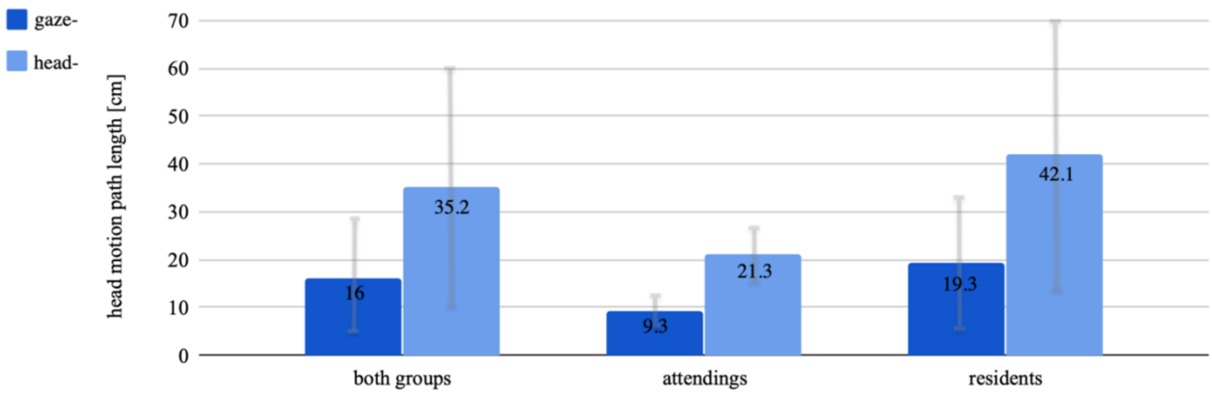

Figure 13. “Accurate analysis of the translation distances revealed that upto 55% of lesser head movement was required while using the gaze tracking in comparison to the other interaction concept.”(Khakhar et. al., 2021)

A p-value of 0.0005 was shown while utilizing the Wilcoxon Signed-Rank test for the data set, which proved that the head movement required for the head positioning interaction was significantly more than that for the gaze tracking interaction concept.

Additionally, an XY axis trajectory analysis also showed that the head positioning interaction concept required more head movement than the gaze tracking interaction concept, as shown in Figures 14 and 15 below.

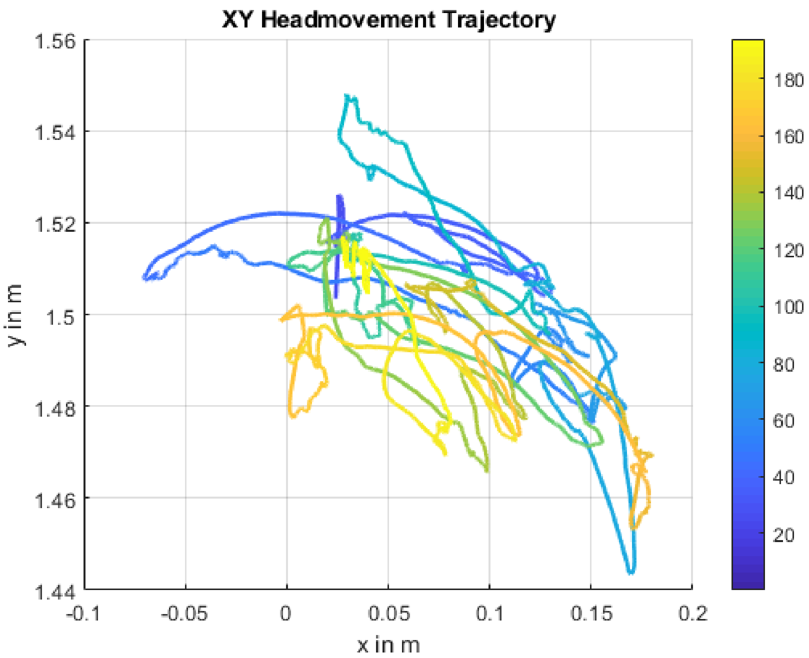

Figure 14 : The XY axis head movement trajectory : “Gaze-tracking Interaction Concept” (Khakhar,R, Fang Y & Dobbelstein D, 2020)

Figure 15 : The XY axis head movement trajectory : “Head-positioning” interaction concept. (Khakhar R, Fang You & Dobbelstein D, 2020)

3.3 NASA Task Load Index Results

Each participant was given the NASA-TLX review protocol immediately after completing both trials. An example of the questions presented in our review protocol is given below (Figure 16)

Q1. How much mental demand was required to control the microscope?

Q2. How much physical demand was required to control the microscope?
Q3. How successful do you think you were in controlling the microscope?

"It consisted of 8 Likert subscales (mental, physical, temporal, performance, effort, frustration, time to learn, and usability) scored between 1 and 5 points. Higher scores indicate a more significant work burden associated with the assigned task."(Khakhar et.al, 2020) The subscales within the questions had a range from 1 to 5, wherein one meant very low, three meant neutral, and five meant very high.

Hands-free Control of a Surgical Microscope - simulated in Virtual Reality

Participant ID:

Which interaction technique did you just use? ☐ **Head movement** ☐ **Gaze control and head pivoting**

Please rate the demand for the control of the virtual microscope with this technique:

	1 – very low	*2 – low*	*3 – neutral*	*4 – high*	*5 – very high*
Mental Demand *how much mental demand was required to control the microscope?*	☐	☐	☐	☐	☐
Physical Demand *how much physical demand was required to control the microscope?*	☐	☐	☐	☐	☐
Temporal Demand *how much time pressure did you feel for controlling the microscope?*	☐	☐	☐	☐	☐
Performance *how successful do you think you were in controlling the microscope?*	☐	☐	☐	☐	☐
Effort *how hard was it for you to reach that level of performance for the control?*	☐	☐	☐	☐	☐
Frustration how insecure, irritated, stressed and annoyed did you feel during the control?	☐	☐	☐	☐	☐
Time to Learn how much time was needed to learn the control of the microscope?	☐	☐	☐	☐	☐
Usability how usable did you perceive the control of the microscope?	☐	☐	☐	☐	☐

Figure 16: The post-trial protocol. (Image Guidance Lab, Berlin, 2020)

The learning acquisition time was near identical for both of the concepts as show by Figures 17 and 18 below, and further analysis is explained in the original publication by Khakhar et al; 2021.

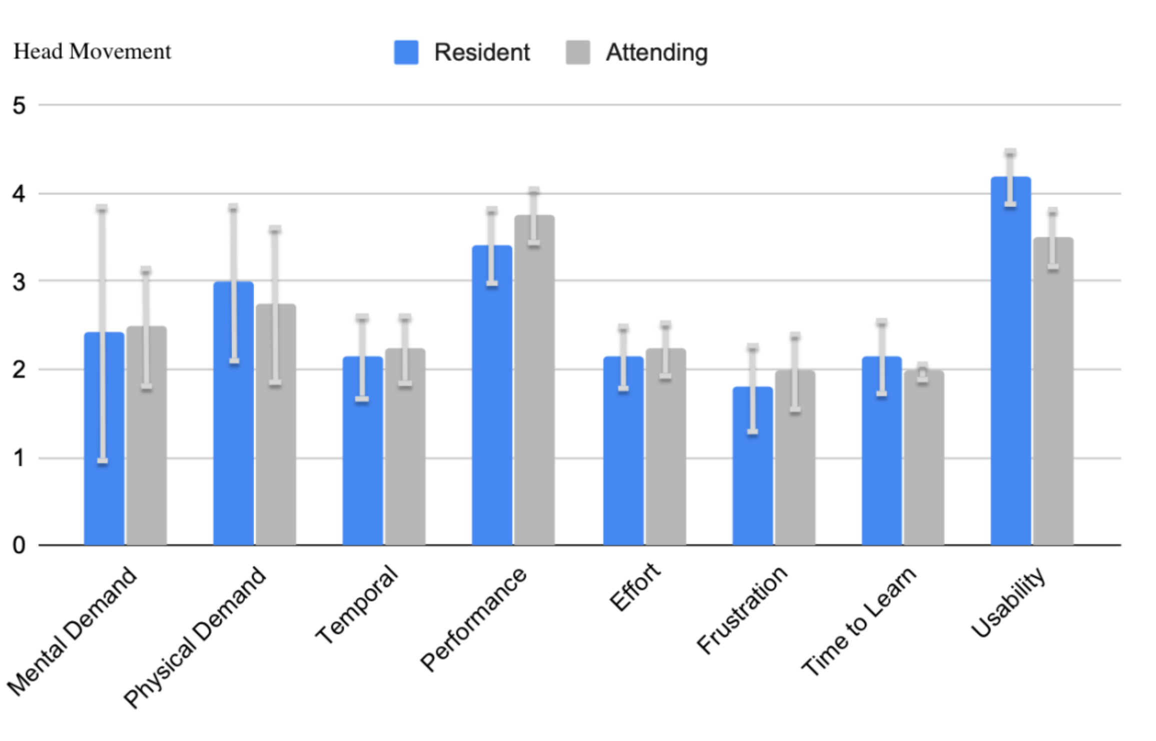

Figure 17: “The post trial protocol results for the head-movement interaction concept.” (Khakhar et. al., 2021)

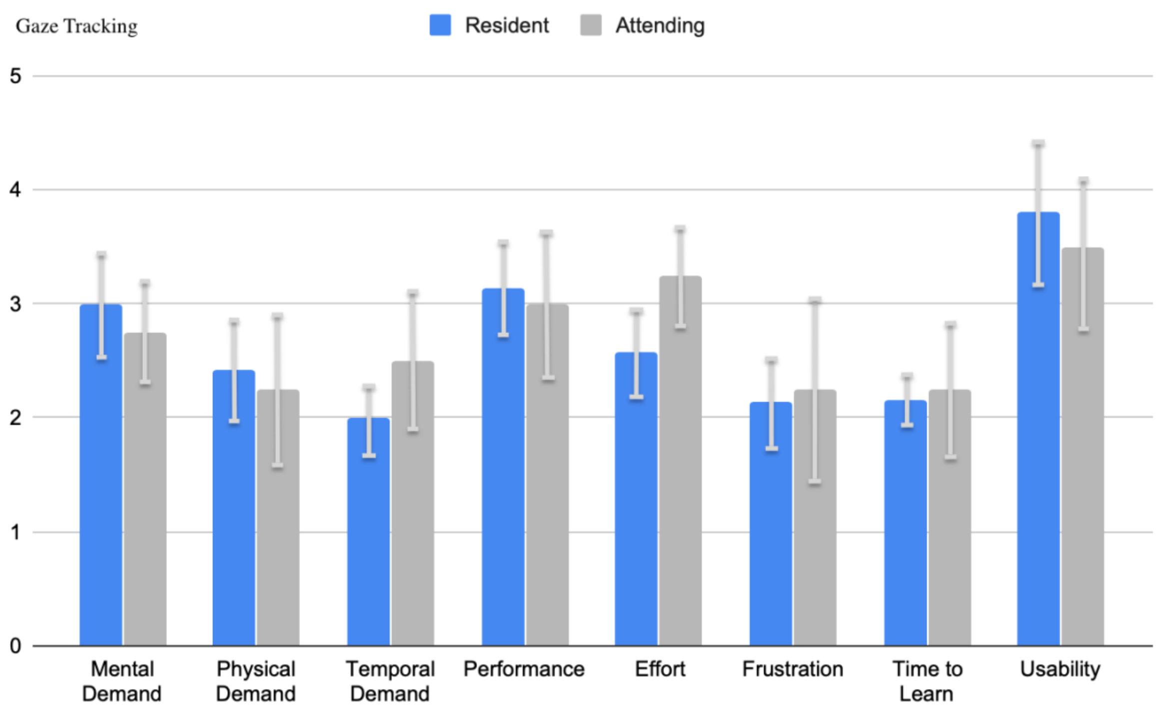

Figure 18 : “The post trial protocol results for the gaze-tracking interaction concept.” (Khakhar et. al., 2021)

“Student t-tests showed no significant difference in workload between the two interaction concepts in workload categories of physical demand, mental demand, performance, effort, and frustration (p = 0.99). Temporal demand was identical between the head-movement and gaze-tracking interaction concepts, with both of the interaction concepts showing a mean temporal demand of 2.18 SD=0.83." (Khakhar et. al., 2021)

3.4 Qualitative feedback

Post-trial-focused user interviews were conducted. This would include questions about the task complexity, constructive criticism of the experiment, the evaluation of the interaction concepts, and reasons for preferring either the gaze tracking or the head positioning interaction concept.

As previously shown above, the more experienced participants could efficiently carry out the tasks in both the interaction concepts. The gaze-tracking was considered the more ergonomically sound alternative for most participants, and the head positioning was the more intuitive one. All the participants acknowledged the interaction concepts as a positive addition to the current operative workflow compared to the current alternative.

4.Discussion

"*Substantial progress in the measurement of test performance and more appropriate utilization of tests and procedures requires more comprehensive technology evaluation that focuses on the clinical impact of the technology on the patient and the patient's health*." – an excerpt from a book titled Assessing Medical technologies from the National Academy Press, Washington, D.C 1985

4.1 Medical Errors

Medical errors can be defined as the failure of the executed action that was intended to deliver the desired results for the patient, leading to suboptimal end-results or detrimental effects to the patient's health. The conditions that lead to these medical errors can be further divided into active and latent conditions. (23) Active, being those caused by the healthcare provider (nurses, doctors), whereas Latent is the systematic conditions that lead to the error. That could be in the form of sub-optimal equipment, systemic structural issues, and failed facility planning. These errors are mainly led by the equipment designers, management, and architects. (24)

This study attempts to address both the active and latent errors within a particular facet/focus of the healthcare system. In this context, as mentioned further below, the common active medical errors can be avoided by optimizing and applying the technological addition mentioned in this study.We also tried to address one of the latent errors mentioned above, such as the ones that could arise from sub-optimal design and planning by working in very close ties with the engineers. A robust and transparent line of communication was held at all parts of the development, which helped us test these interaction concepts promptly as well as quickly address the issues that came along with it.

The complex nature of the healthcare system makes it all the more critical to have a clear understanding of its different elements, and more often have an opportunity where the direct providers of healthcare and the indirect (management, in this context, the engineers) have teamwork that fosters solutions for the problems rather than not address the problems correctly, which often leads further complications instead.
To address this same complexity, delegation of different elements within the healthcare system to different players makes it more streamlined. However, the lack of communication and understanding of the nuances required by them from both sides of the spectrum often creates a functionally dysfunctional system. This has sometimes led to the creation of products with almost no practical, functional utility and also led to an immense loss of workforce and resources.

<u>Different reasonings:</u>

Here we try to explain furthermore the different reasons that lead to medical errors. Some of them were already mentioned and discussed in the introduction before. A few key reasons that have been relevant to this dissertation in the context of the intraoperative microscope are discussed below.

- Lack of sufficient knowledge
- Suboptimal equipment design
- Lack of freedom of movement
- Cognitive stress and Operator Fatigue

Errors due to the lack of sufficient knowledge - This context can be related to a lack of sufficient knowledge by the direct healthcare provider (e.g., the surgeon) regarding the different technological additions in the operating theater, leading to unnecessary loss of pre-and intraoperative operating time. The neurosurgical operating theater is an excellent example of that. It is one of the most technologically intensive operating theaters. There are constant additions in the operating theater in terms of the different technological additions that are provided to create and offer the maximal avenues of optimal patient care. However, they are products that are frequently over-engineered, giving convoluted solutions. Time can be significantly lost or delayed pre- or intraoperatively when tools like the intraoperative brain imaging software, for example, is not calibrated promptly due to a lack of sufficient knowledge about it by the operator or the other participants in the operating theater.

Suboptimal equipment design. In spite of impressive achievements in the optimization of different elements within the microsurgical operating theater, there remain certain elements that need to be addressed. The ancillary interaction appendages involved and created for the operating microscope come with their obvious limitations, as highlighted in the Introduction section above. The foot pedal can be unergonomic in that the operator has too often times resort to awkward change of positions intraoperatively to maneuver and control the operating microscope via the foot pedal. (25) The alternative of the mouthpiece is also one of the appendages, which limits the ability of the operator to communicate information clearly and is also unhygienic.

Lack of freedom of movement. Intraoperatively, oftentimes due to the minimal distance between the operator and the instrument/microscope, the operator is limited within a range for the entire duration of the operation. This, added by the variety of awkward positions the operator must resort to navigate and control the microscope over extended periods of time, can increase the risk of injury. (26)

Cognitive stress and operator fatigue. Long operative hours, the crowded operation environment, along frequent disruptions caused due to the microscope manipulation can increase the operator's cognitive load and accelerate the operator's fatigue(27). The limitations to cognitively acquiring, processing, and retaining information in humans are well known, so it is critical to navigate pragmatically when developing and creating alternatives that can quickly exhaust the operator(28). Heuristic measures after cognitive exhaustion of the operator must be avoided as that often leads to sub-optimal decision making and can have grave consequences for the patient.

The need to highlight and discuss these medical errors is vital as they come with unsavory outcomes. They have massive financial implications on the entire economy as well. The costs related to medical errors in the year 2020 were alone 20 billion dollars for the United States. (29)

In a seemingly complex environment of healthcare delivery, the operating theater is highly susceptible to these errors. (30) The lack of sufficient knowledge can be addressed by creating alternatives that streamline within the highly complex technological operating environment, rather than creating well-lubricated and segregated silos within the same environment. The alternative interaction concepts for the microscope presented in this study address this issue by being relatively intuitive to use and with a relatively short learning curve, thereby automating much of these processes. In terms of a hardware integration within the intraoperative microscope, these alternative interaction concepts add little in terms of the actual addition within the system as one of them is controlled via-body movement, and the other is envisioned to be integrated within a Head-worn visualization system. Minimal body movement is required in order to control these interaction concepts, which allows higher freedom of movement without interruptions in the main operative task. These interaction concepts were designed in a way that would not increase the cognitive and sensory load for the operator to execute the tasks.

The first alternative, which is controlled by body gestures, is a self-controlled intuitive response system steered by the decision of the operator, the other one based on gaze tracking follows similar principles with the addition of it being part of a Head-worn visualization system.

Various intraoperative, perioperative medical errors have been highlighted in the addressed utilizing and testing these interaction concepts. The margins of error are relatively low in direct healthcare, and it is vital to create and develop strategies that are in direct congruence with the actual needs and wants of the moment.

4.2 Virtual Reality

Medical equipment development is a long, arduous process susceptible to market changes in an ever-changing economic and healthcare climate. (31) There are different phases till the finalized product hits the market for use.

A heightened level of scrutiny and tests have to be run through at different phases of development so that the probable damage that could occur due to malfunction can be minimized to a maximum level. In close cooperation within the Clinic, understanding the exact needs of the operator, these interaction concepts were optimized and tested for their clinical applicability. This is also precisely where virtual Reality worked as a practical platform to test them. The costs and the reasoning for bringing a technological change within the current status quo need to be justified, and the testing within the virtual reality spectrum helped us do precisely that.

Various advantages of utilizing Virtual Reality within our study are listed below:
- High ecological Validity (32)
- Affordability & Immersiveness (33)
- Ability to test various technical possibilities

Virtual Reality offered us a compact way of applying various technical possibilities (6 Dimensional Head-motion tracking + Eye-tracking + moving virtual screen) to test the interaction concepts. Virtual Reality is generalizable across various environments giving it a high ecological validity (34) and providing immediate feedback. This allows for faster and effective re-iteration. From the high-tech VR setup’s to the relatively moderate ones, they have become more affordable with time. (35)

Costs, as mentioned earlier, are a critical factor while assessing new technologies that may further propel massive hardware changes within the current state of the art, in this context, the intraoperative microscope. The earlier VR head seats could cost around 5000 dollars, and now a Virtual Reality setup can also be created with a smartphone. Virtual Reality has seen a renewed sense of vigor and interest in it over the past few years, and impressive technological upgrades have been involved. Immersiveness is a crucial element of the Virtual Reality setup. Highly advanced computer graphics and tactile feedback allow for visuals closer to life than ever with a heightened perception of Reality with its tactile feedback further adding to the Immersive experience. (36)

4.3 Evaluating medical technology

The cost of healthcare is an ongoing discussion that has widespread implementations in all facets of society. Most nations strive to find a delicate balance between the costs to

run the healthcare machinery in their respective nations, foster innovation, maintain solid regulatory standards and increase healthcare equity. The healthcare expenditure costs for Germany in the year 2019 accounted for 410.8 billion euros. (37) In the same year, 109.5 billion euros were spent on research and development, which accounted for 3.2% of the Gross Domestic Product (GDP). (38)
According to the US Food and Drug Administration (FDA), a medical device is – "an instrument, apparatus, implement, machine, contrivance, implant, in vitro reagent, or another similar or related article, including a component part or accessory which is: recognized in the official National Formulary, or the United States Pharmacopoeia, or any supplement to them, intended for use in the diagnosis of disease or other conditions, or in the cure, mitigation, treatment, or prevention of disease, in man or other animals." (39)
The medical device industry encompasses a broad umbrella of products – in-vitro diagnostics, prosthetics, medical instruments, ophthalmic instruments, to name a few. The European medical device market is the second-largest market after the US, with a rough estimate of €140 billion in 2020. (40) The surgical microscope is a Class I medical device.

The overriding costs of research and development and healthcare expenditures are relevant topics that need to be reviewed and efficient strategies need to be developed. Here are a few bullet points in that could provide an initial primer while creating and evaluating new medical technology.

- The initial ideation of the product and its testability of the hypothesis needs to be justifiable and thoroughly tested. Medical device development undergoes various rigorous phases. All the phases need to be addressed judiciously and peer-reviewed. This is exactly what was attempted in this study.

- Multiutility. Technical updates such as the ones reviewed in this study need to have higher applicability. The costs of technological additions need to be justified, and along with the multiple factors that play into the decision and adoption of the technology, a lack of valid multiutility can be a deterrent factor.

- The implications and the Clinical influence on the patient's health of the technology should be assessed pragmatically, and innovative solutions should be adopted that can increase the speed and momentum while evaluating it, at the same containing the costs that arise through it.

- Diffusion and cooperation of all different players. Medical device development involves players from diverse fields – physicians, industrial, mechanical, policy-makers, institutions, legal, and regulatory bodies, to name a few. Clear lines of communication with holistic cooperative work will provide solutions to address various problems which could arise later. This study provided us a fantastic opportunity to work closely with the engineers at all phases of the development, which helped us provide solutions to the problems much quicker and efficiently.

4.4 Limitations and Conclusions

"The novel hands-free interaction concepts when applied to tasks involving goal selection and visualization system adjustment were 29% and 18% faster, respectively, than the classical bimanual adjustment of the microscope. The execution of these interaction concepts requires minimal movement from the user's end." (Khakhar et al., 2021)

Certain technical limitations within the study, which are worthy of mentioning, are the HMD device used in this study, which weighed around 500g and could be a reason for fatigue for the participants over long periods. In the VR framework utilized for this study, "the inaccuracy of the gaze tracking estimations could be a challenge for precise alignments." (Khakhar et al.; 2021)

Another variable to consider is the lack of suitable hardware to integrate these interaction principles into the current microscope system at time of the study. However, the Virtual Reality simulation of these concepts was iterated and modified to optimal settings with the cooperation of the team's engineers to achieve a level of precision that most accurately reflected the operational environments. Additionally, the tasks generated for the study were adapted to emulate the operator's movements during the operation.

This clinic-oriented study showed that these interaction concepts could significantly enhance the current operating environment by reducing disruptions and increasing the effectiveness of microsurgical tasks. The physician surgeons who participated in the study also acknowledged that with the nuances regarding each of the concepts mentioned by them stated in the original publication by Khakhar et. al. 2021

These innovative technological concepts function as a valid potential alternative addressing bottlenecks of intraoperative errors, enhancing patient safety, and provide an assuring solution for addressing some of the critical and imminent disruptions as outlined previously.

The peer-reviewed process had substantiated these concepts, continuing to give everybody the certainty to commit the effort and resources that would eventually be required to create the appropriate hardware and hopefully galvanize many further studies in a similar direction.

The operating room of the future is one that, through the application of appropriate technology, makes it more effective, safer for everyone involved, and these interaction concepts integrate within this vision harmoniously.

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Statutory Declaration

“I, Rutvik Khakhar, by personally signing this document in lieu of an oath, hereby affirm that I prepared the submitted dissertation on the topic ‘Hands free adjustment of the microscope in Microneurosurgery/ Freihändige Einstellung des Mikroskops in der Mikroneurochirurgie’ independently and without the support of third parties, and that I used no other sources and aids than those stated.
All parts which are based on the publications or presentations of other authors, either in letter or in spirit, are specified as such in accordance with the citing guidelines. The sections on methodology (in particular regarding practical work, laboratory regulations, statistical processing) and results (in particular regarding figures, charts and tables) are exclusively my responsibility.

Furthermore, I declare that I have correctly marked all of the data, the analyses, and the conclusions generated from data obtained in collaboration with other persons, and that I have correctly marked my own contribution and the contributions of other persons (cf. declaration of contribution). I have correctly marked all texts or parts of texts that were generated in collaboration with other persons.

My contributions to any publications to this dissertation correspond to those stated in the below joint declaration made together with the supervisor. All publications created within the scope of the dissertation comply with the guidelines of the ICMJE (International Committee of Medical Journal Editors; www.icmje.org) on authorship. In addition, I declare that I shall comply with the regulations of Charité – Universitätsmedizin Berlin on ensuring good scientific practice.

I declare that I have not yet submitted this dissertation in identical or similar form to another Faculty.

The significance of this statutory declaration and the consequences of a false statutory declaration under criminal law (Sections 156, 161 of the German Criminal Code) are known to me.”

Date 27.07.2021 Signature

Declaration of your own contribution to the publications

Rutvik Khakhar started this project in 2019 in the context of the ‘Doktorarbeit’ at the Charité Berlin and played a leading role until its completion. In the first phase, Rutvik Khakhar actively contributed to developing and optimizing the tasks used for both sessions. Implementing the task laid the groundwork for a successful continuation of the project.

Once the tasks were optimized, Rutvik Khakhar recruited participating Neurosurgeons to study from the Department of Neurosurgery at the Charité Hospital in Berlin. He performed the measurements autonomously, which included obtaining informed consent, instructing participants about the task, and technically setting up the equipment and management and execution of both of the trials. Rutvik Khakhar acquired all primary behavioural data for both publications. To this end, he performed pilot measurements on the gaze tracking interaction concept and head movement interaction concept and analyzed behavioural results statistically. Tables and Figures 3,4,5,7,8,9,10,11,12,13,17,18 were generated from the statistical and visual interpretation of Rutvik Khakhar.

Rutvik Khakhar contributed substantially to the conception and implementation of the study in the context of the current state of research. He composed and managed all behavioural data (e.g., see ‘Figure 5’ of the manuscript) and participated in analyzing and interpreting the results. Statistical analysis to evaluate the results of the study was conducted independently by Rutvik Khakhar. Interpretation of results was written and generated by Rutvik Khakhar.
Rutvik Khakhar wrote the first draft of the publication autonomously, which was then revised by all co-authors under the leading supervision of Thomas Picht before submission to the journal. Rutvik Khakhar was the corresponding author with the journal throughout the whole submission process. He integrated the comments of peer reviewers

in the manuscript and wrote the first draft of the response letter, which was completed under the leadership of Thomas Picht.

Detailed declaration of own contribution to the top-journal publication

Rutvik Khakhar contributed the following to the below listed publication:

Publication:

Rutvik Khakhar, Fang You, Denny Chakkalakal, David Dobbelstein, Thomas Picht, Hands-free Adjustment of the Microscope in Microneurosurgery,World Neurosurgery, Volume 148,2021,Pages e155-e163,ISSN 1878-8750, https://doi.org/10.1016/j.wneu.2020.12.092. (https://www.sciencedirect.com/science/article/pii/S1878875020326590)

Signature of doctoral candidate

Extract from the Journal Summary List (ISI Web of KnowledgeSM)

Journal Data Filtered By: **Selected JCR Year: 2019** Selected Editions: SCIE,SSCI
Selected Categories: **“SURGERY”** Selected Category Scheme: WoS
Gesamtanzahl: 210 Journale

Rank	Full Journal Title	Total Cites	Journal Impact Factor	Eigenfactor Score
1	JAMA Surgery	8,471	13.625	0.038280
2	ANNALS OF SURGERY	50,639	10.130	0.061400
3	JOURNAL OF NEUROLOGY NEUROSURGERY AND PSYCHIATRY	30,621	8.234	0.028510
4	JOURNAL OF HEART AND LUNG TRANSPLANTATION	12,465	7.865	0.028140
5	ENDOSCOPY	10,838	7.341	0.015620
6	AMERICAN JOURNAL OF TRANSPLANTATION	25,598	7.338	0.046240
7	BRITISH JOURNAL OF SURGERY	23,036	5.676	0.027310
8	EUROPEAN JOURNAL OF VASCULAR AND ENDOVASCULAR SURGERY	9,932	5.328	0.013510
9	Hepatobiliary Surgery and Nutrition	939	5.296	0.002520
10	AMERICAN JOURNAL OF SURGICAL PATHOLOGY	19,940	4.958	0.020820
11	NEUROSURGERY	29,977	4.853	0.021690
12	Digestive Endoscopy	2,867	4.774	0.006000
13	JOURNAL OF THE AMERICAN COLLEGE OF SURGEONS	16,886	4.590	0.026130
14	JOURNAL OF BONE AND JOINT SURGERY-AMERICAN VOLUME	45,256	4.578	0.038360
15	LIVER TRANSPLANTATION	9,816	4.570	0.012610
16	Journal of NeuroInterventional Surgery	5,583	4.460	0.015900
17	JOURNAL OF THORACIC AND CARDIOVASCULAR SURGERY	28,491	4.451	0.034300

Rank	Full Journal Title	Total Cites	Journal Impact Factor	Eigenfactor Score
18	CLINICAL ORTHOPAEDICS AND RELATED RESEARCH	38,340	4.329	0.030260
19	ARTHROSCOPY-THE JOURNAL OF ARTHROSCOPIC AND RELATED SURGERY	16,791	4.325	0.020530
20	Bone & Joint Journal	6,764	4.306	0.021970
21	TRANSPLANTATION	24,561	4.264	0.029910
22	PLASTIC AND RECONSTRUCTIVE SURGERY	39,008	4.209	0.029680
23	Journal of Hepato-Biliary-Pancreatic Sciences	3,686	4.160	0.005640
24	World Journal of Emergency Surgery	1,483	4.100	0.002940
25	ANNALS OF SURGICAL ONCOLOGY	29,538	4.061	0.044180
26	DISEASES OF THE COLON & RECTUM	14,061	3.991	0.012380
27	JOURNAL OF NEUROSURGERY	36,589	3.968	0.027880
28	EJSO	9,499	3.959	0.016680
29	JAMA Otolaryngology-Head & Neck Surgery	3,492	3.848	0.012300
30	Surgery for Obesity and Related Diseases	6,756	3.812	0.013780
31	Aesthetic Surgery Journal	4,118	3.799	0.006000
32	JAMA Facial Plastic Surgery	1,216	3.787	0.003300
33	Neurosurgical Focus	7,703	3.642	0.011260
34	ANNALS OF THORACIC SURGERY	35,221	3.639	0.040380
35	EUROPEAN JOURNAL OF CARDIO-THORACIC SURGERY	16,682	3.486	0.025820
36	OBESITY SURGERY	13,608	3.412	0.019160

Selected JCR Year: 2019; Selected Categories: “SURGERY”

Rank	Full Journal Title	Total Cites	Journal Impact Factor	Eigenfactor Score
37	JOURNAL OF VASCULAR SURGERY	26,553	3.405	0.024980
38	HPB	5,261	3.401	0.010110
39	Journal of Trauma and Acute Care Surgery	9,144	3.381	0.024190
40	International Journal of Surgery	9,699	3.357	0.018420
41	SURGERY	20,162	3.356	0.026320
42	TRANSPLANT INTERNATIONAL	5,148	3.177	0.009340
43	KNEE SURGERY SPORTS TRAUMATOLOGY ARTHROSCOPY	15,042	3.166	0.027740
44	SURGICAL ENDOSCOPY AND OTHER INTERVENTIONAL TECHNIQUES	22,111	3.149	0.032830
45	Journal of Vascular Surgery-Venous and Lymphatic Disorders	1,115	3.137	0.002260
46	JOURNAL OF ENDOVASCULAR THERAPY	3,651	3.102	0.005110
47	Burns & Trauma	538	3.088	0.001320
48	Annals of Cardiothoracic Surgery	1,828	3.058	0.005060
49	LASERS IN SURGERY AND MEDICINE	5,435	3.020	0.003720
50	JOURNAL OF NEUROSURGERY-SPINE	8,067	3.011	0.011410
51	SHOCK	7,919	2.960	0.010370
52	JOURNAL OF NEUROSURGICAL ANESTHESIOLOGY	1,608	2.928	0.001600
53	International Wound Journal	3,446	2.825	0.005580
54	JOURNAL OF SHOULDER AND ELBOW SURGERY	13,857	2.817	0.017380
55	Seminars in Pediatric Surgery	1,805	2.807	0.003030

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Rank	Full Journal Title	Total Cites	Journal Impact Factor	Eigenfactor Score
56	JOURNAL OF SURGICAL ONCOLOGY	11,088	2.771	0.016070
57	Colorectal Disease	6,699	2.769	0.009640
58	Hernia	3,531	2.768	0.004630
59	Perioperative Medicine	220	2.740	0.000800
60	Techniques in Coloproctology	2,312	2.721	0.004270
61	JOURNAL OF REFRACTIVE SURGERY	4,268	2.711	0.005920
62	JOURNAL OF CATARACT AND REFRACTIVE SURGERY	13,229	2.689	0.010870
63	NEUROSURGICAL REVIEW	2,762	2.654	0.003410
64	Updates in Surgery	913	2.587	0.002000
65	JOURNAL OF GASTROINTESTINAL SURGERY	10,471	2.573	0.015000
66	DERMATOLOGIC SURGERY	8,112	2.567	0.006930
67	HEAD AND NECK-JOURNAL FOR THE SCIENCES AND SPECIALTIES OF THE HEAD AND NECK	12,365	2.538	0.017880
68	SURGICAL ONCOLOGY-OXFORD	2,131	2.521	0.003230
69	International Journal of Computer Assisted Radiology and Surgery	2,734	2.473	0.005540
70	WOUND REPAIR AND REGENERATION	5,833	2.471	0.005030
71	SURGICAL CLINICS OF NORTH AMERICA	3,562	2.446	0.003210
72	Journal of Plastic Reconstructive and Aesthetic Surgery	6,717	2.390	0.009290
73	EUROPEAN SURGICAL RESEARCH	1,061	2.351	0.000850
74	LASERS IN MEDICAL SCIENCE	5,412	2.342	0.006700

Rank	Full Journal Title	Total Cites	Journal Impact Factor	Eigenfactor Score
75	OTOLARYNGOLOGY-HEAD AND NECK SURGERY	14,236	2.341	0.016510
76	SURGEON-JOURNAL OF THE ROYAL COLLEGES OF SURGEONS OF EDINBURGH AND IRELAND	1,330	2.311	0.002030
77	Journal of Hand Surgery-European Volume	4,839	2.290	0.004010
78	JOURNAL OF THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS	5,991	2.286	0.007950
79	WORLD JOURNAL OF SURGERY	16,983	2.234	0.020910
80	Journal of Surgical Education	3,099	2.220	0.008210
81	Gland Surgery	1,010	2.190	0.002760
82	LANGENBECKS ARCHIVES OF SURGERY	3,751	2.184	0.004760
83	DIGESTIVE SURGERY	2,305	2.167	0.002590
84	AMERICAN JOURNAL OF SURGERY	17,414	2.125	0.017600
85	JOURNAL OF HAND SURGERY-AMERICAN VOLUME	12,136	2.124	0.010210
86	Journal of Neurosurgery-Pediatrics	4,414	2.117	0.008420
87	INTERNATIONAL JOURNAL OF COLORECTAL DISEASE	6,017	2.108	0.008780
88	INJURY-INTERNATIONAL JOURNAL OF THE CARE OF THE INJURED	15,223	2.106	0.019990
89	Surgical Infections	2,217	2.102	0.004290
90	INTERNATIONAL JOURNAL OF ORAL AND MAXILLOFACIAL SURGERY	8,467	2.068	0.009460
91	BURNS	7,880	2.066	0.007350

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Rank	Full Journal Title	Total Cites	Journal Impact Factor	Eigenfactor Score
92	ARCHIVES OF ORTHOPAEDIC AND TRAUMA SURGERY	6,443	2.021	0.008260
93	International Journal of Medical Robotics and Computer Assisted Surgery	1,485	2.015	0.002480
94	Journal of Visceral Surgery	832	2.012	0.001630
95	Surgical Oncology Clinics of North America	1,270	2.000	0.002160
96	MICROSURGERY	3,087	1.996	0.003410
97	World Journal of Surgical Oncology	5,097	1.963	0.008550
98	CLINICS IN PLASTIC SURGERY	2,542	1.959	0.002980
99	NEUROSURGERY CLINICS OF NORTH AMERICA	1,808	1.957	0.002300
100	Scandinavian Journal of Surgery	985	1.950	0.001380
101	Visceral Medicine	364	1.941	0.000990
102	JOURNAL OF PEDIATRIC SURGERY	16,683	1.919	0.014190
103	PHOTOMEDICINE AND LASER SURGERY	2,697	1.918	0.002140
104	KNEE	4,455	1.913	0.008350
105	BMC Surgery	1,767	1.912	0.003500
106	Seminars in Vascular Surgery	720	1.889	0.000740
107	Operative Neurosurgery	1,183	1.886	0.002780
108	SURGERY TODAY	4,551	1.878	0.006110
109	World Journal of Gastrointestinal Surgery	964	1.863	0.002100
110	JOURNAL OF RECONSTRUCTIVE MICROSURGERY	2,332	1.841	0.002970
110	JOURNAL OF SURGICAL RESEARCH	13,661	1.841	0.019970

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Rank	Full Journal Title	Total Cites	Journal Impact Factor	Eigenfactor Score
112	Asian Journal of Surgery	983	1.838	0.001460
113	NEUROLOGIA MEDICO-CHIRURGICA	3,143	1.836	0.002780
114	World Neurosurgery	15,010	1.829	0.034650
115	Frontiers in Surgery	796	1.826	0.002410
116	ACTA NEUROCHIRURGICA	9,661	1.817	0.009830
117	Orthopaedics & Traumatology-Surgery & Research	4,069	1.809	0.007990
118	AESTHETIC PLASTIC SURGERY	4,121	1.798	0.004080
118	Clinics in Colon and Rectal Surgery	1,216	1.798	0.001350
120	JOURNAL OF CRANIO-MAXILLOFACIAL SURGERY	6,459	1.766	0.011120
121	EUROPEAN JOURNAL OF PEDIATRIC SURGERY	1,719	1.703	0.002390
122	JOURNAL OF INVESTIGATIVE SURGERY	1,037	1.685	0.001230
123	Interactive Cardiovascular and Thoracic Surgery	5,684	1.675	0.009110
124	PEDIATRIC SURGERY INTERNATIONAL	4,237	1.668	0.004780
125	CLINICAL TRANSPLANTATION	4,943	1.665	0.008610
126	Journal of Neurosurgical Sciences	850	1.645	0.001380
127	STEREOTACTIC AND FUNCTIONAL NEUROSURGERY	1,724	1.635	0.002060
128	CANADIAN JOURNAL OF SURGERY	2,575	1.610	0.002830
129	Annals of Thoracic and Cardiovascular Surgery	1,087	1.584	0.001370
130	CURRENT PROBLEMS IN SURGERY	495	1.577	0.000480
131	Facial Plastic Surgery Clinics of North America	879	1.543	0.001310

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Hands-free Adjustment of the Microscope in Microneurosurgery,
World Neurosurgery,
Volume 148,
2021,
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ISSN 1878-8750,
https://doi.org/10.1016/j.wneu.2020.12.092.
(https://www.sciencedirect.com/science/article/pii/S1878875020326590)

Curriculum vitae

My curriculum vitae will not be published in the electronic version of my work for data protection reasons

Complete list of publications

Peer-reviewed journals:

1. Rutvik Khakhar, Fang You, Denny Chakkalakal, David Dobbelstein, Thomas Picht, Hands-free Adjustment of the Microscope in Microneurosurgery, World Neurosurgery,Volume 148,2021, https://doi.org/10.1016/j.wneu.2020.12.092

Congress posters/abstracts:

1. Rutvik Khakhar, Fang you, Denny Chakkalakal, David Dobbelstein and Thomas Picht. Hands-free Adjustment of the Microscope in Microneurosurgery, abstract from the “International Conference on Sustainable Computing (SUSCOM-2021) to be published in SCOPUS indexed Springer Book Series “Advances in Intelligent Systems and Computing (AISC)”.

2. Fang you, Rutvik Khakhar, Thomas Picht and David Dobbelstein. VR Simulation of Novel Hands-Free Interaction Concepts for Surgical Robotic Visualization Systems, abstract from the “Medical Image Computing and Computer Assisted Intervention – (MICCAI 2020)” 23rd International Conference published in part of the Lecture Notes in Computer Science (LNCS, volume 12263).

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