UNIVERSIDADE FERNANDO PESSOA

THE ROLE OF AUGMENTED REALITY IN THE OPERATING MICROSCOPE IN ENDODONTICS: AN INVESTIGATION

[O uso da realidade aumentada no microscópio operatório na Endodontia: uma investigação]

Dissertação de Mestrado

Mestrado Integrado em Medicina Dentária

Laura Dal Pont

Orientador:

Doutor Duarte Nuno Antunes Guimarães

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Questo lavoro lo dedico a Porto, a questa città che mi ha regalato tante emozioni, dove sono cresciuta e mi sono sentita a casa. Per sempre nel mio cuore.

I want to thank all the people who supported me during this journey, who believed in me and did not judge me for loving sports as much as I love dentistry. I want to thank the Professors who transmitted me their passion, and also those who made me improve my meditation and stress dealing skills. I want to thank my family at home, and the new one that rose here in this special city. And finally, I want to thank myself for being me.

Abstract

This study investigates the role of Augmented Reality (AR) integrated into the operating microscope in Endodontics, particularly in assisting inexperienced dental practitioners. The integration of advanced technologies, such as AR, into dental procedures has significantly improved precision, safety, and efficiency in recent years. This research aims to evaluate whether the application of AR could potentially eliminate the skill gap between experienced and unexperienced operators by providing real-time guidance and enhanced visualization of the operating field. Fifty participants without prior clinical training performed access cavities on artificial molar teeth under the guidance of a fifth-year dental student, with the help of AR technology in the microscope. The system included a step-by-step video demonstration and real-time visual support through the AR interface. The fifth-year dental student also performed the access cavity of 5 molar teeth. The results were evaluated based on cavity continuity, size, and positioning, as well as the visibility of the root canals, by an expert endodontist. The findings revealed that, despite their lack of experience, the participants were able to perform procedures comparable to those of the experienced student. Statistical analysis confirmed that there was no significant difference between the scores of the two groups. Moreover, AR facilitated a clearer understanding of the procedure, significantly improving participants' performance and providing a hands-on learning experience. This study highlights the potential of AR to revolutionize dental education, making complex procedures more accessible and reducing the learning curve for new practitioners. Ultimately, the study demonstrates that AR can enhance dental training by improving the quality and efficiency of operations, offering a promising tool for the future of dental and medical education.

Key words: Augmented Reality, Operating Microscope, Endodontics

Resumo

Este estudo investiga o papel da Realidade Aumentada (RA) integrada no microscópio operatório em Endodontia, particularmente no apoio a profissionais de medicina dentária com pouca experiência. A integração de tecnologias avançadas, como a RA, nos procedimentos dentários tem melhorado significativamente a precisão, a segurança e a eficiência nos últimos anos. Esta investigação visa avaliar se a aplicação da RA pode, potencialmente, eliminar a diferença de competências entre operadores experientes e inexperientes, fornecendo orientação em tempo real e uma visualização aprimorada do campo operatório. Cinquenta participantes sem formação clínica prévia realizaram cavidades de acesso em dentes molares artificiais sob a orientação de um estudante de medicina dentária do quinto ano, com o auxílio da tecnologia RA integrada no microscópio. O sistema incluía uma demonstração em vídeo passo a passo e apoio visual em tempo real através da interface de RA. O estudante do quinto ano também realizou a cavidade de acesso em 5 dentes molares. Os resultados foram avaliados por um endodontista especialista, com base na continuidade, tamanho e posicionamento da cavidade, bem como na visibilidade dos canais radiculares. Os resultados revelaram que, apesar da falta de experiência, os participantes conseguiram realizar procedimentos comparáveis aos do estudante experiente. A análise estatística confirmou que não houve diferença significativa entre as pontuações dos dois grupos. Além disso, a RA facilitou uma compreensão mais clara do procedimento, melhorando significativamente o desempenho dos participantes e proporcionando uma experiência prática de aprendizagem. Este estudo destaca o potencial da RA para revolucionar o ensino da medicina dentária, tornando os procedimentos complexos mais acessíveis e reduzindo a curva de aprendizagem dos novos profissionais. Em última análise, o estudo demonstra que a RA pode melhorar a formação dentária, aumentando a qualidade e a eficiência das intervenções, oferecendo uma ferramenta promissora para o futuro da educação médica e dentária.

Key words: Realidade Aumentada, Microscópio Operatório, Endodontia

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Abbreviations

AR – Augmented Reality

3D – Tridimensional

TAC – Computerized Axial Tomography

AC – Access Cavity

RC – Root Canal

RCT – Root Canal Treatment

I. Introduction

In the last decades technology has been growing at an exponential rate, revolutionising day-to-day activities and transforming modern medicine and dentistry. Study and research in the field of engineering has led to a massive improvement in all the other areas, among which the medical one. When it comes to dentistry in particular, the surgical microscope is a great example of the progress that has occurred, enhancing the quality of the operating view and precision. In addition, innovation in materials and mechanics has allowed the development of new instruments which, combined with digital imaging and recent software, have further refined the dentist's work, turning it faster, less invasive and more predictable (B. Liu et al., 2023a).

Endodontics, which is a dental speciality that "focuses on the treatment of diseases affecting the dental pulp and periapical tissues" (Jankowska et al., 2025), has been widely impacted by this growth in technology. Higher image quality has made it possible to have a more accurate diagnostic and prognostic. The implementation of the electronic apex locators together with the use of magnifying glasses and the surgical microscope has set new standards in this medical field. Procedures that in the past could only be dreamed of can now, instead, successfully be put into practice.

This thesis will explore the benefits of the use of recent technological developments in endodontics, focusing on the advances made in informatics – related to software development – and in the optical systems. This study aims to demonstrate how endodontics has been positively impacted by this technological revolution and it will show how, thanks to it, there is still a lot of potential growth in this discipline.

1. The use of the operating microscope from endodontics to the other branches of dentistry

In the area of endodontics, the importance of having the best magnification and visualization possible of the operating field was rapidly recognized. As a matter of fact, in this branch the visual difficulty is outrageous, and at the same time the precision required is sharp, making the root canal treatment an extremely complex procedure. Root canals can, in fact, be tight, curved and ramified, and often bleeding is present due to the state of inflammation, making it further difficult to have an appropriate sight. The microscope enables dentists to create optimal access cavities, improving canal visualization and reducing error risk (Ganesan et al., 2024).

Sometimes root canals suffer a calcification process which makes them more difficult to detect, resulting into an incomplete root-canal treatment. This may lead to the spread of the infection to other sites and cause severe oral health issues (H. Liu et al., 2024). In relation to so, a recent study has reported that “the operating microscope enables the detection of all root canals, establishing full working length in 90% of the cases, with an 80% success rate observed after a 3-year follow-up” (Fornara et al., 2024), proving its relevance in the execution of a successful procedure.

Encountering all the canals present is not the only challenge. One of the main objectives of endodontics is being able to carry out an ideally shaped access cavity, which allows for a longer longevity of the tooth. To achieve so, it is firstly necessary to completely remove the caries. It is then the dentist’s role to evaluate which design is most appropriate for that specific tooth, trying to be minimally invasive in order to preserve dental structure and avoid to excessively weaken the tooth’s resistance. Both the caries removal and the dentist’s assessment are dependent on the capability to see, and the microscope has incredibly facilitated this job (Bud et al., 2021).

It was not a surprise to see an increasing number of endodontics specialists using the microscope on a daily basis for RCT. After seeing the results, specialist of other branches of dentistry begun to explore the use of this instrument in other areas, and it is now employed also in periodontics, restorative dentistry, prosthodontics and implantology. For example, in periodontics and implantology, the microscope improves the view of the soft tissues, allowing for less invasive surgeries. In restorative dentistry the magnification permits the execution of a better margin modelling and optimal material adaptation. Lastly, in prosthodontics it helps to evaluate the quality of the preparation and marginal closure of the crown (Devadharshini et al., 2024).

The reason of this triumph is clear: the operating microscope offers a magnified stereoscopic vision, with a perfectly centred coaxial illumination on the operating field, which permits to the professional to work with an outstanding precision. The combination between magnification, field depth and light intensity has allowed to the surgeons to act on increasingly smaller structures, reducing the error margin and improving clinical results. Today it is recognized that the use of the microscope is not limited to enthusiasts or perfectionists, but it is instead a true extension of sight, able to concretely improve the quality of treatments and reduce mistakes. The progress and development of new, more compact and handy models are helping to break down the practical barriers and spread its use (Calkovsky et al., 2025).

2. The structure of the microscope and the advantages that follow it

In order to be able to truly acknowledge why the microscope is such a powerful tool, it is first necessary to understand how it is structured.

The operating microscope is primarily composed by a multi-lense optical system which implies a series of converging lenses that are able to produce a variety of magnification dimensions while always ensuring a good field depth. The magnification range offered by dental operating microscopes (DOM) is extremely wide: it goes from 4x to 25x, compared to the only 2.5x to 6x capacity of dental loupes (Bud et al., 2021). In today's microscopes this can be easily regulated through an electronic system that is usually connected to a pedal, and the typical objective lense used in dentistry is of 200mm, depending on the hight of the operator (B. Liu et al., 2023b).

The microscope, in addition, features a binocular head, which consists of two telescopes with adjustable eyepieces for users with refractive error (Dal Pont, 2022). These "telescopes" produce a three-dimensional and stereoscopic image, that is essential for the doctor/dentist to be able to have a good comprehension of the working field and correctly carry out his job.

Another clue component is the illumination system with LED or Xenon sources, which is free of shadow due to the true coaxial path of light (Ma & Fei, 2021a). This ensures a deep and uniform illumination, constant throughout the day, diminishing the effect of the changing amount of natural light and reducing eye fatigue. The dentist, in fact, does not require anymore to constantly move the adjunct lamp at every change in working position, as in this case the illumination moves in conjunction with the microscope. Such detail allows the dentist to stay focused on the operating field, reducing chair time and the risk of iatrogenic errors.

From a mechanical point of view the microscope is supported by an articulated arm, which can be mounted on the floor, wall or sealing. This translates into a stable and precise positioning of the instrument which can easily adapt to the ergonomic demands of the operator. Various dental practitioners have declared that since they use the operating microscope they observed a “drastic decrease of the eye fatigue, musculoskeletal pains and the decrease of the psychological fatigue” (Bud et al., 2021). Such result is supported by the presence of an increased visibility, which reduces the temptation of sliding to a bad posture in order to have a better view.

Lastly, many modern microscopes are equipped with an integrated digital cameras which allow to record and/or screen-share the image of the operating field that the dentist is observing through the binoculars (Ma & Fei, 2021b). This greatly enhances teaching, as students and residents can observe exactly what the clinician sees, with a clear and focused image free from the distractions and misalignments that are typical of handheld cameras. Professors can explain procedures more effectively, without needing extra personnel to manage recording equipment, thus saving time and improving efficiency.

3. Telesurgery

In the last century technological evolution has not only continued, it has accelerated. It is now well embedded in many sectors, playing a fundamental role in their performance. This is especially true when it comes to the medical area, where innovation does not stop to surprise, enabling to reach goals that up to few years ago were considered beyond belief. The development of extremely high-resolution cameras which are capable of transmitting images in real-time with extremely low latency has been crucial (Mohan et al., 2021). At the same time, advances in electronics, miniaturization of components and particularly in satellite and broadband connectivity have made remote surgery a reality.

An historical event that demonstrates this convergence of technologies is the first ever remote surgical operation carried out successfully on the 7th September 2001, known as “Lindbergh Operation” (Bernard et al., 2003). A medical team located in New York operated, victoriously, a patient in Strasburg, France. This was made possible through the use of the advanced robotic surgical system ZEUS. The procedure, that was a cholecystectomy, was performed in real-time through a dedicated transatlantic fibre optic connection. The delay between command and execution was less than 200 milliseconds, which is considered acceptable for the precision required in the chirurgical sector.

In the last couple of years telesurgery has also been a strong matter of interest in space medicine. One of NASA's recent main objectives has been to implement the ability to perform remote surgeries in space to assist astronauts in case of medical emergencies. In fact, while the agency's primary mission remains the pursuit of new scientific discoveries and the exploration of space, it is equally committed to ensure the health and safety of its crew members. It was in February 2023 that NASA got a step closer with the so called "spaceMIRA" (Miniaturized in Vivo Robotic Assistant), which managed to perform "several operations on simulated tissue at the orbiting laboratory" whilst remotely controlled by surgeons on Earth (Pantalone, 2023).

Everyone seems now to have finally understood how powerful technology can be if correctly applied, and the benefits that arise from telesurgery are immense. To start with, it gives universal access to surgeons, who can now operate at distance from any country in the world without the need of being physically present (Heemeyer et al., 2025). Beyond this, thanks to the high-quality live stream, many other experts can support and give advices to the operating surgeon by interacting with him and the operating field through systems of augmented reality. Through this system a major safety during complex procedures is guaranteed, where even recently formed doctors are put in the conditions of working with greater serenity and security.

4. Augmented reality

Another clue concept that has developed together with telesurgery is augmented reality. AR refers to the "real time integration of digital information into a user's environment" (Dinh et al., 2023). It differs from virtual reality, which immerses the user into a completely artificial environment. AR instead keeps a visual and special continuity, allowing to overlay images and computer generated information onto the real world, enriching it. A very recent example is the Apple Vision Pro release by Apple on February 2024, which consists of a headset with an integrated AR system capable of projecting videos and images in the real 3D world (Egger et al., 2024).

Throughout the years, augmented reality has found its path in various medical fields, taking them to a whole other level. It is, indeed, a very powerful tool as the doctor is able to clearly see the operating field and at the same time visualize additional digital content inside of it, without the need of removing his eyes from the patient. In spinal surgery, for instance, X-rays or 3D-scans are projected into the actual world "via the use of portable overhead displays" (Chopra et al., 2024), making pedicle screwing easier as the doctor does not lose the focus by checking the information on monitors. As a consequence, shorter operating times are achieved and the chances of mistakes are reduced.

Also in dentistry the utility of AR is a certainty. It allows, in fact, to project with an incredibly high precision the TAC of the mandibular nerve, helping the dentist during delicate procedures such as extractions or implant placement (Mai et al., 2023). It is even used to predict the outcome of fixed prosthodontics treatments, like the placing of facets, and to evaluate whether they are the best option. By doing so, safer working conditions are ensured, as the operand is guided through his actions and can predict the results with a greater accuracy. Better working conditions reduce stress and improve self-confidence, which generally result in a further positive treatment outcome.

The potential of augmented reality is particularly observable when it comes to assisting newly formed Dentist or Doctors who still lack clinical experience. In fact, independently from the amount of time spent studying on books, understanding what is the best treatment option to be performed and/or how it should be carried out is not always granted (Lauer & Lauer, 2018). Every case is, indeed, unique, as different patients have different characteristics, medical histories and risk factors. Thanks to recently developed AR systems, students and professionals can now be followed remotely by other colleagues and guided in their actions through cursors and live chats projected in the binoculars of the microscope.

In the present study, a device positioned between the two optical paths incorporates two camera modules, two displays, and a complex arrangement of prisms. The prisms integrate the digital content into the optical path of the microscope without obstructing the view of the actual surgical field. The digital image from the displays is guided through these prisms, which are embedded in the original optical path, ultimately reaching the dentist's eyes. Instead, the dual-camera setup enables stereoscopic reconstruction of the image as perceived by the dentist through the microscope. However, since the camera sensors are rectangular while the microscope's field of view is circular, the captured image omits a small portion of the upper and lower areas of the surgical scene. In the same way, the displays projecting the information from the computer into the microscope also have a rectangular shape, resulting in the omission of the data located at the corners. For this reason it is important that these data are organized following the circular frame of the binocular. The projected visual data can be customized according to the needs of the dentist, supporting both mixed reality and augmented reality applications (Dal Pont, 2022).

5. Objective of the study

The main objective of this investigation is to prove the importance and effectiveness of augmented reality systems in the dental operating microscope, in the field of Endodontics. This will be achieved by asking a group of 50 individuals, who have no clinical experience, to perform, through the use of AR in the operating microscope, the access cavity of a tooth with artificial pulp. The individuals will be helped remotely throughout the whole procedure, and the outcome will be then evaluated by an external expert. Even a 5th year dentistry student will perform 5 access cavities with the microscope, which will also be evaluated by the same expert for comparison.

6. Creation of the access cavity

The tooth 46, commonly known as the lower right first molar, typically has three root canals: two in the mesial root that are the mesiobuccal and the mesiolingual, and one in the distal root. The canals are generally well-defined, with the mesial canals being the smallest and often requiring careful instrumentation due to their complex anatomy. The access cavity for tooth 46 should be designed to provide efficient access to all three canals while preserving the tooth's structure. In terms of shape, the access cavity should be trapezoidal, allowing for optimal access to the canals – especially the mesiobuccal and mesiolingual –, and ensuring the three canals are adequately reached (Saygili et al., 2018). The cavity should be wide enough to prevent instrumentation difficulties but not too large to avoid weakening the tooth. Regarding dimensions, the access cavity's length should allow full visibility and easy manipulation of endodontic instruments, typically covering the pulp chamber and extending toward the orifice of the canals.

II. Materials and Method

"The conduct of this in vitro study was approved and carried out in accordance with the guidelines of the Ethics Committee of the Faculty of Health Sciences at Fernando Pessoa University (see Annex A)."

1. Bibliographic research methodology

To provide a solid theoretical foundation for this study, the selection of scientific articles was based on the keywords “Augmented Reality”, “Operating Microscope” and “Endodontics”. Publications from 2002 to 2025 were analyzed, totaling 23 articles. The only non-recent article included in the bibliography describes a NASA operation carried out the previous year, which explains the older publication date. In addition to peer-reviewed literature, two university thesis were also included in the bibliographic analysis, providing valuable insights and up-to-date perspectives on clinical applications and experimental developments closely aligned with the subject of this research.

2. Population and sample

Fifty individuals aged between 20 and 30 will be recruited for this study, all of whom have no previous clinical experience. All participants have no formal dental training. Each individual will be asked to perform an access cavity on a lower molar: a right first molar tooth 46 with artificial pulp, under the guidance of a 5th-year dental student, who will be remotely connected via the AR system. In addition, the same 5th-year student will perform five extra access cavities, always with the support of the operation microscope, in order to serve as a reference group. The teeth will be collected anonymously at the end of each procedure for blinded evaluation.

3. Materials and equipment

i. Teeth:

Artificial molars (brand: Yaidu store, model: 46) simulating human anatomy, including a crown structure and a pulp chamber filled with wax to mimic real pulp tissue. All artificial teeth were purchased from AliExpress. The crown dimension was 1,1mm x 1,2mm x 7mm.

ii. Instrumentation:

- Red-ring contra-angle handpiece with integrated water cooling system to prevent overheating during bur use.
- Round bur ISO 1.6 mm
- Diamendo bur ISO 1.5 mm

iii. Microscope:

Leica, equipped with stereoscopic optics, adjustable magnification, coaxial illumination, and an integrated augmented reality system.

iv. Augmented Reality Interface:

The AR system is supported by the application "Microscope Connect" installed on a desktop computer running Windows 10. This application will allow the projection in the microscope of a demo video showing how to carry out the procedure. It will also permit to the 5th-year student to access a live feed of the operator's visual field in the microscope, following him throughout his steps and providing advices if necessary. For example, when required, the student will have the possibility to communicate with the participant in real time through the use of an on-screen cursor and chat function to indicate areas where adjustments must be done.

v. Connectivity:

A dedicated Wi-Fi network will ensure stable, low latency communication between the remote operator and the AR system integrated in the microscope.

4. Variables

There are a number of variables that must be kept under control during the experiment to ensure the reliability of results. Table 1 is describing them, explaining also the importance of controlling them and how this will be done.

Table: 1 Variables

Variable	Why it should be controlled	How it will be controlled
Toth used (shape and size)	Different shapes or sizes could affect the difficulty of the procedure.	All participants will use identical artificial molars (same brand, model number and dimensions).
Video used as a mean of AR support in the microscope	Differences in the instructional video could lead to inconsistent guidance across participants.	The same pre-recorded demo video will be projected.
Operator giving support to the 50 individuals carrying out the study	Variations in instruction style and level of intervention could bias results.	A single 5th year student will be in charge of providing real-time support to all 50 participants.
External expert evaluating the access cavities	Subjectivity or bias in evaluation could affect the reliability of results.	One external endodontist will evaluate all samples in a blinded and anonymized manner using pre-agreed scoring system.
Sight problems	Visual impairments among participants could affect performance independently of the AR system.	Every individual will be allowed to correct visual impairments through the regulation system of the binoculars.

5. Blinding and Evaluation

Once completed, all access cavities (a total of 55 teeth) will be anonymized and submitted to an external expert endodontist with over 25 years of experience. The evaluator will not know the identity of the operator and will assess each tooth using a predefined scoring system from 0 to 10 in the ascending direction of the degree of quality, based on:

- Continuity in the access cavity shape (score from 1 to 10)
- Appropriate size of the cavity (score from 1 to 10)
- Appropriate positioning of the cavity (score from 1 to 10)
- Success to visualize correctly all the canals (YES / INCOMPLETE / NO)

The scoring rubric will ensure a standardized and objective evaluation of the outcomes.

6. Statistical analysis

The statistical analysis was carried out using Python (version 3.11). Normality was assessed using the Shapiro-Wilk test. As one of the groups did not meet the normality assumption, a non-parametric approach was chosen, and the Mann-Whitney U test was applied to understand whether the null hypothesis was to be accepted or rejected.

7. Hypothesis

The hypothesis of this study is that the 50 individuals with no prior clinical or dental experience will be able to perform access cavities in line, in terms of quality, to those executed by the 5th-year dental student. The AR interface, including a step-by-step tutorial video and real-time guidance from the experienced student, is expected to compensate for the participants' lack of training. If confirmed, this would demonstrate the potential of AR in significantly accelerating and enhancing dental training and precision.

8. Ethical considerations

The execution of this experiment does not imply any risk for the safety of the participants. The teeth used are artificial, and the pulp chamber is filled with wax, which eliminates any potential threat of disease transmission that might occur with the use of real teeth. Moreover, to reduce the danger associated with the high-speed rotation of traditional turbines, a red-ring contra-angle handpiece will be used instead, allowing for greater control and safety during the procedure. Additionally, to ensure the maintenance of privacy, all teeth will be labeled with numbers rather than personal names, maintaining full anonymity.

III. Results

Table 2 presents the results of the assessment conducted by an experienced endodontist with 26 years of clinical practice. Each row corresponds to a single tooth prepared by a participant. The “Tooth” column indicates the identification number of the tooth managed by each individual. The evaluator analyzed three main aspects of the access cavity preparation: continuity in shape, size of the access cavity (AC) and positioning of the access cavity (AC). Each of these variables was scored individually.

A “Total score” column is included, representing the sum of the scores from the three variables just stated. This provides an overall performance score for each access cavity.

A final column, “Visualization of the canals”, reports whether the root canals were fully visible after the procedure. The outcomes are categorized as either “Yes” (full visualization) or “Incomplete”. No cases resulted in a complete failure to visualize the canals.

For reference, the 5th-year dental student performed tooth number 3-15-20-46-49.

Table 2 Results

Tooth	***Continuity in shape***	***Size of the AC***	***Positioning of the AC***	***Total score***	***Visualization of the canals***
1	9	9	10	28	YES
2	6	7	7	20	YES
3	8	8	8	24	YES
4	6	7	6	19	YES
5	8	7	6	21	YES
6	5	4	4	13	YES
7	6	5	4	15	INCOMPLETE
8	8	9	8	25	YES
9	8	7	7	22	YES
10	9	7	8	24	YES
11	8	9	10	27	INCOMPLETE
12	7	8	9	24	YES

Tooth	***Continuity in shape***	***Size of the AC***	***Positioning of the AC***	***Total score***	***Visualization of the canals***
13	9	9	9	27	INCOMPLETE
14	8	8	9	25	YES
15	9	7	9	25	YES
16	9	7	9	25	YES
17	8	7	9	24	YES
18	9	10	10	29	INCOMPLETE
19	7	6	7	20	YES
20	9	9	10	28	YES
21	8	7	8	23	INCOMPLETE
22	9	10	10	29	YES
23	7	9	7	23	YES
24	8	9	9	26	YES
25	8	9	10	27	YES
26	9	9	10	28	INCOMPLETE
27	9	7	10	26	YES
28	6	7	8	21	INCOMPLETE
29	9	7	9	25	YES
30	8	9	10	27	YES
31	9	10	10	29	YES
32	9	8	9	26	YES
33	9	8	10	27	INCOMPLETE
34	9	6	6	21	INCOMPLETE
35	8	8	9	25	INCOMPLETE
36	7	8	7	22	YES
37	9	9	10	28	YES
38	8	6	7	21	YES
39	5	8	8	21	YES
40	6	9	8	23	YES
41	6	5	5	16	YES
42	8	8	8	24	INCOMPLETE
43	7	6	8	21	YES

Tooth	*Continuity in shape*	*Size of the AC*	*Positioning of the AC*	*Total score*	*Visualization of the canals*
44	8	8	9	25	YES
45	9	10	10	29	YES
46	7	8	7	22	YES
47	8	7	8	23	YES
48	8	6	9	23	YES
49	9	9	10	28	YES
50	6	6	7	19	YES
51	7	6	6	19	YES
52	9	10	10	29	YES
53	7	9	9	25	INCOMPLETE
54	8	7	10	25	YES
55	6	10	8	24	YES

1. Comparison of the total scores between Group 1 and 2

The frequency tables Table 3 and 4 facilitate the interpretation of the data presented in Table 2. Table 3 refers to Group 1 (the 5th-year dental student), and Table 4 refers to Group 2 (the 50 inexperienced volunteers). The data clearly show that most individuals achieved high scores, with only a few cases falling below 20 points. The distribution of scores in both groups appears very similar, suggesting comparable performance between the student and the volunteers. As it can be seen in the two tables, in both groups the highest concentration of scores achieved is between 21 and 25, and no participants scored below 11.

Table 3 Frequency table for the Total score of Group 1

Total Score	*Frequency*
0-5	0
6-10	0
11-15	0
16-20	1
21-25	3
26-30	1

Table 4 Frequency table for the Total score of Group 2

Total Score	*Frequency*
0-5	0
6-10	0
11-15	2
16-20	5
21-25	26
26-30	17

Table 5 displays the mean total score for each group. Nearly equivalent means are observed, supporting the observation that the inexperienced participants, guided by the AR system, were able to perform at a level nearly equivalent to that of a more experienced operator. This similarity in mean scores was also confirmed by the Mann-Whitney U test which yielded a p-value of 0.377, indicating that there is no statistically significant difference between the two groups.

Table 5 Total score mean of Group 1 & 2

	Group 1	*Group 2*
Total score mean	23.9	24.2

2. Relationship between the variables and canal visualization in Group 2

Since Group 1 is a small set of data where the canal visualization was always complete, the analysis was performed only on Group 2.

Table 6 Relationship between the variables and canal visualization in Group 2

	Mann-Whitney U test (p-value)
Total score	0.431
Continuity in shape	0.381
Size of the AC	0.602
Positioning of the AC	0.569

Table 6 explores the relationship that the total score and each individual variable (continuity, size, and positioning of the access cavity), have with the canal visualization outcome. The results of the Mann-Whitney U test suggest that none of the evaluated parameters shows a statistically significant influence, indicating that canal visibility may occur independently of the assessed cavity quality.

IV. Discussion

This study aimed to determine whether incorporating Augmented Reality (AR) into an operating microscope could allow inexperienced operators to achieve outcomes comparable to those of a trained dental student in endodontic access cavity preparation. The results demonstrated that AR support – through pre-recorded video guidance and real-time remote assistance as shown in Figure 1 and 2 – enabled non-experienced participants to perform with quality matching that of the comparison student. This was evidenced by similar scores in continuity, cavity size, and position, with no statistically significant differences found using the Mann–Whitney U test ($p = 0.377$).

Figure 1: Guidance through AR

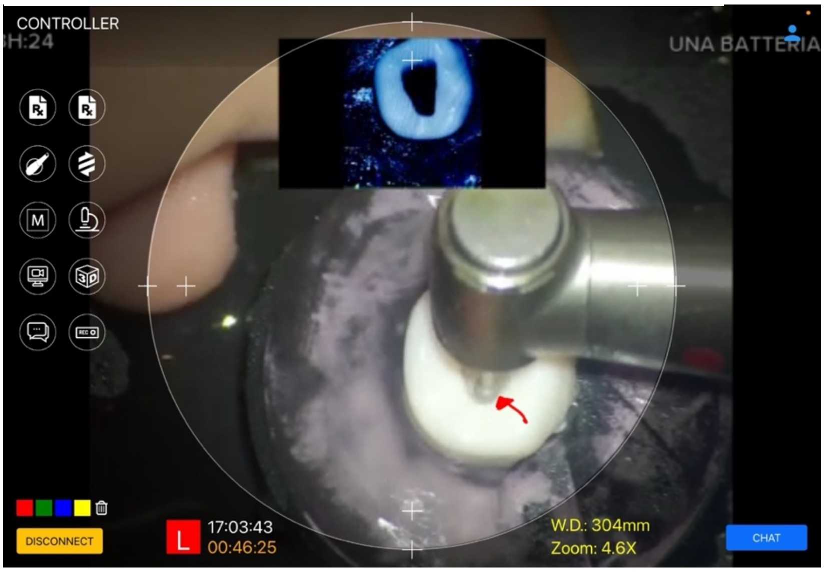
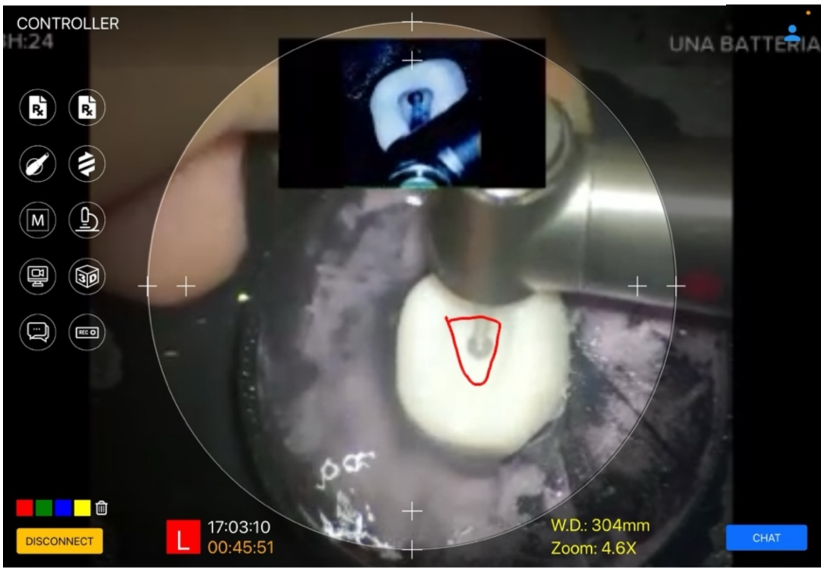


Figure 2: Illustration of the ideal AC shape



These findings align with existing literature on magnification's benefits in dentistry. As Bud et al. (2021) reported in a study exploring the importance of the microscope in various procedures, operating microscopes enhance procedural precision in restorative dentistry. Indeed, clear and detailed visualization of the operating field is crucial for the successful outcome of any procedure. It allows for a clearer understanding of what you are seeing. When the image is sharp and well-lit, the eyes have to exert less effort to focus, which means that less energy is spent on trying to make out the details. This, in turn, frees up cognitive resources for the brain to understand and focus on what needs to be done during the procedure. Such fact was widely explored in a study that addressed the impact of screen contrast on cognitive load and mental effort, highlighting the importance of having an optimal visualization to ensure a better performance (Rasmus Å. Lindell, 2025). In this way, the operator can concentrate on the task at hand, such as performing precise movements, making decisions, or interpreting the anatomy, rather than struggling to interpret unclear or faint images.

In this research it is clear that improved visualization leads to better performance and results. In fact, for the "Visualization of canals" variable three possible outcomes where expected: YES", "INCOMPLETE", and "NO". The "YES" category indicated that all the canals were fully visible, "INCOMPLETE" meant that all the canals were fully visible only when the tooth was tilted, and "NO" indicated that not all the canals were visible. Interestingly, despite the 50 participants having no prior experience, there was never a case where the canals were not visible. It is particularly significant considering that the participants were completely new to the field. This is consistent with what was reported by Al Ali et al. (2024), who demonstrated that stereoscopic vision improves the identification of anatomical structures in simulated dental procedures.

In relation to the success in visualization of the canals, it is important to mention that the stereoscopic field of view provided by the operating microscope is significantly different from what is seen with the naked eye (Dal Pont, 2022). As explained in the latter study, when focusing on a distant and profound object, the human eye perceives the world through monocular vision, which, while detailed, has a limited depth and a reduced peripheral vision. In contrast, the use of a microscope with stereoscopic optics allows for a three-dimensional view, where the resulting image is perceived by both eyes, each with a different viewing angle. This combined vision provides greater depth and a more precise perception of objects, which is crucial in surgical settings, especially in Endodontics, where an extremely detailed view of structures is required.

In the context of canal visualization, the difference between monocular and stereoscopic vision could have influenced the evaluation system used for the "canal visualization" score. When operators, even though inexperienced, were observing through the microscope, the stereoscopic vision provided them with a much clearer and deeper understanding of the RC structure. This interpretation is supported by the findings of (Al Ali et al., 2024)), who specifically examined the role of stereoscopic 3D vision in dental training. Their study showed that “utilizing stereoscopic 3D vision in the training session improved students’ perception of depth which led to more accurate tooth cutting within the target area and less outside the target area removal”. Therefore, even in cases where the scores were recorded as "incomplete" (meaning not all the canals were visible when viewed from a classical sitting position), operators may have actually seen all the canals in their entirety during the stereoscopic visualization. This could explain why there were never any cases where the canals were completely invisible: the enhanced vision provided by the tool allowed the operators to identify all the canals, even those that were difficult to see with the naked eye.

This distinction may also explain the apparent lack of correlation between the total score and canal visualization. Since stereoscopic vision allows for a precise and simultaneous observation of details in three dimensions, while the "canal visualization" evaluation was likely made considering visibility from different angles or requiring tilting the tooth, the "incomplete" evaluations may not have fully accounted for the quality of the stereoscopic vision provided by the microscope, which still allowed for optimal canal visualization. In other words, many of the "incomplete" scores may be the result of an evaluation that did not fully consider the enhanced vision provided by the microscope, which allowed operators to clearly see all the canals during the procedure.

Indeed, only in three cases, out of the 50 treatments performed, the “total score” did not reach the minimum threshold of 18 points, demonstrating that the majority of participants were able to perform the access cavity satisfactorily, despite their lack of experience. The injection in the microscope of a video showing how the act should be performed, together with real-time assistance provided by the 5th year student who could, for example, virtually draw on the operating field of the volunteer to explain how to adjust the shape, where absolutely effective. The AR system and the operating microscope not only facilitated the learning process but also allowed the participants to achieve results that were consistently high-quality. These findings further reinforce the growing role of AR in dental education. As highlighted by (Dzyuba et al., 2022), immersive technologies such as virtual and augmented reality are increasingly recognized for their ability to support skill acquisition at a level comparable to, and in some cases even surpassing, traditional training methods. The present study adds concrete evidence to this evolving perspective, showing how AR can effectively bridge the experience gap and enhance procedural learning even in technically demanding domains such as endodontics.

However, like any study, this one has limitations that deserve attention. One of the main ones is the lack of assessment of the time taken by each operator to complete the procedures. The time required for execution can significantly affect the efficiency of treatment and its quality, and a more in-depth analysis of this aspect could have provided valuable insights into how AR technology could also optimize operational times. Moreover, the fact that the teeth were evaluated by a single teacher, albeit a specialist, may have introduced some degree of subjectivity into the evaluation process. Including a more diversified group of evaluators could further increase the objectivity of the results. Additionally, the experiment involved a limited number of participants (50 + 1), and the control group consisted of a single fifth-year dental student. A greater control group would have ensured better representativeness and a more robust statistical comparison.

V. Conclusion

This study explored the potential of augmented reality (AR) integrated into operating microscopes as a training aid in endodontics. The findings suggest that AR can significantly support novice operators by enhancing their ability to perform precise procedures, such as access cavity preparation, even without prior clinical experience. With the guidance provided by the AR interface – combining step-by-step visual instructions and real-time feedback – participants were able to achieve results comparable to those of a final-year dental student. This highlights AR's capacity to bridge the gap between inexperience and clinical competence, offering a valuable tool in dental education and preclinical training.

Future studies should aim to expand the sample size and include participants with different levels of clinical experience. This would help assess the true effectiveness of AR across a broader range of skills and practice contexts. It would also be interesting to evaluate the application of AR in more complex procedures – such as periodontal surgery or implant placement – to explore the full potential of this technology in advanced operative dentistry. By doing so, we can better understand how AR might be integrated into routine clinical workflows, not only as a teaching aid but also as a support system for real-time clinical decision-making.

In conclusion, augmented reality holds great promise in making advanced procedures more accessible and in enhancing the quality of both training and clinical care. Its integration into dental practice represents a step forward in the digital transformation of healthcare, where innovation can directly improve learning, safety, and treatment outcomes.

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VII. Appendix

1. Annex A: Opinion of the Ethics Committee of the Faculty of Health Sciences of Universidade Fernando Pessoa

UNIVERSIDADE FERNANDO PESSOA

Exma. Senhora
Prof. Doutora Sandra Gavinha
Diretora da FCS

Nº	Data
FCS/MMED – 744/25-2	13 de Maio de 2025

Exma. Senhora Professora Doutora,

A Comissão de Ética apreciou a ressubmissão do projeto de investigação apresentado por Laura Dal Pont, intitulado "The role of augmented reality in the operating microscope in Endodontics: an investigation", a realizar no âmbito do Mestrado Integrado em Medicina Dentária, sob orientação do Professor Doutor Duarte Antunes Guimarães.

O objetivo do estudo é demonstrar que, com recurso ao microscópio e a utilização de novas tecnologias como a realidade aumentada, 50 indivíduos sem experiência clínica ou odontológica prévia são capazes de realizar a cavidade de acesso em dentes artificiais com polpa em cera.

O projeto terá a duração de 1 mês, sendo realizado em Itália (Treviso, TV), na clínica dentária Dal Pont SRL. Os participantes estarão divididos em dois grupos:
Grupo A: 50 indivíduos entre os 20 e 30 anos, sem experiência clínica ou odontológica prévia
Grupo B: 1 estudante do 5° ano de Medicina Dentária

Será explicado verbalmente aos participantes o objetivo do estudo e a sua organização, explicando detalhadamente o procedimento do estudo e fornecendo clarificações sopre todas as questões relacionadas com o trabalho. Os operadores voluntários assinarão o devido consentimento informado para este estudo.

A Comissão de Ética nada tem a opor quanto à realização deste projeto. No entanto, deve a Investigadora atentar nos seguintes pontos:

1- Em relação ao procedimento de acesso ao grupo de participantes, deve retirar que os participantes serão escolhidos do grupo de amigos. Deve evitar esta população, uma vez que laços de afetividade entre os participantes e a investigadora podem condicionar a sua participação.
2- Uma vez que o trabalho de investigação irá ser implementado em Itália, o Consentimento Informado deve ser traduzido para Italiano, cabendo à investigadora responsabilizar-se pela correta tradução.

Com os melhores cumprimentos,

A Presidente da
Comissão de Ética da UFP

Inês Lopes Cardoso

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A Comissão da FCS nada tem a opor à realização do estudo e à sua apresentação como parte do trabalho de dissertação, deve no entanto a investigadora dar cumprimento às recomendações da CE

[illegible]

14-5-25

2. Annex B: Patient Informed Consent Form Template

Modulo di consenso informato

Sei invitato a partecipare, come volontario, al progetto di ricerca "The Role of Augmented Reality in the Operating Microscope in Endodontics: an investigation", ovvero "Il ruolo della realtà aumentata nel microscopio operatorio in Endondonzia: un'indagine".
Questo studio ha l'obiettivo di valutare l'impatto dell'uso della Realtà Aumentata (AR) integrata nel microscopio operatorio nella formazione di operatori inesperti in Endodonzia. Ti verrà chiesto di eseguire una cavità di accesso su un dente molare artificiale con polpa in cera, con il supporto di un sistema AR e sotto la guida remota di uno studente del quinto anno.

Durante la sessione:

- Utilizzerai un microscopio operatorio dotato di sistema di Realtà Aumentata
- Riceverai istruzioni visive in tempo reale da un operatore remoto
- Ti verrà richiesto di eseguire una cavità di accesso su un dente molare artificiale
- Nessun dato clinico o identificativo verrà raccolto

La partecipazione a questo studio è completamente volontaria. Puoi rifiutarti di partecipare o ritirarti in qualsiasi momento, senza alcuna penalizzazione o conseguenza. Non è prevista alcuna compensazione economica.
Lo studio non comporta rischi fisici o psicologici significativi. I denti utilizzati sono artificiali e gli strumenti sono regolati per garantire la sicurezza in un ambiente simulato. Il principale beneficio sarà di tipo didattico, con un possibile miglioramento nella comprensione pratica delle tecniche endodontiche.
I dati raccolti non permetteranno in alcun modo la tua identificazione. Il dente che realizzerai sarà numerato e non associato al tuo nome. Tutti i dati verranno conservati in modo sicuro e saranno distrutti dopo il termine dell'analisi. I ricercatori tratteranno la tua identità nel rispetto delle normative professionali sulla riservatezza e useranno le informazioni esclusivamente a fini accademici e scientifici.
I risultati dello studio ti saranno comunicati una volta completata l'analisi. Non sarai identificato in nessuna pubblicazione derivante da questa ricerca. Il presente modulo di consenso informato è stampato in due copie originali, una delle quali sarà conservata dal direttore della Clinica Medica e l'altra ti verrà consegnata.

Io, ____________________________________, titolare del documento ______________, sono stato informato in modo chiaro e dettagliato sugli obiettivi del progetto di ricerca "The Role of Augmented Reality in the Operating Microscope in Endodontics: an investigation" e ho chiarito ogni mio dubbio.

Sono consapevole di poter chiedere ulteriori informazioni in qualsiasi momento e di poter cambiare idea riguardo la mia partecipazione.
Dichiaro di acconsentire a partecipare a questo studio. Ho ricevuto una copia originale del presente modulo di consenso informato e ho avuto la possibilità di leggerlo e chiarire ogni mia eventuale perplessità.

_____ del _____ del ________.

Firma del partecipante

____

3. Python

```
data = pd.read_csv('/content/Copy of total score_50.csv')
data.head()
scores = data['Total score']
stat, p = shapiro(scores)
print("\nRisultato Shapiro-Wilk:")
print(f"Statistic: {stat:.4f}")
print(f"P-value: {p:.4f}")
df = pd.read_csv('/content/Copy of total score_5.csv')
df.head()
scores = df['Total score student']

stat, p = shapiro(scores)
print("\nRisultato Shapiro-Wilk:")
print(f"Statistic: {stat:.4f}")
print(f"P-value: {p:.4f}")

df = pd.read_csv('/content/Copy of total score x visualization_50.csv')
df.head()
df['canal_binary'] = df['Visualization of the canals'].map({'P': 0, 'Y': 1})

group_0 = df[df['canal_binary'] == 0]['Total score']
group_1 = df[df['canal_binary'] == 1]['Total score']

stat, p_value = mannwhitneyu(group_0, group_1, alternative='two-sided')

print(f"\nMann-Whitney U statistic: {stat}")
print(f"P-value: {p_value:.5f}")

df['canal_binary'] = df['Visualization of the canals'].map({'P': 0, 'Y': 1})

X = sm.add_constant(df[['Total score']])
y = df['canal_binary']

model = sm.Logit(y, X)
result = model.fit(disp=False)

coeff = result.params['Total score']

ll_full = result.llf
ll_null = result.llnull
lr_stat = 2 * (ll_full - ll_null)
df_diff = result.df_model
from scipy.stats import chi2
p_val_global = chi2.sf(lr_stat, df_diff)

print(f"Coefficiente (Total score): {coeff:.4f}")
print(f"P-value del modello (Likelihood Ratio test): {p_val_global:.4f}")
```

```
import pandas as pd
from scipy.stats import mannwhitneyu


df = pd.read_excel('/content/total score x visualization_50.xlsx', header=2,
usecols="B:G")

df.columns = df.columns.str.strip()


variabili = [
    'Total score',
    'Continuity in shape',
    'Size of AC',
    'Positioning of the AC'
]

for var in variabili:
    print(f"\nMann-Whitney U Test: '{var}' vs 'Visualization of the canals'")

    gruppi = df['Visualization of the canals'].unique()

    gruppo1 = df[df['Visualization of the canals'] == gruppi[0]][var]
    gruppo2 = df[df['Visualization of the canals'] == gruppi[1]][var]

    stat, p = mannwhitneyu(gruppo1, gruppo2, alternative='two-sided')

    print(f"U statistic: {stat}")
    print(f"P-value    : {p}")
```