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Application of virtual reality in simulated training for arthroscopic surgeries: A systematic literature review

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Abstract

INTRODUCTION: In recent years, technology has provided significant contributions to the health area with innovative projects such as artificial intelligence, virtual reality, augmented reality, etc.
OBJECTIVE: This review aims to review studies that propose solutions with virtual reality (VR) technologies for the training of surgeons in the arthroscopic surgery procedure.
Method: We identified 352 articles from the Scopus database, from 2017 to the present, of which 31 studies were retrieved by a screening procedure based on the principles of the PRISMA declaration for the study of this systematic literature review (RSL).
Results: The implementation of virtual reality in surgical simulations has significantly reduced the percentage of risk in the execution of arthroscopic surgeries.
Conclusions: The virtual reality implemented in the simulations of arthroscopic surgeries stands out and represents a promising tool that will allow improvements with respect to the formation of skills and the anticipation of possible events. However, it is necessary to address certain limitations, such as the accuracy and realism of simulations, as well as the implementation of haptic or perceptual systems to improve tactile or visual feedback during simulation.

Keywords: virtual reality, arthroscopic surgeries, systematic literature review

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1. Introduction

Arthroscopic surgical training has had a direct dependence on the operating room, where technical skills are developed under the specific supervision of a specialist. In fact, this training methodology or training is no longer feasible due to decreased hours and ethical concerns (1). Therefore, currently, surgical processes based on training simulations are evolving and innovating technically in arthroscopic surgeries. In fact, technical training based on simulations of surgical training is an essential prerequisite for performing tests or surgical practices in an operating room, since the skills necessary for performing an arthroscopy are not acquired solely by observation and assistance in a real surgery (1).

In recent years, virtual reality (VR) has been a usual complement to surgical training given its great technological development, but there are also several barriers that may be restricting its effective implementation, such as lack of access to advanced technology, the need for specific training for surgeons, the high cost and the lack of solid scientific evidence on its long-term effectiveness (1) (2) (3).

Nonetheless, this systematic review article discusses arthroscopic training simulation procedures using virtual

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reality (VR), efficiency, performance, and objective skill acquisition improvements (2) (4) (5). In fact, some features of virtual reality simulators are available to the market such as: ARTHRO (symbionix), ArthroSim and ArthroVision (3) that demonstrate their high effectiveness in their orthopedic simulated processes (4) (6).
Also, these simulators of replacement of hip, knee, shoulder, among others; They are the acetabular widening, the fixation of the acetabular cotyle, the broaching of the femoral cancan and the placement of the stem, which are based on constant study. Therefore, it is mentioned that simulation is also an excellent way to learn the skills and abilities (1) (4) (7) (8).
In fact, in the study the review article was published by Vaughan et al., 2016, where 11 preoperative planning tools for hip replacements were analyzed, in addition to 9 hip trauma fracture training simulators such as: DHS BoneDoc8 simulator, VirtaMed ArthroSTM, ulna fracture fixation simulator in virtual reality with Geomagic Premium, among other existing arthroscopy simulators (9 knee, 9 shoulder and 1 hip) to date, it is outdated and therefore a new systematic literature review (RSL) was developed (1).

Therefore, it implies an update of the study on the technologies related to virtual reality in health sciences for the improvement and evolution in the surgical processes of simulation in arthroscopy. The objective of this systematic review is to review studies developed that propose solutions with virtual reality (VR) technologies to identify the effectiveness of arthroscopic surgeries using surgical training simulators, similar to previous studies (9) (10).

In this sense, the document is structured as follows. Section 2, Methodology, presents the strategic method used for the systematic literature review (RSL), which will allow the approach of the PICO research question and the specific components related to it and then identify the study selection documents through the PRISMA statement. Section 3, Results, describes, and organizes the results obtained on the effectiveness of virtual reality (VR) through simulations in arthroscopic processes, applied methodologies, simulators and tools used in virtual reality. Section 4, Discussion, raises the discussion in a general way about virtual reality (VR) based on simulations of arthroscopic surgeries, interpreting the methodologies used, current perspectives and limitations found. Finally, in section 5, Conclusions, the most important main findings, and limitations of this systematic literature review are highlighted, indicating the importance of future research on virtual reality based on simulations of arthroscopic processes.

2. Methodology

According to the review of identified articles, the research resulted in 352 study articles obtained from the SCOPUS database. To this end, it was carried out in accordance with the PRISMA statement, to propose the criteria for the selection of study articles. Likewise, the PRISMA flowchart allows documenting the process of selecting articles, visualizing them, and proposing selection criteria to then evaluate them through inclusion and exclusion criteria and finally, use them as study articles from a database, in this case, SCOPUS, similar to past studies (10) (11) (12) (13) (14) (15) (16). To this end, the PICO strategic method was used as the main search methodology. This strategic method allows you to pose a structured question, with identifiable components to which keywords can be assigned in a way that allows greater robustness in the approach of the search equation (17) (18) (19) (20). Therefore, the following PICO question was elaborated: What methods of Virtual Reality application are used for arthroscopic surgical simulations? We also identified the review questions and corresponding topics associated with the main PICO question (21) (22).

Table 1. Review Questions

	REVIEW QUESTIONS	ITEMS
RQ1	What trends can be identified in the bibliometric analysis of studies?	- Place of development of study - Year of publication - Study authors -Publishing
RQ2	What was the goal of the research study?	- Problems identified. - Objectives of simulations with VR in arthroscopy.
RQ3	What virtual reality (VR) simulators were used for arthroscopic processes?	- Arthroscopic surgeries applied - Simulators used.
RQ4	What virtual reality methodologies have been used in arthroscopic simulations?	- Methodological techniques used in VR. - Applied evaluation models.
RQ5	What virtual reality (VR) tools have been used for the simulated operation?	- Types of VR tool used. - Software used. - Test systems.
RQ6	What results were obtained from arthroscopic simulations applying virtual reality?	- Levels of effectiveness of simulations applied to VR. -Achievements - Limitations found of VR.

And, in addition, a table was developed to visualize the identified components and the keywords associated with it together with the selection search equation, similar to other studies identified (23) (24) (25) (26) (27).

Table 2. PICO Methodology

	Keywords		
P	Object of study	Arthroscopic surgery	"Arthroscopic surgery" OR arthroscopy OR "arthroscopic procedures"
I	Intervention	Virtual reality	"Virtual reality" OR vr OR "computer simulation" OR "Image-guided surgery" OR "immersive virtual reality"
C	Context	-	-
Or	Results	Surgical simulations	simulation OR "simulation training" OR "simulation test" OR "simulation mode" OR training OR "surgical training" OR "surgical simulation"

Table 3. Search Equation

	Search equation
	(TITLE-ABS-KEY ("arthroscopic surgery" OR arthroscopy OR "arthroscopic procedures") AND TITLE-ABS-KEY ("Virtual reality" OR vr OR "computer simulation" OR "Image-guided surgery" OR "immersive virtual reality") AND TITLE-ABS-KEY (simulation OR "simulation training" OR "simulation test" OR "simulation mode" OR training OR "surgical training" OR "surgical simulation"))

In this study, the population or object of study (P) is related by arthroscopic surgery, which is the main component of the PICO question where it will focus the key points of the research in reference to what types of arthroscopic surgery virtual reality simulations have been implemented, the keywords identified are: "arthroscopic surgery" OR arthroscopy OR "arthroscopic procedures". The intervention (I) considered the use of virtual reality, is related to what techniques or methods of application of virtual reality have been implemented in the surgical process of simulation, the indexed keywords are: "Virtual reality" OR vr OR "computer simulation" OR "Image-guided surgery" OR "immersive virtual reality"; And, finally, the results (O) detail the main results obtained on training or simulations in arthroscopic surgical processes, where finally the keywords to complete the main search equation are: Simulation OR "simulation training" OR "simulation test" OR "simulation mode" OR training OR "surgical training" OR "surgical simulation".

In view of the table shown, the identified components and the keywords associated with each component, the study search equation is formulated that will allow selecting articles to then evaluate and reference them as study articles. Also, the proposed search equation is: (TITLE-ABS-KEY ("arthroscopic surgery" OR arthroscopy OR "arthroscopic procedures") AND TITLE-ABS-KEY ("Virtual reality" OR vr OR "computer simulation" OR "Image-guided surgery" OR "immersive virtual reality") AND TITLE-ABS-KEY (simulation OR "simulation training" OR "simulation test" OR "simulation mode" OR training OR "surgical training" OR "surgical simulation")).

Therefore, the inclusion and exclusion criteria were defined to evaluate the articles not related to the study that is proposed to be developed:

Table 4. Inclusion and Exclusion criteria

Inclusion Criteria	Exclusion Criteria
CI1: Articles related to simulations of arthroscopic surgeries.	CE1: Articles or Conference Papers prior to 2017.
CI2: Articles related to arthroscopic virtual reality techniques.	CE2: Publications in languages other than English or Spanish.
CI3: Articles related to virtual reality as a learning method in orthopedic surgical processes.	CE3: Types of documents other than original articles or Conference Papers.
CI4: Articles that offer evidence of the effectiveness of the use of virtual reality in training or simulations of arthroscopic surgeries.	CE4: Articles related to traumatological rehabilitation of orthopedic surgeries.
CI5: Articles related to productivity or improvement of VR application in arthroscopy.	CE5: Articles not related to VR in arthroscopic surgeries.

The study selection process that was developed in the SCOPUS database, 352 study documents were identified.

Because of this, through the PRISMA flowchart, the process of selecting items step by step is detailed as follows:

1. The total number of articles identified is 353 documents through the systematic search of SCOPUS.
2. Then, a filter is made by year of choice of articles from 2017 onwards and by original articles and Conference Paper.
3. Then, the documents obtained through the filter are 101 articles. Likewise, through the revision of the title and abstract of articles, 66 documents were retrieved.

4. Therefore, we searched for articles retrieved in full text, where 7 articles have not been retrieved, while 59 full-text articles have been obtained for evaluation.
5. Subsequently, 59 articles have been imported into Mendeley and evaluated by inclusion and exclusion criteria, where 27 articles are not related to the proposed research topic.
6. Finally, the subtotal corresponding to the IC and CE is 32 articles, where it gives us a result of 32 articles that will be used as part of study documents.

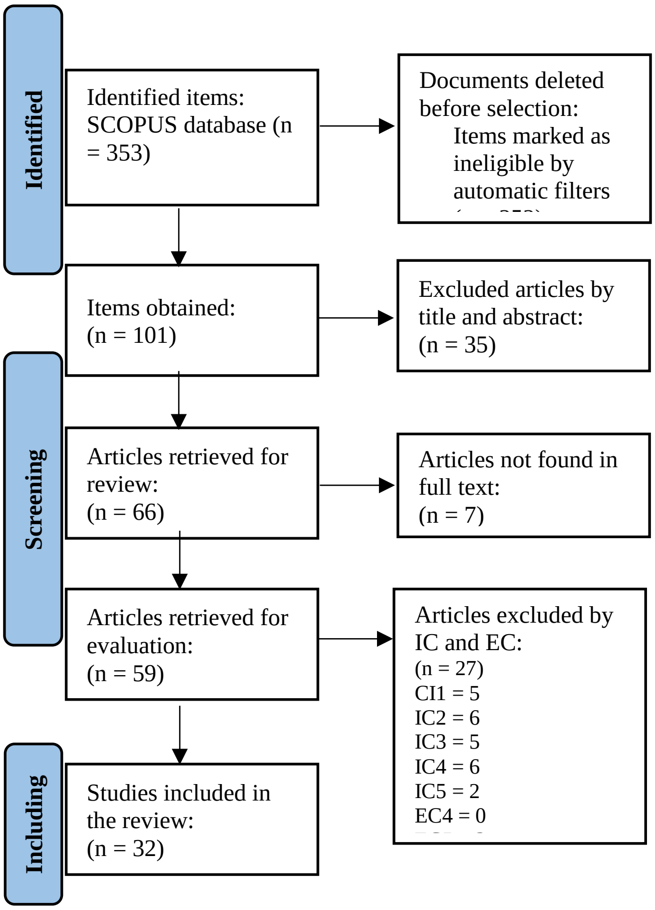

Figure 1. PRISMA Flowchart

Table 5. Inclusion and Exclusion criteria

References	Authors	Editorial
(28) (29)	Demirel et al., 2017 McCracken et al., 2018	John Wiley and Sons Ltd
(6) (30)	De Luca et al., 2019 Bartlett et al., 2019	Springer Verlag
(31) (32) (33) (34) (35) (51)	Putzer et al., 2022 Honda et al., 2022 Kobayashi et al., 2021 Jacobsen et al., 2021 Higashihira et al., 2020 Shigi et al., 2019	SAGE Publications Inc.
(36)	Cai et al., 2022	Springer Science and Business Media Deutschland GmbH
(37) (38)	Huri et al., 2021 Hauschild et al., 2021	Turkiye Klinikleri
(39) (40)	Feeley et al., 2022 Choi et al., 2018	Elsevier B.V.
(4) (41)	Polce et al., 2020 Dinc et al., 2022	NLM (Medline)
(42) (43)	Foo et al., 2021 Peserico et al., 2019	Churchill Livingstone
(44) (45)	Kwak et al., 2019 Chae et al., 2018	Public Library of Science
(46) (47) (48)	Bhattacharyya et al., 2017 Bhattacharyya et al., 2018 Banaszek et al., 2017	Lippincott Williams and Wilkins
(49) (50)	Bishop et al., 2021 Bauer et al., 2019	W.B. Saunders
(51)	Shigi et al., 2021	Mosby Inc.
(52)	Bartlett et al., 2020	Springer
(53) (54)	LeBel et al., 2018 Tronchot et al., 2021	Elsevier Inc.
(55)	Al-Hijari et al., 2020	Institute of Electrical and Electronics Engineers Inc.

3. Results

The totality of study documents included for this systematic review were from 32 studies addressing between the years of 2017 and 2023. Because of this, the papers reviewed, 30 were published as original articles and only 2 were published as Conference Papers.

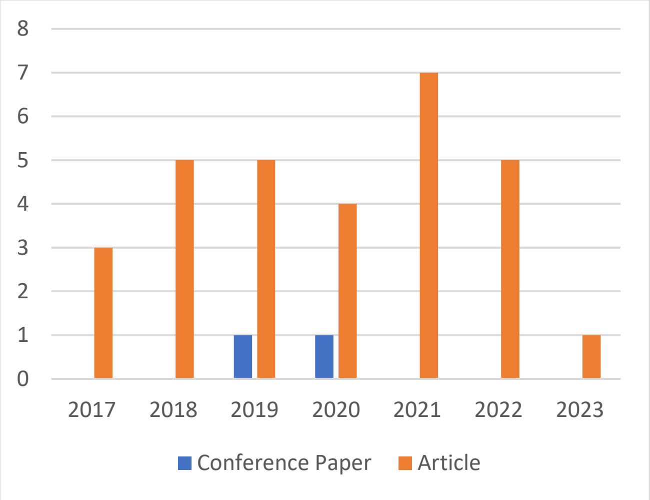

Figure 2. Publication of studies by year and type of documents

3.1. RQ1: What trends can be identified in the bibliometric analysis of studies?

The study papers that are part of the study of this systematic literature review (RSL) have been analyzed and studied by several authors from different parts of the world such as South America (31) (39) (56) (57) (58) (59), North America, Asia and Europe (28) (29) (38) (49) (54) (48) (32) (44). Likewise, 7 studies did not identify exactly the origin of the publications, however, they have been implicated in relation to the continuous improvement of arthroscopic surgeries, through simulations with virtual reality (VR) (45) (46) (34) (47) (52) (50) (51) (30). In turn, argued the technological advances of VR with disposition for arthroscopic surgical processes based on practical simulations for the development of chiropractic skills. In addition, the publishers that link the publication of the study documents were identified and the countries of origin where the studies were developed were specified.

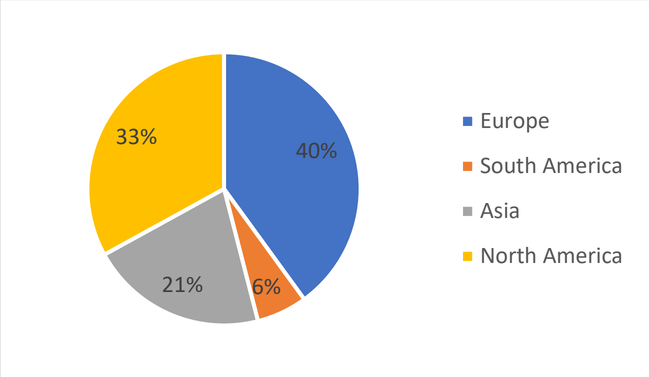

Figure 3. Publication of studies by year and type of documents

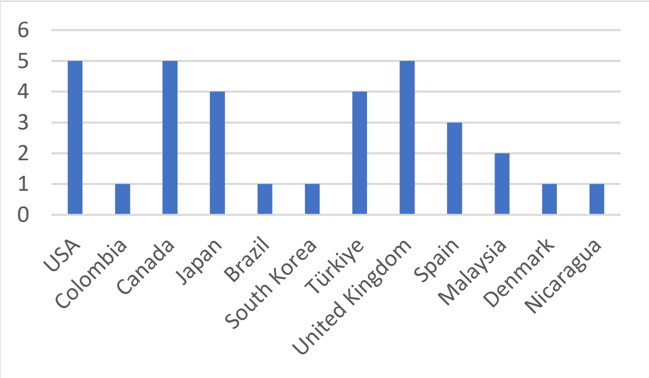

Figure 4. Origin of study publications by country

3.2. RQ2: What was the goal of the research study?

The main objective of the research is to contextualize the technological advances related to arthroscopic simulations by identifying the degree of precision and efficiency on the use of virtual reality technologies to develop learning skills in arthroscopic surgical processes. Likewise, studies have been identified that raised development objectives of new simulators or prototypes of practical training simulations (SBT) to develop chiropractic skills, another study proposes to create a realistic model of the temporomandibular joint (TMJ) for use in simulation training for arthroscopy procedures (6) (60). These results are consistent with those shown by similar studies (61) (62) (63) (64) (65) (66) (67).
Another study also proposes to develop a simulator platform for surgery repair and diagnosis of arthroscopic rotator cuff tear based on virtual reality. In addition, it was proposed to develop a real-time bone drilling simulator for the placement of anchors in an arthroscopic surgery simulation (28) (41). Therefore, other studies proposed to analyze and validate the efficiency of arthroscopic simulations with VR technologies through performance and learning curve comparisons evaluate the feasibility of the 3D printed simulator (31) (36) and determine the effectiveness of virtual reality (VR) simulators compared to desktop simulators (BT) (4).

3.3. RQ3: What virtual reality (VR) simulators were used for arthroscopic processes?

There are different approaches to the simulation of arthroscopic surgeries such as knee, shoulder or hip that aim to improve the training and skills of doctors in the practice of chiropractic processes. One of them is the simulators, both virtual and physical reality, which allow different procedures such as rotator cuff repair or repair of articular cartilage tears in a controlled manner. On the one hand, a haptic, multi-procedural VR simulator was used where the practical process of this simulator is through 3D patients, especially in knee, femur, and spine surgeries. Another simulator used is the VR Surgical Simulator (Insight Arthro VR; GMV) which provides training tools for improving technical skills in arthroscopy. These results show the importance of considering the guidelines of education in virtual environments (68) (69) (70) (71) (72), learning communities (73) (74) and the link with other virtual platforms (75) (76) (77) (78).
The Simbionix Arthro Mentor VR simulator was also used, where the utility of this simulator is to train hip arthroscopy skills through a realistic and practical experience in the manipulation of surgical instruments and tissues in the process of surgery. Similarly, a physical simulator was used to train basic skills in arthroscopy, which allows doctors to train and improve certain aspects or skills in a controlled environment. In addition, some studies have shown that practice or simulator training can significantly improve the performance of arthroscopy procedures by taking full advantage of technology, such as the study of the improvement in the performance of surgeons after shoulder simulator training (4) (6) (48) (44) (30).

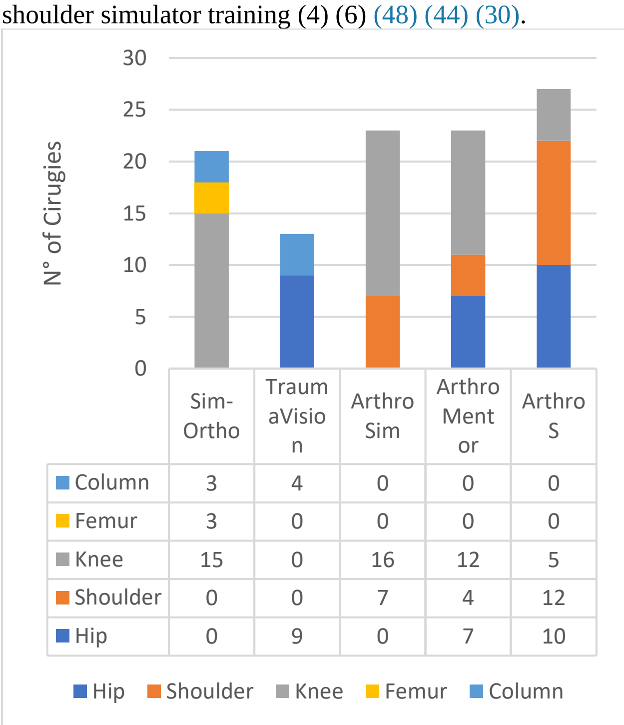

Figure 5. Simulators used in different types of arthroscopies surgery.

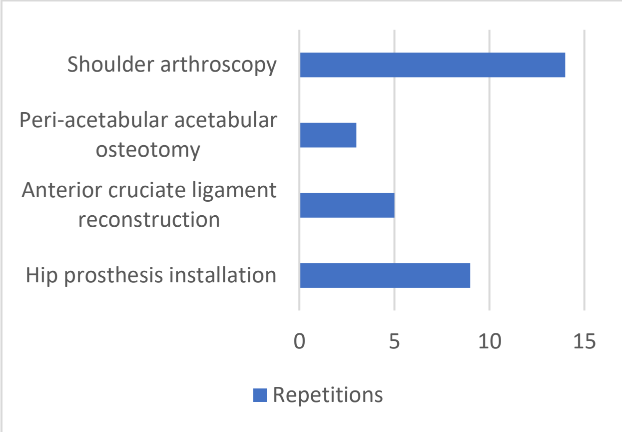

Figure 6. Types of surgeries and repetitions.

3.4. RQ4: What virtual reality methodologies have been used in arthroscopic simulations?

When performing arthroscopic simulations in virtual reality (VR), different methodologies have been used that are adapted to the specific objective of the simulation and the surgical procedure in question. The studies show different approaches that have been used to improve the efficiency and realism of these simulations. Also, some studies like the used a rapid iteration methodology. This allows users to continuously practice improving their surgical skills. Through constant repetition, doctors and students can hone their technique and develop a greater skill to perform procedures such as partial meniscectomy and avascular necrosis of the femoral head with femoroacetabular impingement (31) (33).
On the other hand, studies by Higashihira et al., 2020 used a combination of intuitive interaction techniques and a design focused on medical education to create more realistic and detailed simulations. This methodology aims to provide an immersive and authentic experience for doctors, contributing to more effective training (35).
Currently, the implementation of virtual reality (VR) in health, aims to accurately recreate anatomical structures and surgical scenarios, which helps improve the accuracy and fidelity of simulation in training and evaluation of arthroscopic skills.
Anatomical studies and simulation tests have been used in some studies to constantly improve the sense of immersion and realism of the simulation. These techniques are used to create realistic and effective simulations for training and evaluating arthroscopy skills (35).

Another study also used specific techniques for arthroscopy simulation, in which computer-assisted and hip arthroscopy were used to treat avascular necrosis of the femoral head with femoroacetabular impingement. It was also focused by computer simulation models based on CT images and used to analyze the effect of pelvic tilt changes of FAI (33).

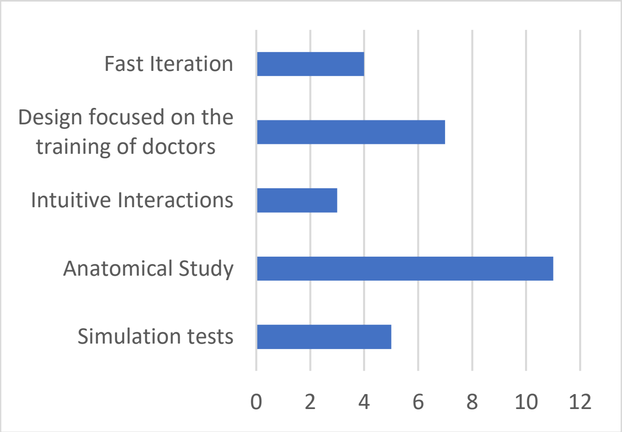

Figure 7. Methodological techniques used.

3.5. RQ5: What virtual reality (VR) tools have been used for simulated operation?

Simulation with virtual reality (VR) tools is effective in training and improving surgical skills in arthroscopic orthopedic surgery. The use of these tools provides a safe and controlled environment for surgeons to hone their skills without putting patients' lives at risk.

In the study by Banaszek et al., 2017 (48), 3D printed models were used to visualize osteophytes during hip arthroplasty. The 3D printed model allows the surgeon a better understanding of the bone structure and location of such osteophytes. Instead, studies such as Luca et al., 2017 and Wu et al., 2023 used virtual simulators and multi-procedure physical simulators, respectively, to improve arthroscopic skills training and increase the learning curve. These simulators allow for continuous and repetitive practice, a better understanding of anatomy and a reduced effective training time. Another study by McCracken et al., 2018 (29), developed a stationary simulator to improve the surgeon's skill and accuracy in shoulder arthroscopy, optimize access to the shoulder joint, and ensure tissue preservation (6) (79).

For this reason, the utilization of virtual reality tools in the simulation of surgical procedures, particularly in arthroscopic orthopedic surgeries, has proven to be an excellent way to provide a safe and controlled environment for surgeons in training and for surgeons looking to improve their skills. Virtual models, simulators and 3D printing tools are technological tools that have been used to improve surgical practice (36).

3.6. RQ5: What results were obtained from arthroscopic simulations applying virtual reality?

The use of virtual reality in the training and practice of orthopedic surgeries, specifically in the areas of hip, shoulder, and knee, has been studied in various scientific articles. Therefore, a thorough analysis has been conducted on the effectiveness of virtual reality (VR) in alleviating these common symptoms.

Therefore, the effectiveness of virtual reality has been investigated and the effectiveness of VR training in orthopedic surgery has been explored. The results highlighted that training using virtual reality simulators can improve surgical dexterity and increase the learning curve, suggesting a potential benefit for procedures and emphasizing hip, shoulder, and knee arthroscopy. Virtual reality simulators provide an immersive and realistic experience, allowing surgeons to practice repeatedly in a safe and controlled environment, thus improving their skill in complex surgical techniques. In addition, a controlled laboratory study of shoulder arthroscopy simulator training was conducted. The results showed that virtual reality training improved the performance of surgical procedures (4) (38).

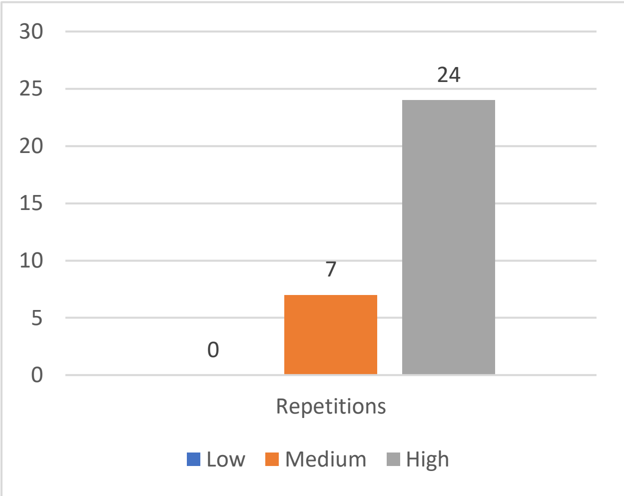

Figure 8. Effectiveness of shoulder VR.

The real-time feedback provided by the simulators allows surgeons to improve their accuracy and skill in specific techniques used in shoulder surgeries. In addition, the use of the virtual reality (VR) hip arthroscopy simulator had an acceptable degree of high realism, where the visual representation of the hip joint was identified as realistic, as well as the visual representation of the instruments on screen. In fact, the study noted that the hip simulator provided a non-threatening learning environment, where the simulator as a training tool was highlighted as very useful. The results also showed significant performance improvements with the use of hip arthroscopy simulators, improved surgical process times **(48) (52)**, increased accuracy and success rates and decreased collisions as well as efficiency largely improved markedly (4).

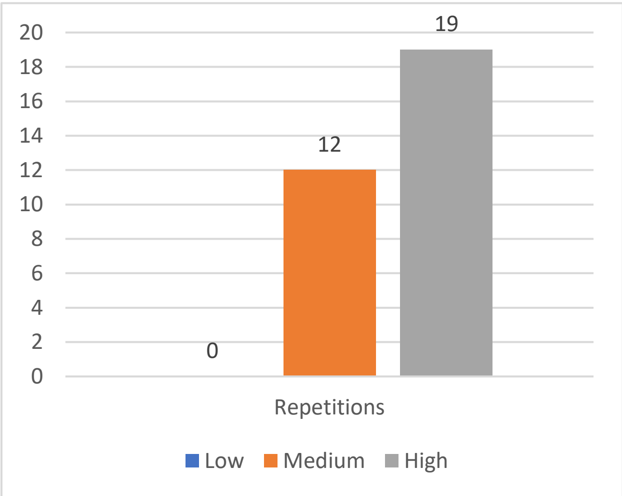

Figure 9. Effectiveness of VR in hip.

In the field of knee arthroscopy, simulator training was discussed among medical students and residents. Virtual reality simulators have proven to be an effective tool for improving knee arthroscopy skills and continued use of these devices can lead to a progressive improvement in surgical performance (31).

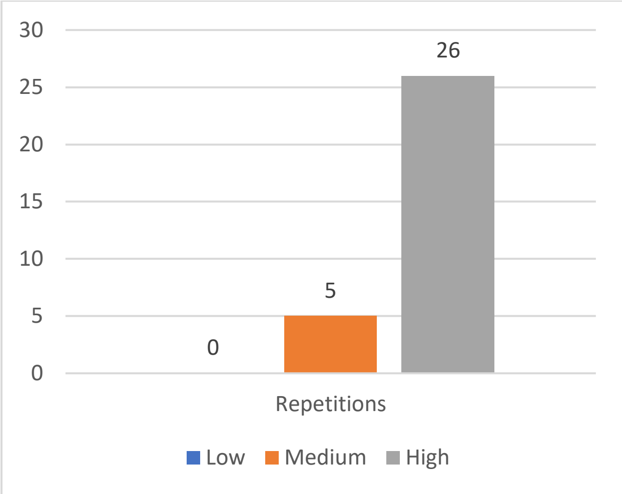

Figure 10. Effectiveness of VR in knee.

However, we found some study limitations such as the lack of standardized assessment of surgical skill acquisition. Similarly, the lack of quantification of benefits in the real practice of training with the use of simulators. In addition, learning curves were identified by modules of independent simulators tag (4) (52). Another limitation found is the lack of research into the cost-effectiveness of using simulators, which is an important consideration for hospitals and training centers (54). However, similar studies have demonstrated the importance of considering multiple variables, such as networks, dimensions, and sociopsychological factors (68) (80) (81) (82) (83) (84).

4. Discussion

In this review study, it is inferred through the results obtained on the use of VR in arthroscopic simulations, the use of the VR simulator (Insight Arthro VR; GMV) has established improvements in arthroscopy technical skills, greater precision in surgical processes through the progressive simulations that are developed. In turn, the Simbionix Arthro Mentor VR simulator developed more accurate hip arthroscopy skills, where it allowed practitioners to simulate a more real hip surgery process, that is, obtain a real chiropractic experience (6). Given this, the use of surgical instruments simulated on screen and tissues in the process of surgery, demonstrated an increasing efficiency in surgical processes of knee, shoulder and hip, but compared to these arthroscopic processes, the use of the simulator of VR hip arthroscopy (31) (38) (48) (52).

It has demonstrated a greater degree of scope of realism, where it is reflected in representational images. Likewise, the use of 3D models that allows the understanding of bone architecture and the visualization of osteophytes, improves the precision of the hip arthroscopic process. However, the limitations identified establish the independence of effectiveness only by some simulator modules, especially hip arthroscopies, where this exerts an imbalance of the learning curve. In addition, the skills obtained in the simulations are not yet standardized and not yet cost-effective in consideration for the use of simulators in work environments such as hospitals and training centers (4) (54) (48) (52). Therefore, future research studies are required to address different types of comparative simulators, standardize evaluation methods, and evaluate the performance of practitioners with surgical training simulators and the results obtained from it.

5. Conclusion

The main objective of this review is to review developed studies that propose solutions with virtual reality (VR) technologies to identify the effectiveness of arthroscopic surgeries using surgical training simulators. Taking into account the constant advancement of technology and the benefit it generates.

In conclusion, different simulators were found with unique functionalities, which allow from simulating a surgery to the measurement of capacity and skills of surgical processes of the interns. The results are focused on an anatomical part (knee, shoulder and / or hip) that show us a different percentage, since the complexity of the human body does not allow virtual reality to meet 100% realism in simulations. In most studies, it has been demonstrated the difficulty of generating a simulation of the hip part, since it constitutes a large part of anatomical structure unlike the shoulder and knee. To achieve an improvement in the implementation of virtual reality (VR) in simulations of surgeries not only of the hip, but it is also necessary to continue researching and developing new advances that allow us the appropriate realism to further reduce the percentage of risk. However, it is critical to continue to address limitations, such as the need to improve the accuracy and realism of simulations to bring them even closer to surgical reality. The implementation of haptic and perceptual systems is also becoming important to provide more detailed tactile and visual feedback during training or training, which would aid a more immersive and realistic simulation experience. Likewise, collaboration between health professionals, instructors and virtual reality developers should be encouraged to ensure the effectiveness and safety of its application in arthroscopic surgery processes.

Acknowledgements.
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