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Influence of different loupe systems and their light source on the vision in endodontics

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 Microscope

SUMMARY

The aim of this study was to evaluate the performance of Galilean and Keplerian loupes in the endodontic lumen with and without integrated light. Although the use of an operating microscope is widely recommended in endodontics it is uncertain whether an adequate loupe system with coaxial light source might replace the microscope for some endodontic work. Twenty-four dentists (age 27–64 years) underwent a miniaturized visual test inside the endodontic lumen of a natural molar: at the canal entrance, 5 mm inside the canal, and at the apex. The tooth was mounted in a phantom head in a simulated clinical setting. The naked eye (negative) and the microscope 6× (positive) served as control groups, and Galilean loupes 2.5× and Keplerian loupes 4.3× with and without a coaxial light

source as experimental groups. A structure of 0.05 mm corresponding to the smallest instrument (06) was the threshold for sufficient vision. The loupe type, coaxial light source and the dentists' age had a statistically significant influence at all locations. None of the loupes helped to visualize structures at the apex. At the canal entrance, the visual threshold was reached by dentists <40 years with Galilean loupes, by dentists ≥40 years with Keplerian loupes, with and without coaxial light. Dentists <40 years detected structures <0.05 mm inside the root canal with Keplerian loupes and coaxial light. The microscope offered highly superior results. The naked eye was insufficient to reach the visual threshold at any location.

Introduction

For decades, endodontic treatments were performed in the dark, guided by radiographs, anatomic knowledge, tactile sense and experience (DAHLSTRÖM ET AL. 2016). The introduction of the operating microscope in dentistry (SELDEN 1989; CARR 1992) allowed for new approaches to endodontic procedures, such as the detection of small orifices, the diagnosis of vertical root fractures, the repair of deep perforations and the elimination of obstacles inside the root canal (RUDDLE 1994; VELVART 1996; BALDASSARI-CRUZ & WILCOX 1999; DE CARVALHO & ZUOLO 2000; BALDASSARI-CRUZ ET AL. 2002; SCHWARZE ET AL. 2002). The operating microscope has become widely accepted as part of an endodontist's equipment despite a lack of proof that its use *per se* enhances the clinical prognosis of endodontic treatments (DEL FABBRO ET AL. 2015).

A recent study compared the performance of the naked eye with that using a dental loupe system and an operating microscope with miniaturized visual tests inside the endodontic lumen of a natural tooth (PERRIN ET AL. 2014A). In this clinical simulation, the naked eye was unable to detect the dimension of the finest endodontic instrument (0.06 mm) at any location of the endodontic lumen while Galilean loupes with a coaxial light source allowed young dentists aged <40 years to detect this dimension at the canal entrance. This was not the case for older dentists or for other locations inside the root canal system. The microscope with 6× magnification offered highly superior vision inside the tooth, which was influenced neither by the location nor by the dentists' age.

In the above-mentioned study of PERRIN ET AL. (2014A) Galilean loupes 2.5× were used with a coaxial light source as typically used in dentistry (EICHENBERGER ET AL. 2015; PERRIN ET AL. 2014B). The question if Keplerian (prismatic) loupes with their higher magnification could reach the postulated threshold for an adequate endodontic treatment was not answered. Neither analyzed was the impact of the coaxial light source on the visual performance inside the endodontic lumen. The aim of the present follow-up study was to evaluate the performance of Galilean and Keplerian loupes in the endodontic lumen with and without coaxial light source.

Materials and methods

The intra-radicular visual tests

The setup of the visual tests was described in detail in an earlier publication (PERRIN ET AL. 2014A). Miniaturized visual tests on the base of microfilms were fixed inside the endodontic lumen of a natural first molar (FDI 26) as shown in Figs. 1 and 2. The three main canals had been shaped to an apical diameter of 0.6 mm to gain enough space for the visual test charts. A phantom head with the prepared tooth 26 was positioned on a dental chair and fitted with a dental rubber dam to simulate a clinical setting.

The eye charts with E-optotypes were validated for dental purposes by EICHENBERGER ET AL. (2011). To define the direction of the optotype it is necessary to see the spaces between the three bars of the E. The dimension of this space is therefore the measured value of the test and is equal to 1/5 of the external dimension of the E-optotype. The range of the bar distance was at the canal entrance between 0.02 mm and 0.05 mm and inside the canals between 0.01 mm and 0.025 mm. To obtain a positive correlation between the smallest detected structure and the visual performance, the metric dimension (e.g. 0.05 mm) was converted into the reciprocal value (e.g. 20 mm⁻¹).

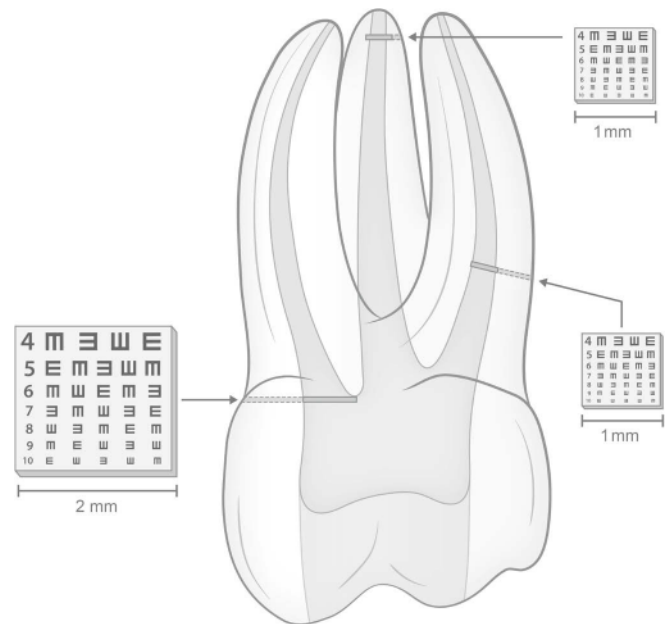


Fig. 1 Location and scale of the visual tests inside tooth 26 at the canal entrance, 5 mm inside the canal and at the apex

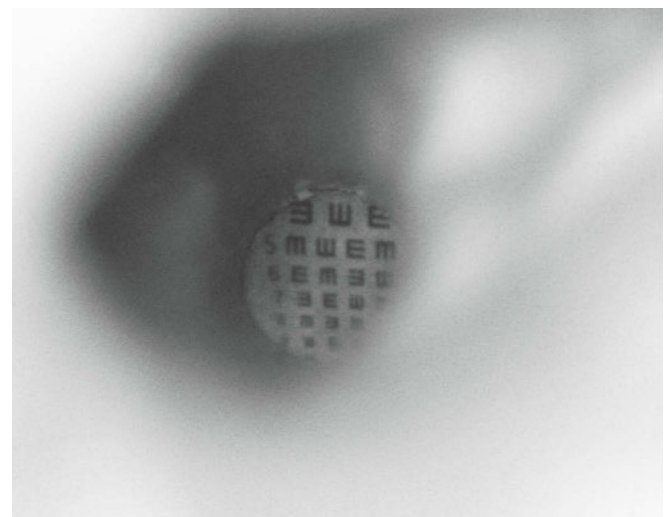


Fig. 2 Visual test with E-optotypes in the middle third of the distobuccal canal

Participants and optical test conditions

The visual tests were performed with the test group of PERRIN ET AL. 2014A (24 dentists, mean age 40 years, median age 35 years, range 27–64 years). The participating dentists were faculty members or private practitioners related to the faculty. Inclusion criteria were the habitual use of loupes and microscope and a confirmed near visual acuity in the range of former studies (EICHENBERGER ET AL. 2011; PERRIN ET AL. 2017). All participants performed a respective near visual test and could be included in the study.

The visual tests were performed under the following experimental conditions:

- G: Galilean loupe, 2.5× magnification, 380 mm working distance (EVC250N, SurgiTel, Ann Arbor, MI, USA) with self-adjusted operating lamp (Delight, Planmeca OY, Helsinki, Finland)
- GL: as for G, with coaxial LED light source (HighLight, DCI, Kiel, Germany), results transferred from PERRIN ET AL. 2014A

- K: Keplerian (prismatic) loupe, 4.3× magnification, 400 mm working distance (MagLight, Zeiss, Oberkochen, Germany) with self-adjusted operating lamp (as above)
- KL: as for K, with coaxial LED light source (as above)

The following conditions and results from PERRIN ET AL. 2014A served as positive (M) and negative (NV) control group:

- NV: Natural vision, correction glasses if necessary, freely chosen working distance with self-adjusted operating lamp (as above)
- M: Operating microscope Leica M300, integrated light source Leica CLS150MR, magnification 6× (Leica Microsystems, Heerbrugg, Switzerland)

All test subjects were familiar with the use of loupes and microscopes. Individuals who needed glasses for correction of visual deficiencies had to wear them during the tests. The possible influence of the dentists' age was evaluated by comparing two groups, <40 years (n = 9) and ≥40 years (n = 15), according to EICHENBERGER ET AL. (2011).

The threshold for an acceptable visual performance was defined as 0.05 mm or 20 mm⁻¹ based on the dimension of the finest available endodontic file (ISO 06), which has a tip of 0.06 mm (PERRIN ET AL. 2014A).

Statistical analysis

All analyses were performed with Software R, Version 2.12.1 using the additional packages exactRankTests and nparLD (R-project, Institute for Statistics and Mathematics, University of Vienna, Vienna, Austria). To test the global influence of the location, the optical conditions and the dentists' age, a non-parametric ANOVA model for repeated measurements (i.e. F1_LD_F2 model from BRUNNER ET AL. 2002) was applied. Post-hoc tests were done with exact one-sided Wilcoxon Signed Rank Tests using Holm's correction method (HOLM 1979).

The difference between the performance of the dentists in the two age groups (</≥40 years) was tested using exact Wilcoxon Rank Sum Tests with Holm's correction method.

A difference of one recognized line was considered as equivalent. The recognition of the E-optotype as a structure but not its direction was defined as 5 mm⁻¹ at the canal entrance (large eye chart), and 10 mm⁻¹ inside the canal (small eye charts) according to the dimension of the E-optotype. The level of significance was set at 0.05 for all tests.

Results

The results of the experimental groups were with one exception in the range of the visual test charts. The apical test with Galilean loupes had to be excluded due to the fact that none of the test persons could recognize any chart line.

The triple interaction "optical aid used; age of the examiner; location of the test inside the root canal" was statistically significant (p = 0.04), indicating that all three parameters had a significant influence on dentists' visual acuity in the root canal system. Keplerian loupes with coaxial light had a significantly higher median outcome than Galilean loupes with coaxial light at all locations. Use of a coaxial light source increased significantly the median outcome in all locations for both loupe types (p in all tests <0.01).

The effect of the loupe type and the coaxial light source at the different locations is shown as a boxplot in Fig. 3. While natural vision could not reach the threshold of 0.05 mm at any location the microscope 6× showed highly superior results than all other conditions. The effect of a coaxial light source was strong positive at the location 5 mm inside the canal and weak positive at the canal entrance and the apex.

The results for the two age groups (</≥40 years) are shown as boxplots in Figs. 4 and 5. A statistically significant difference between the age groups was found for Galilean loupes with and without a coaxial light source at the canal entrance

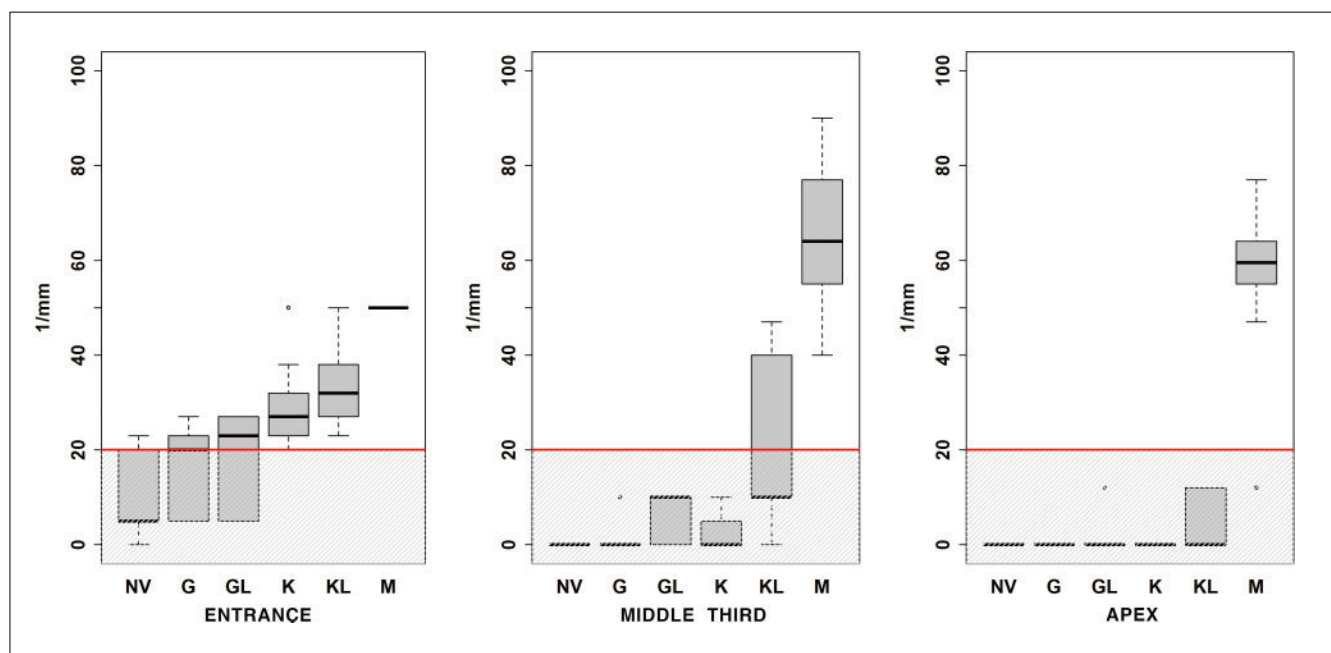


Fig. 3 Visual performance of the 24 test persons at the canal entrance (mb), 5 mm inside the canal (db) and at the apex (p). Natural vision (NV), Galilean loupes 2.5× (G) with coaxial light (GL), Keplerian loupes 4.3× (K) with coaxial light (KL) and microscope 6× (M). The red line marks the threshold of 20 mm⁻¹ corresponding to 0.05 mm or the tip of the smallest endodontic instrument. Note the superior performance of Kepler loupes versus Galilean loupes at all locations and the strong effect of a coaxial light source at position db inside the canal. Natural vision could not reach the threshold of 20 mm⁻¹ at any location.

($p < 0.01$). For Keplerian loupes and for the other locations, no significant differences between the age groups were seen.

The threshold value of 20 mm^{-1} (0.05 mm) was reached at the canal entrance by the younger group (< 40 years) with Galilean loupes and by the older group (≥ 40 years) with Keplerian loupes independent of the light source. Some dentists in the younger group reached the threshold inside the canal when using Keplerian loupes and coaxial light at 5 mm (distobuccal).

For all other conditions inside the canal, the threshold could not be reached with loupes.

Discussion

Galilean and Keplerian loupes are the main two loupe systems used in dentistry (Figs. 6 and 7) (PERRIN ET AL. 2016). Galilean loupes are the most popular due to their light weight, but their magnification factor is limited to $2.5\times$ by physical constraints. Keplerian loupes are sophisticated optical systems with an open

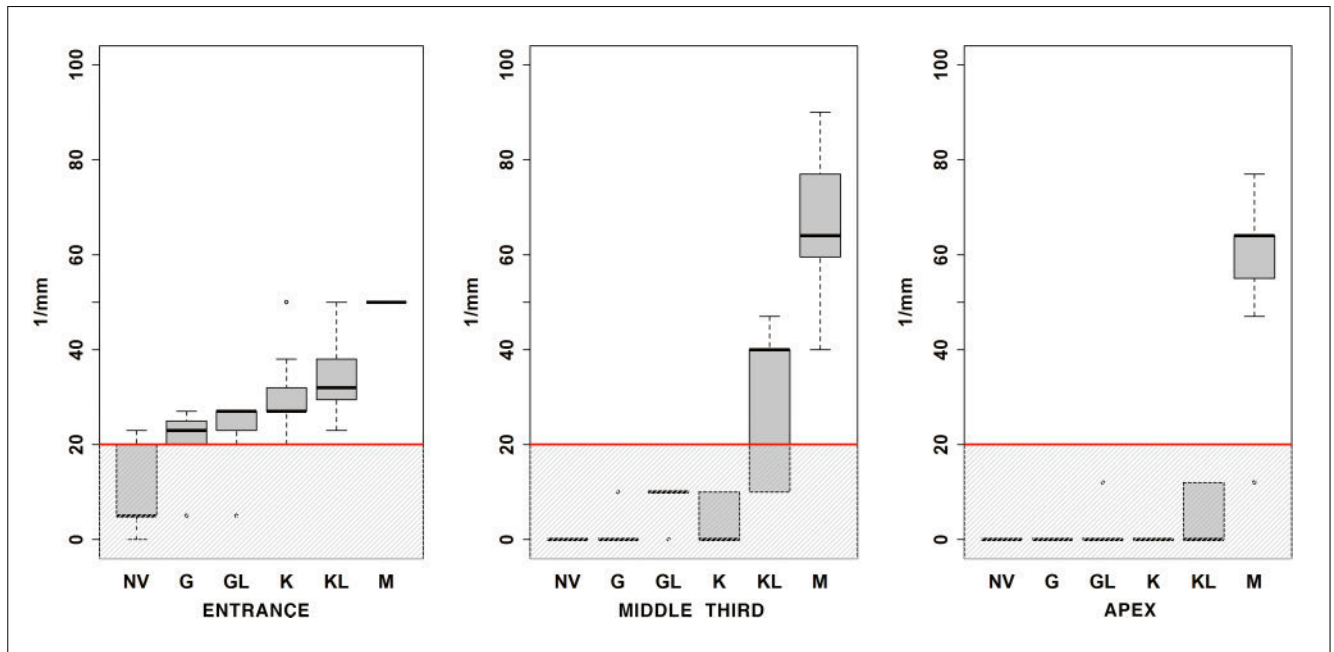


Fig. 4 Visual performance of the group < 40 years at the canal entrance (mb), 5 mm inside the canal (db) and at the apex (p). Natural vision (NV), Galilean loupes $2.5\times$ (G) with coaxial light (GL), Keplerian loupes $4.3\times$ (K) with coaxial light (KL) and microscope $6.4\times$ (M). The horizontal line over the grey area marks the borderline value for a sufficient visual acuity. The younger dentists could reach the threshold at mb when using G or GL and, partly, inside the canal db when using KL. Natural vision was insufficient at all locations.

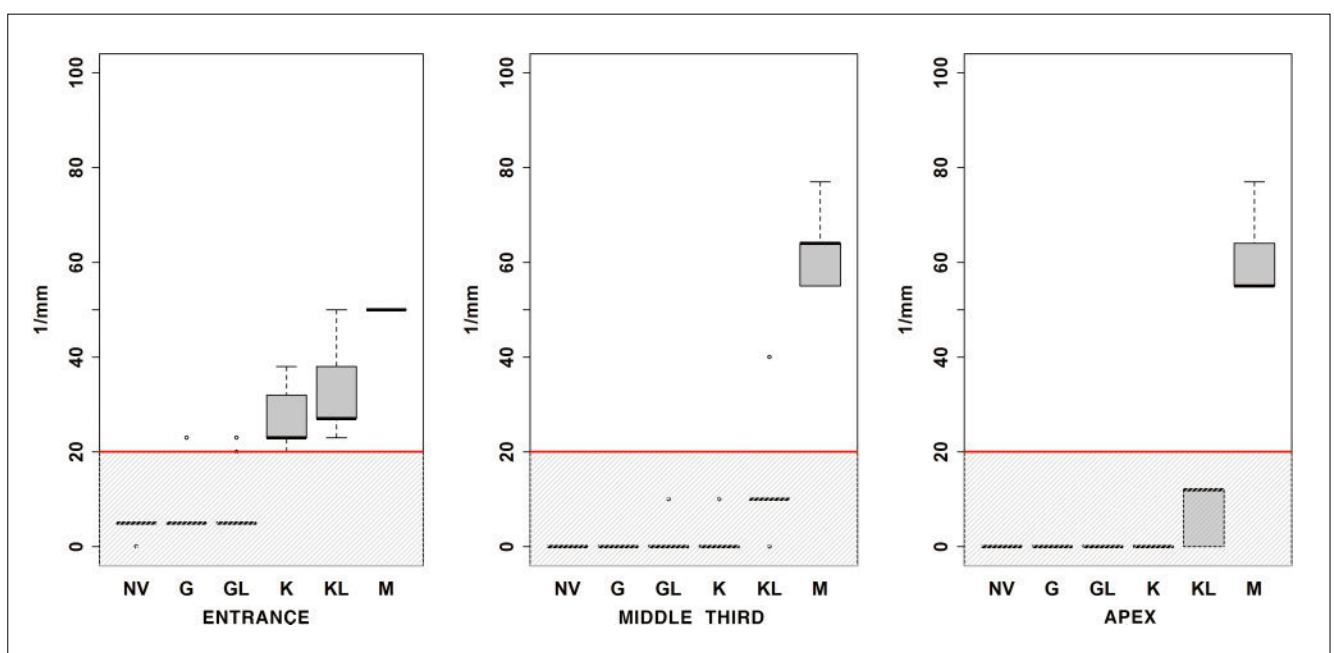
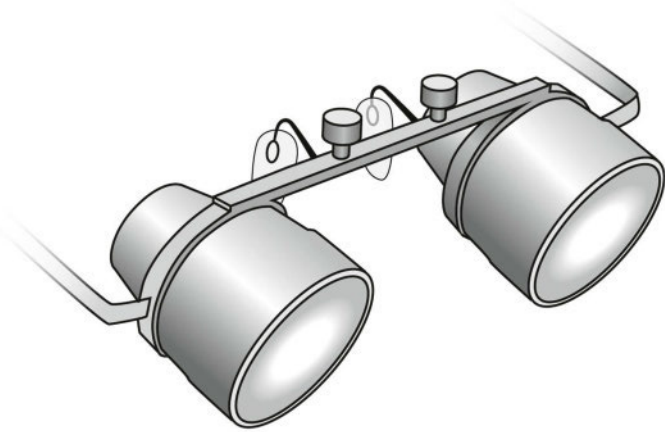
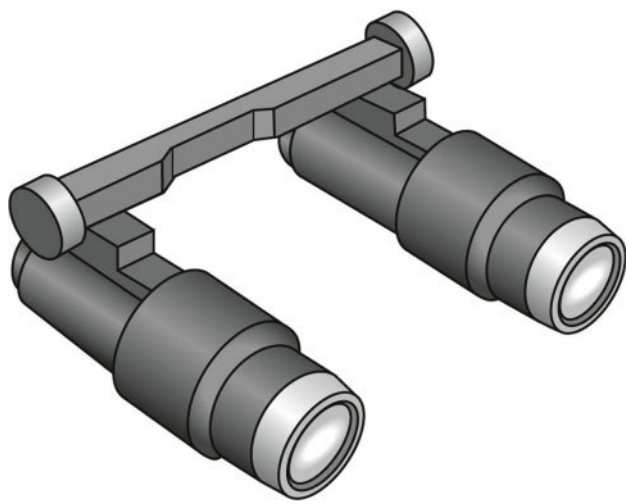


Fig. 5 Visual performance of the group ≥ 40 years at the canal entrance (mb), 5 mm inside the canal (db) and at the apex (p). Natural vision (NV), Galilean loupes $2.5\times$ (G) with coaxial light (GL), Keplerian loupes $4.3\times$ (K) with coaxial light (KL) and microscope $6.4\times$ (M). The horizontal line over the grey area marks the borderline value for a sufficient visual acuity. The older dentists could reach the threshold at mb when using K or KL while NV, G and GL were insufficient at all locations. Notice the unimpaired visual acuity with the microscope at all locations.



2.5x

Fig. 6 Galilean loupe



4.5x

Fig. 7 Keplerian (prismatic) loupe

magnification factor. This factor, however, is generally limited to between 3.5 \times and 4.5 \times for ergonomic reasons. Keplerian loupes are less popular with dentists owing to their heavier weight, but recent studies have revealed their highly superior visual performance compared to Galilean loupes (EICHENBERGER ET AL. 2011, 2013, 2015; PERRIN ET AL. 2014B, 2016). Remarkably, in a recent questionnaire, 74% of Swiss hand surgeons could not explain the difference between Galilean and Keplerian loupe systems (PERRIN ET AL. 2016). It would be worthwhile to find out whether dentists are better informed.

Most of the results from the experimental groups were within the range of the visual tests indicating that the dimension of the respective E-optotypes was adequate. At the canal entrance (mb) we used bigger test charts than inside the canals to include an evaluation of unaided vision and of loupes with a low magnification. Nevertheless, we overestimated the

visual performance of the participants since we found a clustering out of the range of the bar distances in the visual tests. We solved this problem by including an additional value for test subjects who could detect the E-optotype as a structure but could not identify its direction. Additional chart lines with taller optotypes could solve this problem for future studies. However the dimension of the test chart will be limited by the narrow space inside the endodontic cavity. The preparation of the palatal canal until ISO #60 straightened the natural curvature enough to allow a direct vision on the apical test chart. The threshold of 20 mm⁻¹ (0.05 mm) for sufficient visual acuity inside the endodontic lumen can be considered as plausible. The smallest available instruments to pass through a calcified entrance or to fracture inside a canal have a tip of 0.06 mm. For properly performed endodontic treatments this dimension should be detectable.

The influence of the optical aid, the coaxial illumination and the dentists' age on visual performance in the endodontic lumen was highly significant for all three factors.

One would expect that Keplerian loupes, with their higher magnification factor, would be superior to Galilean loupes and this was found to be true for all test locations. The influence of a coaxial light source on the dentists' visual performance was highly significant for both loupe systems at all locations. This can be explained by the narrow shape of the endodontic lumen. The question if the light source has an impact on the required dimension of the access cavity could be a topic of further research. As mentioned above, the apical test with Galilean loupes had to be excluded due to multiple zero results. The results of this study indicate that discrimination between Galilean and Keplerian loupes is important in a clinical context and with respect to the dentists' age.

The results confirm that the operating microscope is the superior option for excellent vision at all endodontic locations. However, Keplerian loupes, particularly when equipped with a coaxial light source, might replace the microscope for endodontic treatments inside the pulp chamber. For young dentists (<40 years) this is also true for the coronal part of the root canal. This statement is based on the objective visual tests conducted in this study and on the proposed visual threshold. Further clinical research would be necessary to verify this finding.

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Zusammenfassung

Einleitung

Die Verwendung von Lupen wird zunehmend als Voraussetzung für eine moderne Zahnmedizin gesehen. Entsprechend häufig gehören vor allem Galilei-Lupen mit Vergrößerungsfaktor 2,5 \times zur Ausrüstung einer zahnärztlichen Allgemeinpraxis. Als Vergrößerungshilfen deutlich weniger verbreitet sind Kepler-(Prismen-)Lupen mit höherem Vergrößerungsfaktor und das Operationsmikroskop. Letzteres gilt heute als Standard für hochwertige Wurzelkanalbehandlungen, insbesondere bei komplexen Fällen. Im Pulparaum ist das Mikroskop im Vergleich zu einer Galilei-Lupe oder dem blossen

Auge deutlich überlegen. Dies hat eine Studie mit miniaturisierten Sehtests im Pulparaum eines natürlichen Zahnes unter simulierten klinischen Bedingungen gezeigt. Offen blieb in dieser Studie, ob eine stärker vergrößernde Kepler-Lupe mit koaxialer Lichtquelle bessere Ergebnisse als die verwendete Galilei-Lupe erzielt hätte und damit das Operationsmikroskop für Wurzelkanalbehandlungen zumindest teilweise ersetzen könnte. Dies wäre aufgrund einer einfacheren Anwendung und geringeren finanziellen Investition grundsätzlich wünschenswert. Es war Ziel dieser Studie, die Wirkung von Galilei- und Kepler-Lupen auf die Detailerkennung im Pulparaum zu vergleichen und zusätzlich den Einfluss einer koaxialen Lichtquelle zu evaluieren.

Material und Methode

Bei 24 Zahnärzten (Alter Mittelwert 40, Median 35, Bereich 27–64 Jahre) wurde mit E-Optotypen-Sehtests innerhalb des Pulpacavums eines extrahierten Molaren (Zahn 26) die Detailerkennung gemessen mit (I) Galilei-Lupe 2,5× und (II) Kepler-Lupe 4,3×, je mit und ohne integrierte Lichtquelle. Als positive beziehungsweise negative Referenz galten die Werte, die in der Studie von PERRIN ET AL. (2014) für das Operationsmikroskop (6×) und für das Sehen mit blossem Auge ermittelt wurden. Drei miniaturisierte Sehtests wurden am Wurzelkanaleingang, 5 mm vom Wurzelkanaleingang entfernt sowie am Apex platziert. Die Messungen wurden unter simulierten klinischen Bedingungen durchgeführt. Als Grenzwert für eine genügende Sicht galt das Erkennen einer Struktur $\leq 0,5$ mm, was der Dimension des kleinsten verfügbaren Endo-Instrumentes (ISO 0,06) entspricht. Analysiert wurde der Einfluss des Alters (< versus ≥ 40 Jahre), des Lupentyps (Galilei versus Kepler) sowie der Lichtquelle (OP-Lampe versus integrierte Lichtquelle) auf die Detailerkennung.

Resultate

Alle drei analysierten Parameter (Alter, Lupe, Licht) hatten einen signifikanten Einfluss auf die Detailerkennung. Zusammengefasst erreichten unter 40-jährige Probanden den geforderten Grenzwert am Wurzelkanaleingang mit einer Galilei-Lupe unabhängig von der Lichtquelle, während Probanden über 40 Jahre dafür eine Kepler-Lupe benötigten. Innerhalb des Wurzelkanals erreichten nur Probanden unter 40 Jahren eine genügende Sicht, dafür brauchten sie aber eine Kepler-Lupe mit integriertem Licht. Der Grenzwert 0,05 mm wurde mit blossem Auge fast nie, mit dem Mikroskop jedoch immer erreicht. Dies war unabhängig vom Alter der Probanden und von der Lokalisation der Sehtests.

Diskussion

Diese Studie zeigt, dass bei der vorliegenden Fragestellung tatsächlich zwischen den in der Zahnmedizin meist verwendeten Galilei-Lupen und den stärker vergrößernden Kepler-Lupen unterschieden werden muss. Kepler-Lupen mit integriertem Licht scheinen vor allem innerhalb der Pulpakammer das Operationsmikroskop bedingt ersetzen zu können, falls ein solches nicht verfügbar ist. Junge Probanden unter 40 Jahren konnten damit Strukturen im Rahmen der kleinsten endodontischen Instrumente auch innerhalb des oberen Kanalteils erkennen. Hingegen sind die gängigen Galilei-Lupen 2,5× für den Einsatz in der Endodontologie weitgehend ungenügend. Dies gilt auch bei Verwendung einer integrierten Lichtquelle. Unabhängig vom Alter der Probanden bleibt das Operations-

mikroskop für die Visualisierung der Wurzelkanäle das Hilfsmittel der Wahl.

Résumé

Introduction

De nos jours, l'utilisation de méthodes de grossissement optique est de plus en plus considérée comme condition indispensable à une médecine dentaire moderne. De ce fait, les aides optiques et en particulier les lunettes-loupes de Galilée au grossissement de 2,5× font désormais partie de l'équipement du cabinet dentaire. Bien moins répandus sont les loupes prismatiques (système de Kepler) à grossissement élevé ainsi que le microscope opératoire. L'utilisation de ce dernier est à présent considérée comme standard pour une endodontie de qualité élevée, en particulier lors de cas complexe. Dans la chambre pulpaire, l'exactitude du microscope opératoire surclasse nettement la précision fournie par des loupes Galilée ou par l'œil nu. Ceci a été démontré dans une étude menée sous conditions cliniques simulées au moyen de tests visuels miniaturisés placés à l'intérieur de la chambre pulpaire d'une dent naturelle. Cette étude reste ouverte à la possibilité que les loupes de type Kepler au fort grossissement et munies d'une source lumineuse coaxiale puissent fournir de meilleurs résultats que les loupes Galilée et pourraient ainsi substituer partiellement le microscope opératoire. Ceci offrirait les avantages d'une utilisation plus simple et d'un investissement moins coûteux. Cette présente étude a pour but de comparer les effets des loupes de Galilée aux loupes de Kepler sur la reconnaissance des détails à l'intérieur de l'espace pulpaire et ainsi que d'évaluer l'influence d'une source lumineuse coaxiale.

Matériel et méthode

L'acuité visuelle de 24 dentistes (âge moyenne 40 ans, médiane 35 ans, étendue 27 à 64 ans) a été mesurée à l'aide de tests visuels à optotypes E placés à l'intérieur de la chambre pulpaire d'une molaire (dent 26) préalablement extraite avec (I) des loupes de Galilée 2,5× et (II) des loupes de Kepler 4,3× à chaque fois avec et sans source lumineuse coaxiale. Les valeurs présentées dans l'étude de PERRIN ET AL. (2014) font office de références positives respectivement négatives pour le microscope opératoire (6×) et la vision à l'œil nu. Trois tests d'acuité visuelle miniaturisés ont été placés respectivement à l'entrée du canal radiculaire, dans le canal à 5 mm de l'entrée de celui-ci ainsi qu'à l'apex. Les mesures se sont déroulées dans des conditions cliniques simulées. La limite d'une acuité suffisante a été déterminée par la reconnaissance d'une structure $\leq 0,5$ mm, ce qui équivaut à la dimension du plus petit instrument utilisé en endodontie (ISO 0,06). L'âge (< versus ≥ 40 ans), le type de loupe (Galilée versus Kepler) ainsi que le type de source de lumière (lampe opératoire versus lumière coaxiale) ont été considérés comme paramètres influençant l'acuité visuelle.

Résultats

Tous les trois paramètres (âge, type de loupe, type lumière) ont montré une influence significative sur l'acuité visuelle. En résumé, les sujets de moins de 40 ans parvenaient à discriminer la valeur limite à l'entrée du canal radiculaire avec des loupes de Galilée indépendamment de la source de lumière, tandis que les sujets de plus de 40 ans nécessitaient des loupes prismatiques type Kepler. À l'intérieur du canal, la valeur limite n'était discriminable que par les sujets de moins de

40 ans lorsqu'ils portaient des loupes de Kepler avec une lumière coaxiale. La limite du 0,05 mm n'a presque jamais été discriminée à l'œil nu. Au contraire, le microscope opératoire l'a permis dans tous les cas. Et cela indépendamment de l'âge du sujet ainsi que de la localisation du test.

Discussion

Cette étude montre l'importance de différencier les populaires loupes de Galilée des loupes de Kepler au plus fort grossissement. Pour les actes à l'intérieur de la chambre pulpaire, il

semble que les loupes prismatiques avec lumière coaxiale pourraient partiellement remplacer un microscope opératoire lorsque celui-ci est inaccessible. À l'aide de celles-ci, les sujets de moins de 40 ans étaient capables de distinguer les structures limites se situant à l'intérieur de la partie coronale du canal. En revanche, les courantes loupes de Galilée 2,5× sont largement insuffisantes pour une utilisation en endodontologie, même lors d'utilisation d'une source de lumière coaxiale. Indépendamment de l'âge du sujet, le microscope opératoire reste le premier choix pour visualiser les canaux radiculaires.

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