

PHILIPPE PERRIN
MARTINA EICHENBERGER
KLAUS W. NEUHAUS
ADRIAN LUSSI

Clinic for Restorative, Preventive and Pediatric Dentistry,
University of Bern, Bern

CORRESPONDENCE

Dr. med. dent. Philippe Perrin
Clinic for Restorative, Preventive and Pediatric Dentistry
Freiburgstrasse 7
CH-3010 Bern
Switzerland
Tel. +41 31 632 25 70
Fax +41 31 632 98 75
E-mail: philippe.perrin@zmk.unibe.ch

SWISS DENTAL JOURNAL SSO 126:
222–228 (2016)
Accepted for publication:
14 March 2015

Visual acuity and magnification devices in dentistry

A review

KEYWORDS

near vision test,
magnification,
loupe,
microscope

SUMMARY

This review discusses visual acuity in dentistry and the influence of optical aids. Studies based on objective visual tests at a dental working distance were included. These studies show dramatic individual variation independent of the dentists' age. The limitations due to presbyopia begin at an age of 40 years. Dental professionals should have their near vision tested regularly. Visual deficiencies can be compensated with magnification aids. It is important to differentiate between Galilean and Keplerian loupes. The light-weight Galilean loupes allow an almost straight

posture and offer improved ergonomics. Younger dentists profit more from the ergonomic aspects, while dentists over the age of 40 can compensate their age-related visual deficiencies when using this type of loupe. Keplerian loupes, with their superior optical construction, improve the visual performance for dentists of all age groups. The optical advantages come at the cost of ergonomic constraints due to the weight of these loupes. The microscope is highly superior visually and ergonomically, and it is indispensable for the visual control of endodontic treatments.

Introduction

Magnifying optical aids are part of the basic equipment in microsurgery, and have for more than a century allowed watch- and clockmakers to do their very precise work. The empirical finding that the precision of fine motor skills is limited more by the eyes than the hands is equally old. The proper use of loupes or surgical microscopes in dentistry has made its way into the curriculum of many universities over the past few years, and is also strongly promoted by the manufacturers. Thus, magnifying aids are becoming increasingly more common in dental practices (MERANER & NASE 2008, FAROOK ET AL. 2013, EICHENBERGER ET AL. 2015). Almost everyone using loupes and microscopes is convinced that these instruments have advantages and improve

both the quality and ergonomics of their work (MERANER & NASE 2008, EICHENBERGER ET AL. 2015). The discrepancy between these subjective impressions and the scientific evidence is, however, blatant. The relevant dental literature is mostly limited to case reports, overview articles or expert opinions, thus hardly qualifying as so-called external evidence (VAN GOGSWAARDT 1990, SYME ET AL. 1997, MILLAR ET AL. 1998, PERRIN ET AL. 2000, FORGIE ET AL. 2001, FRIEDMAN 2004, JAMES & GILMOUR 2010). Additionally, the few existing, relevant studies in endodontology, caries diagnostics, and restorative dentistry are partially contradictory (LUSSI ET AL. 1993, HAAK ET AL. 2002, LUSSI ET AL. 2003, ZAUGG ET AL. 2004, ERTEN ET AL. 2005, TZANETAKIS ET AL. 2007, MENDES ET AL. 2006, KEINAN ET AL. 2009, KOTTOOR ET AL. 2010, MITROPOULOS ET AL. 2012).

Obviously, this has methodological reasons as well, because for many years, there were no adequate near vision tests for dental needs (EICHENBERGER ET AL. 2011). Therefore, it was only indirectly possible to draw conclusions about visual acuity and the influence magnification aids had on it from such studies. The only exception is a study from New Zealand, where normal-sized eye charts were shrunk in a device using additional lenses, and the near vision of a group of dentists and dental students was determined (BURTON & BRIDGMAN 1990). A disadvantage of this method is that it cannot be transferred to the clinical situation.

In a series of current studies, novel, miniaturized eye tests for dentistry were validated (EICHENBERGER ET AL. 2011). They revealed considerable differences between the visual acuity of the tested dentists – under standardized as well as clinical conditions – and a significant influence of presbyopia (EICHENBERGER ET AL. 2013, PERRIN ET AL. 2014A, PERRIN ET AL. 2014B, EICHENBERGER ET AL. 2015).

The aim of this literature review is to summarize the most important findings of scientific studies on visual acuity in dentistry using objective near vision tests. The terms relevant for the present overview can be found in the glossary in Table I.

Materials and methods

A literature search for the period from 1950 to May 2015 was conducted in the PubMed database using the key words “visual acuity and dentistry” and “near vision test and dentistry”. The criterion for inclusion was that the participants had to have taken a vision test at dental working distance. Only original papers were evaluated and discussed. Additionally, a manual search of the references of the included original papers was conducted. A few

publications that did not meet the inclusion criterion were included in the review to provide more insight on the subject.

Results

The PubMed literature search yielded a total of 228 papers (Fig. 1). After eliminating the titles that occur twice, 223 publications remained, of which 200 papers deviated from the topic of the review. Of the 23 abstracts, eight literature reviews and seven papers lacking a near vision test were excluded. Of the eight remaining articles, five met the inclusion criterion of having conducted a near vision test. One of these papers was by a research team from New Zealand (BURTON & BRIDGMAN 1990), the other four publications were from our own research group (EICHENBERGER ET AL. 2011, EICHENBERGER ET AL. 2013, PERRIN ET AL. 2014A, PERRIN ET AL. 2014B).

Discussion

Near vision test

For measuring the visual acuity at dental working distance, enough small vision tests are mandatory to obtain the full range of results. This is impossible using the classic near vision tests, due to the limitations of the traditional technique of letterpress printing (RAWLINSON 1988, RAWLINSON 1993, FORGIE ET AL. 2001). Therefore, one condition for valid studies on dentists’ visual acuity and the influence of magnification aids is the development of miniaturized eye test-s of an adequate dimension. Burton and Bridgman minimized an eye chart through suitable lenses, thus enabling evaluation of the near vision test at dental working distance (BURTON & BRIDGMAN 1990). As mentioned, however, the clinical situation cannot be simulated using this technique.

Tab. I Glossary with relevant terms on visual acuity and magnification aids

<p>Visual acuity: Threshold of the ability to perceive fine details of an object, the perceptibility of which depends on the angle of view (GOERSCH 2004). The value can be determined by a visual test and refers to the angle of the incident rays, is dimensionless, and does not depend on the viewing distance. The reciprocal value increases with higher acuity.</p>
<p>Detail detection: Detail detection refers to the distance of separately perceived structures as a linear dimension. The value is directly dependent on the viewing distance: the smaller the distance, the larger the image (linear) and the light quantity (squared). The reciprocal dimension of the perceived structure increases with higher detail detection (mm⁻¹).</p>
<p>Accommodation: Process by which the eye changes optical power to focus on an object.</p>
<p>Presbyopia: Presbyopia is characterized by a progressive loss of accommodation width caused by sclerosis of the eye lens, increased glare sensitivity and decreased contrast sensitivity. Presbyopia first occurs around age 40 (GILBERT 1980, WOO & ING 1988, POINTER 1995, EICHENBERGER ET AL. 2011); often, however, it is only discovered and corrected years later, when it poses limitations in daily life.</p>
<p>Single-lens loupe: The single-lens loupe is the simplest and most cost-efficient type of loupe. For optical reasons, the distance to the object decreases with increasing magnification. From factor 2× on, this results in ergonomic problems in dentistry.</p>
<p>Galilean loupe: Galilean loupes are the most common type of loupe in dentistry. They have a typical conical shape. The optical system consists of a combination of convex and concave lenses, the working distance of which can be adjusted to the given ergonomic needs. Although the magnification factor is physically limited to 2.5×, it is possible to reach a higher magnification of up to 3.5×, albeit with optical compromises (limited field of vision, blurring around the edges).</p>
<p>Keplerian (prismatic) loupes: These are characterized by their cylindrical shape. Keplerian loupes consist of a complex convex optic system of lenses and prisms. This system allows various magnifications and working distances. The preferred range of magnification in dentistry is between 3.5× and 6×, in order to minimize the influence of the limited depth of focus. The considerable optical advantage over Galilean loupes is offset by greater weight and higher price.</p>
<p>Surgical microscope: Various magnification settings and orthograde illumination of the working area. Due to the depth of focus and overview, the most common magnification used in dentistry is between 4× and 10×. The working distance is adjusted to the height of the surgeon by the choice of objective. The surgical microscope has important ergonomic advantages based on the upright sitting position (back and cervical vertebrae) the surgeon can adopt, and the fatigue-proof, parallel line of view without accommodation.</p>

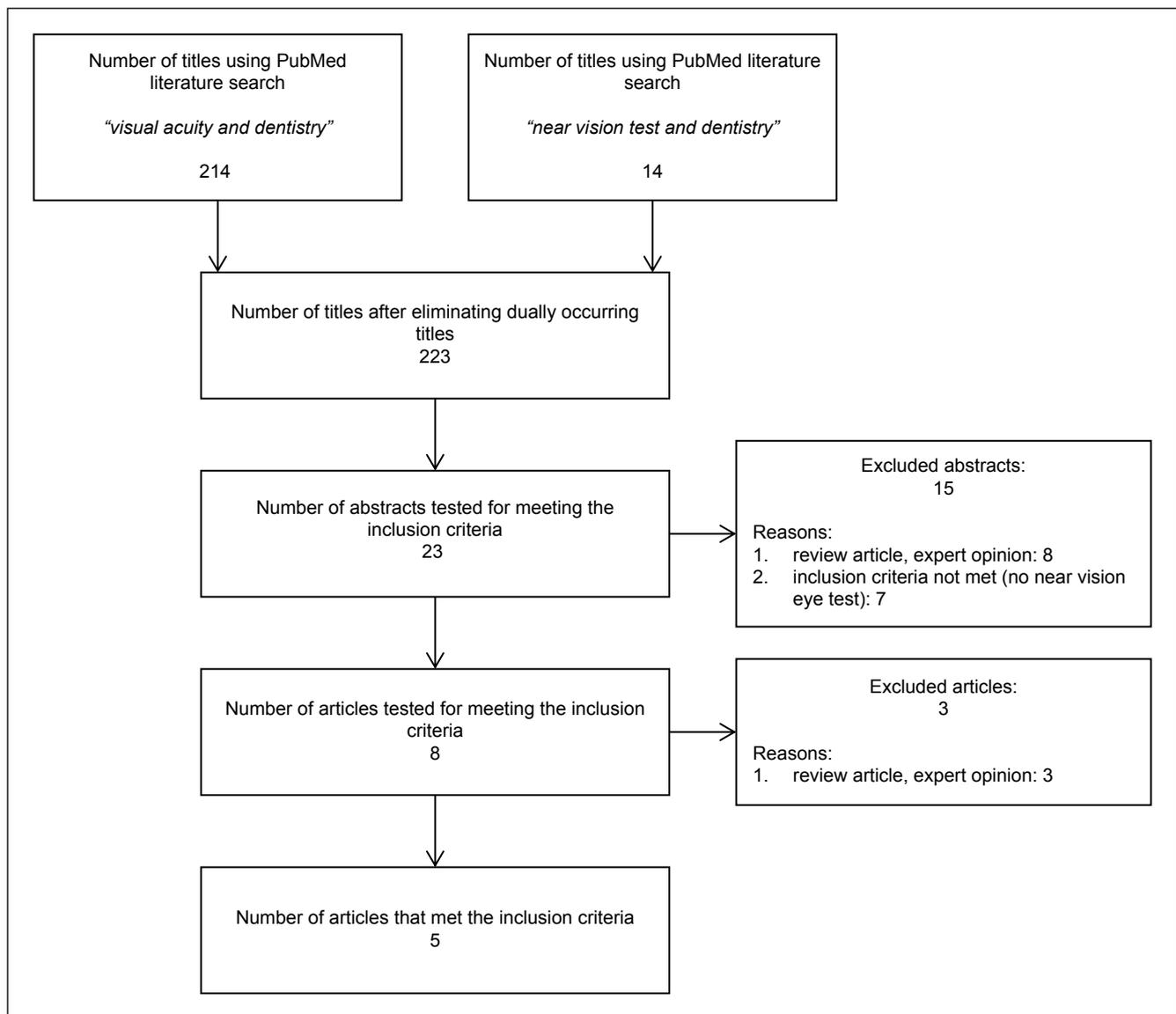


Fig.1 Flow chart of the PubMed literature search

A simulation of the clinical situation is possible using diapositive films (EICHENBERGER ET AL. 2011, EICHENBERGER ET AL. 2013, PERRIN ET AL. 2014A, EICHENBERGER ET AL. 2015). With a standardized imaging technique, eye charts – even those with multiple lines in a single millimeter – can be depicted in defined sizes on such slides. The eye charts are transparent, and can be used with transmitted light at a fixed distance of 30 cm above the negatoscope (Fig. 2). In this manner, they provide standardized conditions to determine individual near-visual acuity, as well as the influence of age and magnification aids (EICHENBERGER ET AL. 2011, PERRIN ET AL. 2014B). The miniaturized eye charts can also be cut out, fixed on a white background, and placed in a tooth cavity of a dental phantom head (Fig. 3). Thus, vision tests can be conducted intraorally at the actual, clinically relevant location of interest (Fig. 4) (EICHENBERGER ET AL. 2013, PERRIN ET AL. 2014A, EICHENBERGER ET AL. 2015). Here it is not the visual acuity that is clinically relevant, but the question of whether or not a certain structure can be recognized under the given circumstances. This recognition of detail is defined by a series of variables. While the working distance, visual aids, and light source can be defined, the intraoral lighting conditions, for

example, are influenced by the positioning of the mirror, the exact location of the test, and by possible light reflection.

Influence of the individual

Standardized measurements at dental working distance were conducted with more than 300 dentists using the previously mentioned miniaturized eye charts (EICHENBERGER ET AL. 2011, EICHENBERGER ET AL. 2013, PERRIN ET AL. 2014B). Using corrective eyeglasses, if necessary, without magnification aids always showed similar results: the detection of detail, meaning the dimension of the smallest detected structure, varied by a magnitude of 250%–300% independent of age or whether the person came from a university or a private practice. This means that there were dentists or students in each measured group who could discern 2–3 times smaller structures than others (EICHENBERGER ET AL. 2011, EICHENBERGER ET AL. 2013, PERRIN ET AL. 2014B). Using a questionnaire, it became clear that a significant number of the test persons were not in any way aware of their vision deficits. About a third (32%) of the test persons with near-visual acuity below the median of the group was convinced they had normal to very good visual acuity as a dentist

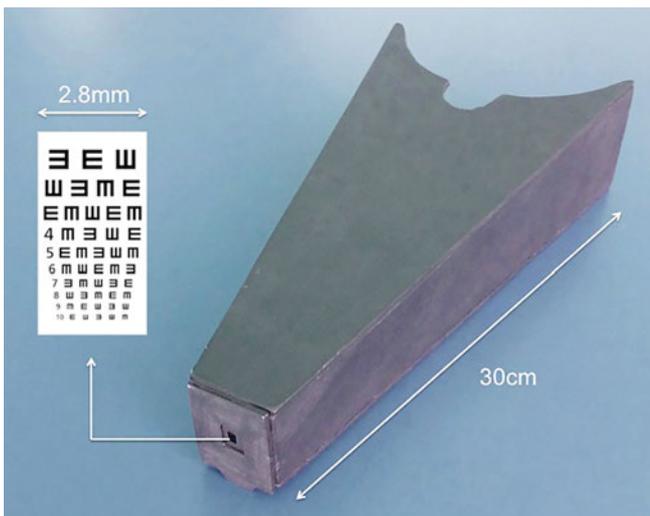


Fig. 2 The transparent visual test is located at the tip of a funnel and is used over the negatoscope for the standardized assessment of near vision.



Fig. 4 Simulations of the clinical situation with the dental phantom head as a "patient"



Fig. 3 To simulate the clinical situation, the eye chart can be attached inside the tooth cavities of a dental phantom head.

(EICHENBERGER ET AL. 2015). This conviction was especially common in dentists over the age of 40.

Influence of age

Presbyopia is associated with limited accommodation, an increased need for light, decreased sensitivity to contrast, and increased sensitivity to glare (GILBERT 1980, WOO & ING 1988, POINTER 1995). These limitations begin at about 40 years of age, which was confirmed by the previously mentioned studies using the miniaturized eye charts (EICHENBERGER ET AL. 2011, EICHENBERGER ET AL. 2013, PERRIN ET AL. 2014B). Burton and Bridgman conducted a standardized, optically minimized vision test at working distances of 25 and 33 cm with 172 dentists and dental students (BURTON & BRIDGMAN 1990). A definite decline in near-visual acuity with increasing age was verified in this study: 96% of the test persons with insufficient test results were over 45 years old. Additionally, older dentists chose a significantly greater working distance than did the students (BURTON & BRIDGMAN 1990).

Presbyopia is often only noticed when it complicates everyday life, especially when it comes to reading small print. The dimension of small print, however, is much greater than the

dimensions relevant for dentistry. Therefore, age-related visual deficiencies in quotidian dental routine often go unnoticed for years. Accordingly, the mentioned self-evaluation using a questionnaire showed that those over the age of 40 often overestimated their own visual acuity (EICHENBERGER ET AL. 2015).

To check smaller details, the working distance is reduced (if possible), thus making use of natural magnification via physical proximity. Hence, the effects of presbyopia on clinical routine were most evident with only corrective eyeglasses and having free choice of working distance (Fig. 5) (EICHENBERGER ET AL. 2013). Whether or not an increase in depth of focus and a lens-like effect of compressed tear fluid caused by squinting influence near vision was not the subject of present study, but could nonetheless be an interesting question for future studies.

The following sections address the options for compensation of presbyopia using magnification devices.

Influence of magnification devices

Are all loupes the same?

The range of available loupes is wide and difficult for laymen to comprehend. However, knowledge of the categorization into single-lens loupes, Galilean loupes, and Keplerian (prismatic) loupes is fundamental (see Glossary, Tab.I). When choosing a loupe, there is always a trade-off between optics and ergonomics: a brilliant, greatly enlarged image entails additional weight, less depth of focus, and a limited field of vision. This relationship is due to laws of physics and cannot be avoided. Loupe manufacturers are suspected of exaggerating the magnification of their loupes for marketing reasons and seem to offer a larger field of vision and better depth of focus than their competitors at the same degree of magnification.

To clarify this question, loupes from different manufacturers were compared at a university of applied sciences (NTB, Buchs, Switzerland) (NEUHAUS ET AL. 2013). The spectrum of optical properties was, as expected, wide (Fig. 6). The discrepancies between the declared and the effective degree of magnification, especially of the Galilean loupes, were dramatic. For example, a loupe from a renowned manufacturer, said to have a magnification of 2.8 \times , merely had one of 2.2 \times . As a matter of fact, none of the tested Galilean loupes actually had the magnification factor claimed by the manufacturer.

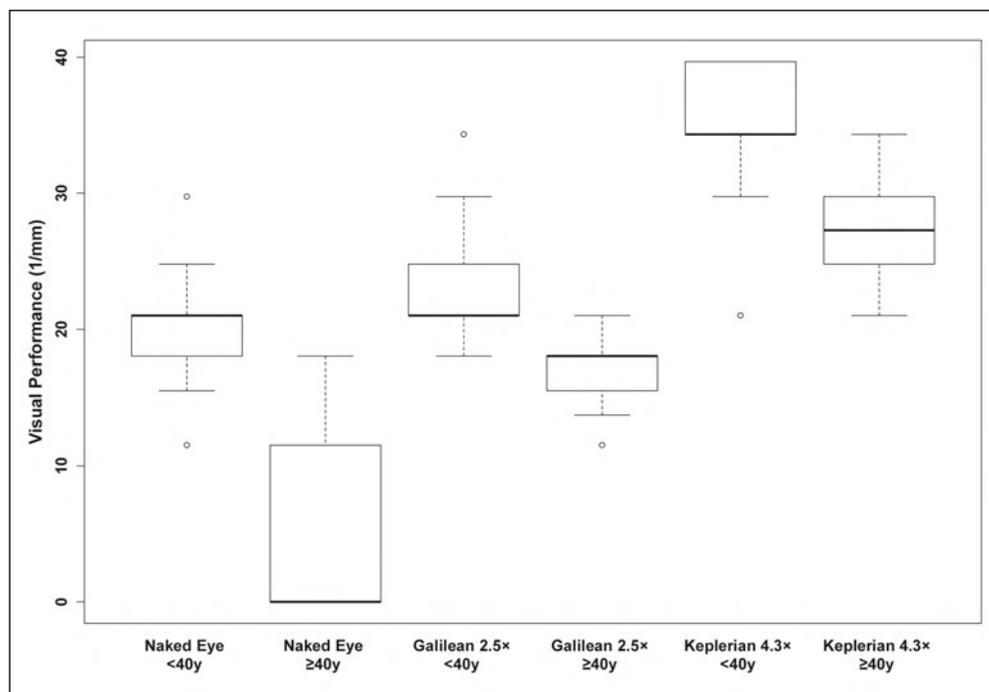


Fig. 5 Recognition of details in the clinical situation with the dental phantom head. The working distance when working with the naked eye could be chosen freely; when working with loupes, it depended on the focal length. The difference between the age groups of < versus ≥ 40 years of age (when working with the naked eye) is remarkable. The influence of the age was lower when working with the Galilean or Keplerian loupes. The detail detection of dentists <40 years of age with the naked eye and a freely chosen working distance could only be slightly improved using the Galilean loupes, due to the larger working distance. The visual deficits of the dentists of ≥ 40 years of age could largely be compensated by the Galilean loupes. In general, the Keplerian loupes allowed significantly better detail detection in both age groups (EICHENBERGER ET AL. 2013). y = years.

Meanwhile, a very simple optical test is available that can determine the actual factor of magnification of Galilean loupes (www.meridentoptergo.com/Liitetiedostot/Chart%20MO_13-03-26.pdf): the Galilean loupe is held upside down above a pattern of parallel lines which must be aligned. This allows the effective factor of magnification to be determined. It must be mentioned, however, that an inaccurately declared factor of magnification says nothing about the optical quality of the loupe. This manifests itself especially on the edges of the field of vision (Fig. 6).

Galilean versus Keplerian (prismatic) loupes

Overall, the use of loupes led to improved visual acuity in all of the test groups (EICHENBERGER ET AL. 2011, EICHENBERGER ET AL. 2013, PERRIN ET AL. 2014A, PERRIN ET AL. 2014B). According to our findings, Galilean loupes, however, offered mainly ergonomic advantages for younger test persons, whereas they can almost completely compensate presbyopia in the group ≥ 40 years of age. Keplerian loupes are far superior to the Galilean loupes (EICHENBERGER ET AL. 2011, EICHENBERGER ET AL. 2013, PERRIN ET AL. 2014B). They enable significantly better detail detection in all age groups by a magnitude of 200% to 400% compared to the naked eye (Fig. 5) (EICHENBERGER ET AL. 2013). This is due to the greater factor of magnification on the one hand, and on the other hand to the superior optical properties of the Keplerian loupes compared to the Galilean systems (EICHENBERGER ET AL. 2011).

Surgical microscope

Using the miniaturized eye charts in tooth cavities, the vision of dentists using a surgical microscope was tested (EICHENBERGER ET AL. 2013). Based on their dimensions, the eye charts used were adequate for magnifications of 4 \times and 6.4 \times . Higher magnifications – common in fact, when working clinically with the surgical microscope – could not be evaluated. Even though the examined magnifications were within the range of the Keplerian loupes, detail detection was significantly higher using the



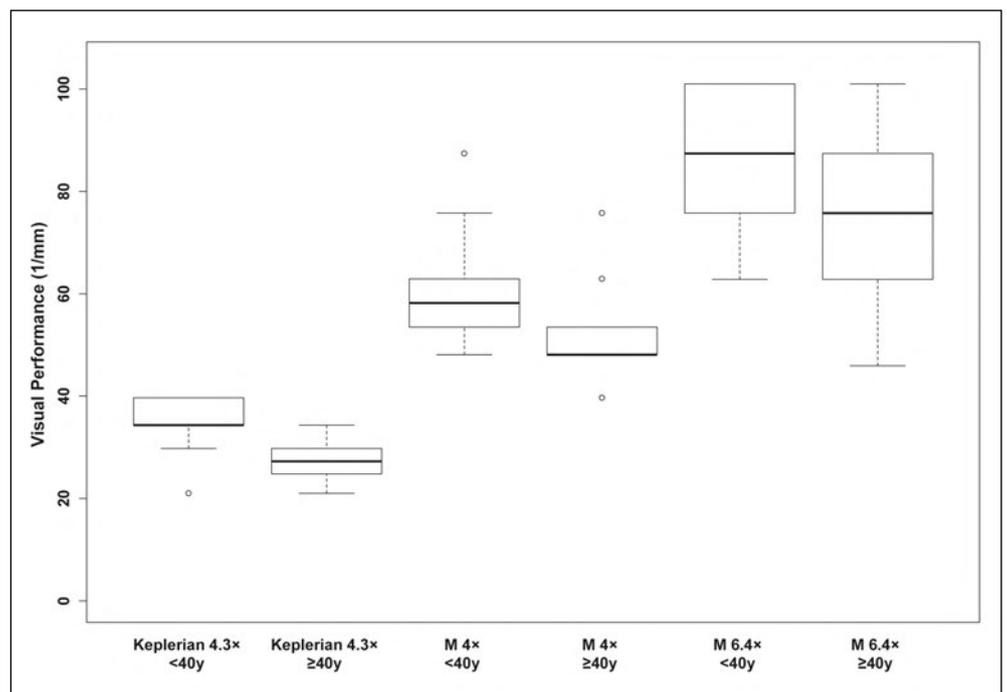
Fig. 6 The objective examination of the different types of loupes used in dentistry, conducted at a university of applied sciences, showed that there were large differences between the tested loupes. The same grid was photographed through one Galilean loupe (declared 2.8 \times ; left) and two Keplerian loupes (declared 3.5 \times and 3.6 \times ; center and right, resp.). The relationship between field of vision and factor of magnification (left and right) is apparent, as well as the obvious difference in quality within a similar factor of magnification (center and right). In most of the loupes, a discrepancy between the declared and the actual factor of magnification was found (NEUHAUS ET AL. 2013).

surgical microscope under clinical conditions (Fig. 7). Whether the reason for this superiority can be found in the completely static positioning of the microscope, i.e., it is not disturbed by the tremor of the head, or in the differences in optical construction remains unclear and can be the subject of further studies.

Influence of presbyopia on the effect of magnification aids

The age-dependent differences decreased with increasing optical quality of the loupes, and were almost nonexistent when using the microscope (Figs. 5 and 7) (EICHENBERGER ET AL. 2013, PERRIN ET AL. 2014A). Test persons ≥ 40 years of age recognized the same structures with a 2.5 \times Galilean loupe as younger subjects did with the naked eye (Fig. 5) (EICHENBERGER ET AL. 2013). Thus, presbyopia can be easily compensated using loupe glasses. The detail detection of young test persons in clinical situations was, on the other hand, hardly increased using a Galilean loupe (Fig. 5) (EICHENBERGER ET AL. 2013). The reason for these repeatedly confirmed findings is the loss of the previously mentioned natural magnification by physical proximity; for ergonomic reasons, a relatively large working distance is chosen, and physical proximity to the patient is prohibited by the focal

Fig. 7 The age differences in detail detection between the Keplerian loupes and the surgical microscope are slight. The increase in detail detection when using the microscope even with a small magnification factor is remarkable (EICHENBERGER ET AL. 2013).
y = years; M = microscope



length of the magnifying glass. Keplerian loupes and microscopes led to a better detection of detail, thanks to their higher factor of magnification and their advantages in optics for all age groups (Figs. 5 and 7) (EICHENBERGER ET AL. 2013).

The special case of endodontics

Although the attempt is always made to illuminate the tooth cavity as much as possible during dental treatment, it is practically impossible to illuminate root canals. Hence, endodontic treatments are the only dental procedures that take place almost completely in the dark. They are dominated by experience, tactile sense, and radiographic diagnostics. For more than two decades now, the surgical microscope – with its variable magnification and orthograde illumination – has been promoted as a milestone in endodontology. It enables visualization of the pulp chamber and endodontic treatment with visibility (CARR 1992, VELVART 1996). The literature contains a controversial discussion as to whether or not this is also possible using loupes. Therefore, a retrospective study using 312 clinical cases compared the frequency with which a second mesio-buccal canal was found in maxillary molars, depending on whether the naked eye (18%), a loupe (55%), or a surgical microscope (57%) was used (BURLEY ET AL. 2002). The indirect conclusion that can be drawn on the effect of the magnification indicates a highly significant influence, although to the same extent for loupes and microscopes. Another study on finding second mesio-buccal canals in maxillary molars compared a loupe with a 2.5× magnification to the surgical microscope with a magnification of 8× (SCHWARZE ET AL. 2002). One hundred extracted and opened molars were examined first with the loupe and later with the microscope. Using the loupe, 41% of the histologically existing canals were identified, and using the surgical microscope 94% were identified. The difference was highly significant.

To objectively answer the question of visualization for endodontic treatments, a study was conducted where the previously described miniaturized eye charts were glued into the

root canals of an extracted tooth: mesio-buccally at the canal entrance, distal-buccally at a depth of 5 mm, and palatally to the apex (PERRIN ET AL. 2014A). The tooth was attached in a phantom head on a dental chair, as described above, and the vision tests were conducted under various optical conditions: A) facultative corrective eyeglasses, freely selected distance, and a surgical lamp, B) Galilean loupe 2.5× with an integrated light source, C) surgical microscope 6×. Twenty-six dentists between the ages of 27 and 60 took part in the study. The size of the smallest endodontic instrument (file tip 06) was used as the limit for sufficient visibility (PERRIN ET AL. 2014A). Inside the root canal, only the surgical microscope provided sufficient visualization; this was the case for all test persons, independent of age. At the entrance of the root canal, the dimension 0.06 mm could be detected by dentists <40 years of age using a Galilean loupe and light; older dentists ≥40 years needed the surgical microscope also for this location. Some yet to be published results show that using a Keplerian loupe with higher factor of magnification (4.3×), all subjects from the older age group (≥40 years) were also able to meet the 0.06 mm requirement at the canal entrance. Within the root canal, however, even these loupes do not provide sufficient visibility. Whether this is due to insufficient magnification or lighting remains unanswered by this study. The detail detection with the microscope was dependent neither on the localization of the eye charts nor on the age of the test person.

Using the miniaturized eye chart in the root canal system, it was possible to objectively show the special importance of the surgical microscope in endodontology under simulated clinical conditions. For finding canal entrances it can partially be replaced by loupes.

Light and ergonomics

Light as an influence on the visibility in the generally dark oral cavity was not the subject of this review. It must, however, be assumed that the lighting has a relevant and age-dependent influence on the vision of dentists.

The ergonomic advantages of magnification aids in terms of working distance and posture are pointed out regularly. This aspect was also not examined in the studies analyzed here. Nevertheless, it must be noted that these possible advantages have to be discussed at least in the case of loupes, due to the limited range of motion and simultaneously tilted position of the head.

Conclusion

The visual acuity of dentists varies greatly under clinical conditions and should be checked regularly. Attention must be paid especially to the early onset of presbyopia around the age of 40. Loupes can easily compensate visual deficits. The factor of magnification declared by the manufacturer can deviate from the actual factor of the loupe. The surgical microscope enables excellent detection of detail even at lower magnifications. Whether the better detection of details improves the clinical prognosis of dental work has not been scientifically proven and should be investigated further. The influence of lighting and the role played by ergonomics in dentists' vision should also be examined in future studies.

Résumé

Cet aperçu bibliographique résume l'acuité visuelle en médecine dentaire et l'influence d'aides optiques. La recherche littéraire s'appuyait sur des études se basant sur des tests visuels objectifs et à distance de travail dentaire. Ces études montrent une acuité visuelle très variable et une influence importante de l'âge du dentiste. Les altérations presbytes de l'œil sont inévitables, ceux-ci causent des déficits visuels qui commencent à l'âge de 40 ans. Il est indispensable de tester régulièrement l'acuité visuelle, si possible en distance de travail.

Une restriction visuelle peut être facilement compensée par des aides optiques. Les loupes se partagent en systèmes Galilée et Kepler. Les loupes Galilée sont légères et ergonomiques, mais plus faibles du côté optique que les systèmes Kepler. Elles permettent une posture droite et, après l'âge de 40 ans, la compensation de l'acuité visuelle au niveau d'un jeune dentiste. Les loupes Kepler augmentent, grâce à leur optique sophistiquée, la vision à tous âges, au coût d'être plus lourdes. Le microscope opératoire fascine par une visualisation parfaite pour tous les traitements; il est d'ailleurs indispensable dans le domaine de l'endodontie.

Bibliography

- BURTON J F, BRIDGMAN G F:** Presbyopia and the dentist: the effect of age on clinical vision. *Int Dent J* 40: 303–312 (1990)
- BURLEY L J, BARROWS M J, BEGOLE E A, WENCKUS C S:** Effect of magnification on locating the MB2 canal in maxillary molars. *J Endod* 28: 324–327 (2002)
- CARR G B:** Microscopes in endodontics. *J Calif Dent Assoc* 20: 55–61 (1992)
- EICHENBERGER M, PERRIN P, NEUHAUS K W, BRINGOLF U, LUSSI A:** Influence of loupes and age on the near visual acuity of practicing dentists. *J Biomed Opt* 16: 035003 (2011)
- EICHENBERGER M, PERRIN P, NEUHAUS K W, BRINGOLF U, LUSSI A:** Visual acuity of dentists under simulated clinical conditions. *Clin Oral Investig* 17: 725–729 (2013)
- EICHENBERGER M, PERRIN P, RAMSEYER S T, LUSSI A:** Visual acuity and experience with magnification devices in Swiss dental practices. *Oper Dent* doi:10.2341/14–103–C (2015)
- ERTEN H, UCTASLI M B, AKARSLAN Z Z, UZUN O, BASPINAR E:** The assessment of unaided visual examination, intraoral camera and operating microscope for the detection of occlusal caries lesions. *Oper Dent* 30: 190–194 (2005)
- FAROOK S A, STOKES R J, DAVIS A K, SNEDDON K, COLLYER J:** Use of dental loupes among dental trainees and trainees in the UK. *J Investig Clin Dent* 4: 120–123 (2013)
- FORGIE A H, GEARIE T, PINE C M, PITTS N B:** Visual standards in a sample of dentists working within Scotland. *Prim Dent Care* 8: 124–127 (2001)
- FRIEDMAN M J:** Magnification in a restorative dental practice: from loupes to microscopes. *Compend Contin Educ Dent* 25: 48, 50, 53–55 (2004)
- GILBERT J A:** The dentist and the aging eye. *J Mo Dent Assoc* 60: 22–24 (1980)
- GOERSCH H:** Wörterbuch der Optometrie. 3. Aufl., Optische Fachveröffentlichung GmbH, Heidelberg (2004)
- HAAK R, WICHT M J, HELLMICH M, GOSSMANN A, NOACK M J:** The validity of proximal caries detection using magnifying visual aids. *Caries Res* 36: 249–255 (2002)
- JAMES T, GILMOUR A S:** Magnifying loupes in modern dental practice: an update. *Dent Update* 37: 633–636 (2010)
- KEINAN D, NUNI E, SLUTZKY-GOLDBERG I:** Is a C-shaped configuration possible in teeth other than mandibular molars? *Quintessence Int* 40: 541–543 (2009)
- KOTTOOR J, VELMURUGAN N, SUDHA R, HEMAMALATHI S:** Maxillary first molar with seven root canals diagnosed with cone-beam computed tomography scanning: a case report. *J Endod* 36: 915–921 (2010)
- LUSSI A:** Comparison of different methods for the diagnosis of fissure caries without cavitation. *Caries Res* 27: 409–416 (1993)
- LUSSI A, KRONENBERG O, MEGERT B:** The effect of magnification on the iatrogenic damage to adjacent tooth surfaces during class II preparation. *J Dent* 31: 291–296 (2003)
- MENDES F M, GANZERLA E, NUNES A F, PUIG A V, IMPARATO J C:** Use of high-powered magnification to detect occlusal caries in primary teeth. *Am J Dent* 19: 19–22 (2006)
- MERANER M, NASE J B:** Magnification in dental practice and education: experience and attitudes of a dental school faculty. *J Dent Educ*, 72, 698–706 (2008)
- MILLAR B J:** Focus on loupes. *Br Dent J* 185: 504–508 (1998)
- MITROPOULOS P, RAHIOTIS C, KAKABOURA A, VOUGIOUK-LAKIS G:** The impact of magnification on occlusal caries diagnosis with implementation of the ICDAS II criteria. *Caries Res* 46: 82–86 (2012)
- NEUHAUS K W, PERRIN P, LUSSI A:** Substantial difference between declared and real magnification in medical loupes. *Medical Instrumentation* 1: 1–3 (2013)
- PERRIN P, JACKY D, HOTZ P:** [The operating microscope in dental general practice]. *Schweiz Monatsschr Zahnmed* 110: 946–960 (2000)
- PERRIN P, NEUHAUS K W, LUSSI A:** The impact of loupes and microscopes on vision in endodontics. *Int Endod J* 47: 425–429 (2014A)
- PERRIN P, RAMSEYER S T, EICHENBERGER M, LUSSI A:** Visual acuity of dentists in their respective clinical conditions. *Clin Oral Investig* 18: 2055–2058 (2014B)
- POINTER J S:** The presbyopic add. II. Age-related trend and a gender difference. *Ophthalmic Physiol Opt* 15: 241–248 (1995)
- RAWLINSON A:** A study to investigate the visual quality of dental undergraduates using a simple screening programme. *Aust Dent J* 33: 303–307 (1988)
- RAWLINSON A:** A simple eyesight screening programme for dental undergraduates: results after 7 years. *Aust Dent J* 38: 394–399 (1993)
- SCHWARZE T, BAETHGE C, STECHER T, GEURTSSEN W:** Identification of second canals in the mesiobuccal root of maxillary first and second molars using magnifying loupes or an operating microscope. *Aust Endod J* 28: 57–60 (2002)
- SYME S E, FRIED J L, STRASSLER H E:** Enhanced visualization using magnification systems. *J Dent Hyg* 71: 202–206 (1997)
- TZANETAKIS G N, LAGOUKAKOS T A, KONTAKIOTIS E G:** Endodontic treatment of a mandibular second premolar with four canals using operating microscope. *J Endod* 33: 318–321 (2007)
- VAN GOGSWAARDT D C:** [Dental treatment methods using the loupe]. *ZWR* 99: 614–617 (1990)
- VELVART P:** [The operating microscope. New dimensions in endodontics]. *Schweiz Monatsschr Zahnmed* 106: 356–367 (1996)
- WOO G C, ING B:** Magnification devices for the presbyopic dentist. *J Can Dent Assoc* 54: 447–449 (1988)
- ZAUGG B, STASSINAKIS A, HOTZ P:** [Influence of magnification tools on the recognition of simulated preparation and filling errors]. *Schweiz Monatsschr Zahnmed* 114: 890–896 (2004)