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Augmented and virtual reality in dental medicine: A systematic review

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ABSTRACT

Background: The aim of this systematic review was to provide an update on the contemporary knowledge and scientific development of augmented reality (AR) and virtual reality (VR) in dental medicine, and to identify future research needs to accomplish its clinical translation.

Method: A modified PICO-strategy was performed using an electronic (MEDLINE, EMBASE, CENTRAL) plus manual search up to 12/2018 exploring AR/VR in dentistry in the last 5 years. Inclusion criteria were limited to human studies focusing on the clinical application of AR/VR and associated field of interest in dental medicine.

Results: The systematic search identified 315 titles, whereas 87 abstracts and successively 32 full-texts were selected for review, resulting in 16 studies for final inclusion. AR/VR-technologies were predominantly used for educational motor skill training (n = 9 studies), clinical testing of maxillofacial surgical protocols (n = 5), investigation of human anatomy (n = 1), and the treatment of patients with dental phobia (n = 1). Due to the heterogeneity of the included studies, meta-analyses could not be performed.

Conclusions: The overall number of includable studies was low; and scientifically proven recommendations for clinical protocols could not be given at this time. However, AR/VR-applications are of increasing interest and importance in dental under- and postgraduate education offering interactive learning concepts with 24/7-access and objective evaluation. In maxillofacial surgery, AR/VR-technology is a promising tool for complex procedures and can help to deliver predictable and safe therapy outcomes. Future research should focus on establishing technological standards with high data quality and developing approved applications for dental AR/VR-devices for clinical routine.

1. Introduction

Digital applications are broadly used in all disciplines of dental medicine today. In addition to three-dimensional (3D) imaging as well as computer-aided design and computer-aided manufacturing (CAD/CAM) [1], computer simulations are showing huge potential and stimulating increased attention [2]. Virtual simulation applications offer top-up information to the real environment, and thus open novel opportunities in the clinically operational field and in education [3,4].

One of the biggest confusions in the area of simulation technology is the differentiation between augmented reality (AR) and virtual reality (VR): AR is a technology that superimposes a computer-generated virtual scenario atop an existing reality in order to create a sensory perception through the ability to interact with it. It is developed into applications and used on mobile devices to blend digital components into the real world in such a way that they enhance each other, but can also be easily used apart [5]. In contrast, VR is an artificial computer-generated simulation of a real life environment or situation. It immerses the user by making them feel like experiencing the simulated reality firsthand, primarily by stimulation of vision and audience in real-time. The two main features of VR are immersion and interaction. Immersion indicates the presence in the virtual setting; and interaction refers to the operator's performance of modification [6] [Fig. 1].

A successful AR/VR-system is built on the following essential functionalities to be operated and closely integrated with one another: real and virtual data sources, tracking, registration techniques, visualization processing, perception locations, and feedback mechanisms [7]. To date, AR/VR has been applied to various fields of social life such as industrial processing, entertainment, marketing; and medicine is not an exception, especially in the surgically dominated disciplines using

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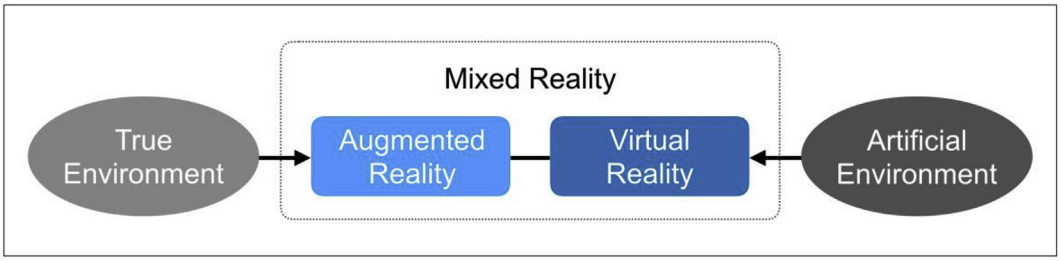

Fig. 1. Pictured definitions of augmented reality (AR) and virtual reality (VR).

minimally invasive approaches such as endo- and laparoscopic surgery [8]. However, the infiltration rate and routine implementation of AR/VR-technologies in dentistry is still unknown. Therefore, the aim of this systematic review was to provide an update on the current knowledge, to report on the scientific progress of AR and VR in the field of dental medicine, and to identify further research needs that will accomplish its clinical translation.

2. Methods

The systematic review respected the PRISMA-guidelines of Preferred Reporting Items of Systematic Reviews and Meta-Analyses [9].

2.1. Search strategy

A systematic search was performed in PubMed MEDLINE, EMBASE, CENTRAL, also comprising the Google Scholar up to 2018-12-31 for articles in peer-reviewed English-language journals published in the last 5 years. A modified PICO search was executed for Population/TOPIC, Intervention/METHOD and Outcome/INTEREST; whereas Comparison was omitted.

Defined categories were collected from a mix of Medical Subject Headings [MeSH-Terms] and free-texts: (((virtual reality) OR (augmented reality)) AND ((dentistry) OR (dental medicine) OR (prosthodontics) OR (periodontology) OR (implantology) OR (endodontology) OR (orthodontics) OR (oral surgery) OR (maxillofacial surgery))). Supplementary searches of the reference lists of the identified full-texts were conducted, and a hand search was performed in relevant journals [Table 1].

Table 1
Alphabetical list of screened journals for supplementary manual search.

- American Journal of Orthodontics & Dentofacial Orthopedics
- British Journal of Oral & Maxillofacial Surgery
- Clinical Implant Dentistry & Related Research
- Clinical Oral Implants Research
- Clinical Oral Investigations
- Dentomaxillofacial Radiology
- European Journal of Oral Implantology
- European Journal of Orthodontics
- Facial & Plastic Surgery Clinics of North America
- Implant Dentistry
- International Journal of Oral & Maxillofacial Implants
- International Journal of Oral & Maxillofacial Surgery
- Journal of Clinical Periodontology
- Journal of Clinical Prosthodontics
- Journal of Cranio-Maxillofacial Surgery
- Journal of Computerized Dentistry
- Journal of Dental Research
- Journal of Oral & Maxillofacial Surgery
- Journal of Oral Implantology
- Journal of Periodontology
- Journal of Periodontal & Implant Science
- Journal of Prosthetic Dentistry
- Journal of Prosthodontics
- Journal of Prosthodontic Research
- Oral Surgery Oral Medicine Oral Pathology & Radiology
- Orthodontics & Craniofacial Research

2.2. In-/Exclusion Criteria

This systematic review included randomized controlled trials (RCTs), clinical prospective and retrospective cohort studies, cross-sectional studies, case-control-studies and case reports.

Inclusion Criteria:

- Clinical trials only;
- Examination of at least one human subject related to the topic of dental AR/VR;
- Information available on the AR/VR-technology used and its association of the dental discipline.

Exclusion Criteria:

- Animal studies and *in-vitro* investigations;
- Multiple publications on the same population;
- Insufficient information on defined AR/VR-technology used.

2.3. Data extraction

Two reviewers (TJ/NUZ) individually inspected the identified titles and abstracts. Full-texts of all matched abstracts were assimilated and screened for meeting the defined inclusion criteria outlined above. Disagreement was resolved by discussion. The two reviewers used a data extraction form for further analysis:

- Author(s), year of publication, study design;
- Dental discipline;
- Defined outcome(s);
- Number of included participants and patients, respectively;
- Key findings of obtained results.

The results of the included studies were categorized related to the defined outcomes on a patient level, and if possible, a meta-analysis was intended. Assessment of risk of bias in each study was based on trial level involving random sequence generation, allocation concealment, blinding, completeness of outcome data, selective reporting, and other bias using the Cochrane Collaboration Tool for RCTs (https://oralhealth.cochrane.org) [Fig. 2].

The Newcastle-Ottawa Assessment Scale was used to judge the non-randomized studies for study group selection, comparability of the groups, and the ascertainment of the outcomes (http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp) [Fig. 3].

3. Results

3.1. Included studies

The systematic search was finalized on 2018-12-31. Of the total of

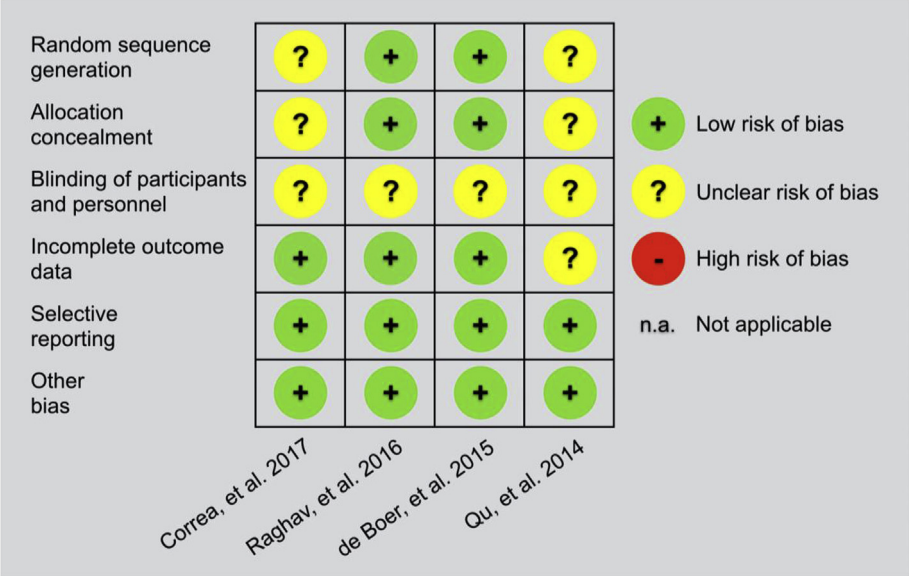

Fig. 2. Presentation of risk of bias evaluation for included RCTs according to the Cochrane Collaboration's Tool (https://oralhealth.cochrane.org).

315 titles by the systematic search, 87 abstracts were considered as possibly appropriate and further inspected, and consecutively, 32 full-texts were identified [Fig. 4]. Finally, a total of 16 full-texts were excluded from further examination [Appendix A]. Reasons for exclusion:

- No study in the field of AR/VR-technology (n = 11);
- Narrative reviews and/or opinion letters (n = 3);
- Experimental in vitro investigations [no clinical trials] (n = 2).

Conclusively, 16 full-texts were included for detailed analysis (Qian et al., 2018, Scolozzi & Bijlenga 2017, Correa et al., 2017, Khelemsky et al., 2017, Miki et al., 2016, Al-Saud et al., 2017, Yamada et al., 2016, Raghav et al., 2016, Espejo-Trung et al., 2015, de Boer et al., 2016, Qu et al., 2015, Suebnukarn et al., 2014, Fernandez-Alvarez et al., 2014, Eve et al., 2014, Urbankova et al., 2013, Zinser et al., 2013) [Appendix B]. Comprehensive information of each included study is tabularized for overall study data, specific outcome(s) and associated field of dental interest in Table 2. Included studies were evaluated to be of adequate quality according to the study design. Publication dates ranged from 2013 to 2018. Study types were classified in cross-sectional (n = 7), RCTs (n = 4), human cadaver (n = 2), prospective cohort (n = 1), retrospective cohort (n = 1), and case reports (n = 1) [Table 2].

3.2. Descriptive analysis

Out of the 16 studies, those categories were outlined for analysis [Fig. 5]:

- Nine studies exploring educational training and learning methods (A);
- Five studies reporting on clinical protocols in maxillofacial surgery (B);
- One study investigating the treatment of patients with dental phobia (C);
- One study focusing on human anatomy (D).

Diverse approaches, techniques and methods were used, and the level of evidence of the identified studies varied in principal. Due to this heterogeneity in the various fields of dental interests, validated comparisons among the selected publications were not feasible, and meta-analyses have not been accomplished.

3.2.1. Dental education

Among the nine included studies in the field of dental education, the topics varied widely from practical motor skill training in tooth preparation techniques including learning objectives in training the 3D vision, up to complex maxillofacial rehabilitation approaches. Most of

	Selection [max. 4 stars]	**Comparability** [max. 2 stars]	**Outcome** [max. 4 stars]
Khelemsky, et al. (2017)	★★★	★	★★
Miki, et al. (2016)	★★	—	★
Al-Saud, et al. (2016)	★★	—	★
Yamada, et al. (2016)	★★	—	★
Espejo-Trung, et al. (2015)	★★★	★	★★
Suebnukarn, et al. (2014)	★★★	★	★★
Eve, et al. (2014)	★★★	★	★★
Urbankova, et al. (2013)	★★	—	★
Zinser, et al. (2013)	★★	—	★

Fig. 3. Presentation of risk of bias evaluation for included non-randomized studies according to the Newcastle-Ottawa Assessment Scale (http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp).

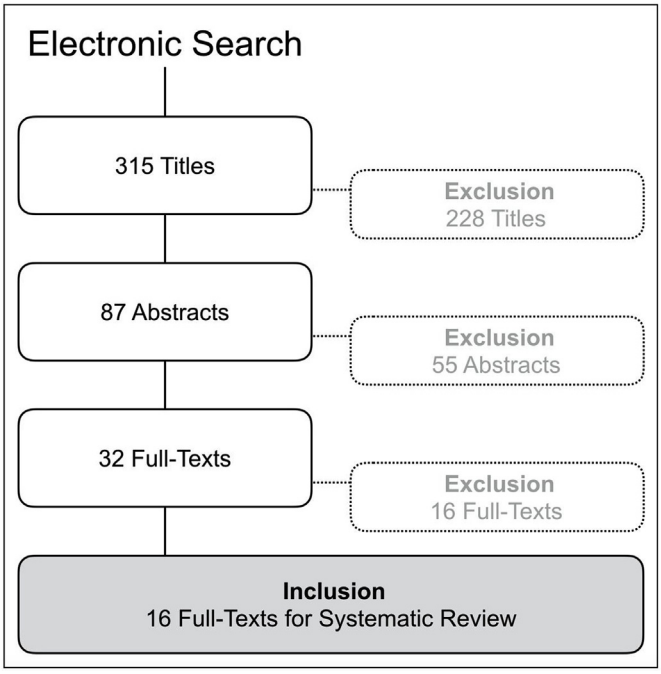

Fig. 4. Flow-chart of the systematic search results.

the education AR/VR-studies can be assigned either to pre-clinical tooth preparation simulations (undergraduate) or surgical training protocols (postgraduate).

Eve et al. (2014) analyzed the performance of dental undergraduate students versus prosthodontics residents on a simulated caries removal exercise using a novel haptic VR-simulator. Efficiency, defined as percentage of carious lesion removed over drilling time, improved significantly over the course of the experiment for both novice and experienced operators. Al-Saud et al. (2016) investigated the impact of feedback on the rate of motor skill acquisition with a haptic VR-simulator (MOOG, Nieuw-Vennep, the Netherlands) for tooth preparation. The learning of basic manual dexterity skills was accelerated when untrained participants were provided with haptic device feedback in conjunction with an experienced dental instructor, relative to groups with access to the device only or instructor only feedback. Urbankova et al. (2013) tested manual dexterity using haptic VR-technology in pre-clinical dental education. The results of the trial suggested a role for VR-simulators in identifying students with potential learning challenges in the pre-clinical stages of dental training. Another study by Suebnukarn et al. (2014) also evaluated the validation of a haptic VR dental simulator (prototype device) for motor skill training. The results showed validity for the VR-simulator by demonstrating its discriminant capabilities between that of experts and non-experts. Espejo-Trung et al. (2015) developed a new learning objective using AR-technology in order to explore the acceptance of gold onlay in teaching preparation design at a dental school in Brazil. De Boer et al. (2015) examined the differences in the performance and appreciation of students working in a virtual learning setting. The use of 3D-vision in a virtual learning scenario demonstrated a significant positive effect on the performance of the students and on their appreciation of the environment compared to 2D-vision.

Correa et al. (2017) investigated the validation of a dental anesthesia-training simulator for the inferior alveolar nerve block. The shown simulation was tested highly suitable with respect to the application of the needle involving the appropriate localization, depth of insertion, as well as the sensitivity of virtual tissue resistance.

In more complex surgical treatment techniques, Khelemsky et al. (2017) analyzed the validity of a novel cognitive VR-simulator (prototype project named Touch Surgery) for orbital floor reconstruction. The presented VR-simulation could serve as a useful cognitive training and assessment tool in maxillofacial surgery residency programs. Miki et al. (2016) performed a study to evaluate a basic training system comprising VR-technology for the removal of submandibular glands. The VR-training system using endoscope-assisted surgery was effective in the training of novice oral surgeons.

3.2.2. Maxillo-facial surgery

Five publications reported on AR/VR-technologies in the field of oral and maxillo-facial surgery. The range of indications was diverse and included hard tissue surgeries, such as mandibular reconstruction and distraction osteogenesis, orthognathic surgery, saliva gland operations as well as the transplantation of facial dermal grafts.

One of the upmost critical steps for the treatment of pleomorphic adenoma (lacrimal gland) is the correct choice of excision technique. Scolozzi & Bijlenga (2017) reported on a case report the successful removal of a recurrent pleomorphic adenoma of the lacrimal gland in a 42-year-old woman using a specific microscope-based AR-system.

Yamada et al. (2016) evaluated the usefulness of mandibular reconstruction surgeries in 21 consecutive study participants using custom-made titanium mesh trays and particulate cancellous bone and marrow. VR-simulation was performed using computer software based on the pre-operative radiographic data for a 3D-printed skull model and titanium mesh sheet bent to adapt to this model. Qu et al. (2014) used an AR-toolkit for distraction osteogenesis in 20 patients with hemifacial microsomia to define the mandibular osteotomy line and assist with intra-oral distractor positioning. The results of this RCT demonstrated the efficiency of the tested approach for guiding intra-operative distraction osteogenesis over the control procedure using a conventional method without AR-toolkit. The introduced AR-toolkit might be helpful for precise positioning of intra-oral distractors in patients with hemifacial microsomia applying craniofacial surgery. Zinser et al. (2013) introduced a computer-assisted protocol using orthognathic surgical navigation supplemented by an interactive image-guided visualization with real-time AR-technology. The aim was to analyze accuracy and versatility in an *in-vivo* setting. The presented AR-technology enabled precise waferless stereo-tactic maxillary positioning, which may offer an alternative approach to the use of arbitrary splints and conventional 2D orthognathic surgery.

Fernandez-Alvarez et al. (2014) performed a study to validate a VR-software for the recording of anthropometric measurements as a first step towards matching donors with recipients in the pre-operative planning process, which preceded the harvest of a facial allograft. The VR-approach reveled delivered equivalent measurements to those produced using a conventional analogue method. The 3D reconstructions obtained by using a VR-software could play a useful role to facilitate the characterization of the donor face.

3.2.3. Dental phobia

Dental phobia is one of most common phobic conditions in our society today. Raghav et al. (2016) determined the efficacy of the treatment of patients with dental phobia with a novel non-invasive Virtual Reality Exposure Therapy (VRET) compared to a control group applying informational pamphlets. Based on the reported results with an intermediate follow-up of 6 months, the authors concluded that VRET might provide a possible alternative treatment for dental anxiety and phobia.

3.2.4. Anatomy

Studying the 3D-anatomy of the cavernous blood sinus is essential for the treatment of lesions in this region in skull base surgery. Cadaver dissection is the conventional method that has limitations with regard to understanding spatial anatomy. Quian et al. (2018) developed a virtual scenario of the cavernous sinus and implemented it into a VR-system. The VR-based observation procedure was accurate, convenient, noninvasive, and time and specimen saving.

Table 2
General data of the 16 included trials: study design, dental discipline, defined outcome(s), number of study participants/patients, and key findings.

No.	Study (year)	Study design	Dental discipline	Outcome(s)	No. of study participants/ patients	Key findings
1.	Quian et al. (2018)	Human Cadaver Study	Anatomy	Feasibility of visualization of the cavernous blood sinus	5 human cadavers	VR models of the cavernous blood sinus is helpful for globally and objectively understanding anatomy
2.	Scolozzi & Bijlenga (2017)	Case Report	Maxillo-Facial Surgery	Clinical case presentation	1 patient	Stereoscopic and magnified view of the surgical field for real-time surgical assistance needs high learning-curve
3.	Correa et al. (2017)	RCT (2 arms)	Education/Teaching	Training dental local anesthesia	26 participants	12 novices/12 intermediate/2 experts: VR is satisfactory for the training of dental anesthesia
4.	Khelemsky et al. (2017)	Cross-Sectional Study	Education/Teaching	Training orbital floor reconstruction	49 participants	39 novices/10 experts: VR could serve as a useful cognitive training tool in maxillofacial training
5.	Miki et al. (2016)	Cross-Sectional Study	Education/Teaching	Training endoscope-assisted Gl. submandibularis removal	13 participants	13 experts: VR training is effective related to the surgical removal of the Gl. submandibularis
6.	Al-Saud et al. (2016)	Cross-Sectional Study	Education/Teaching	Training motor skill acquisition	63 participants	63 novices: VR training with haptic device feedback and experienced dental instructor is accelerated
7.	Yamada et al. (2016)	Cross-Sectional Study	Maxillo-Facial Surgery	Effectiveness of AR/VR in maxillo-facial surgery	21 patients	VR simulation for mandibular reconstructive surgery is clinically useful
8.	Raghav et al. (2016)	RCT (2 arms)	Dental Phobia/ Psychology	Efficacy of AR/VR for treatment of dental phobia	30 patients	VR provides a possible alternative treatment for dental anxiety and phobia
9.	Espejo-Trung et al. (2015)	Cross-Sectional Study	Education/Teaching	Training motor skill acquisition	77 participants	28 novices/19 intermediates/30 experts: VR as new learning objective demonstrates high acceptance within all groups with different levels of experience
10.	de Boer et al. (2015)	RCT (2 arms)	Education/Teaching	Training motor skill acquisition	124 participants	124 novices: VR has a significant positive effect on the performance and their appreciation of the environment
11.	Qu et al. (2014)	RCT (2 arms)	Maxillo-Facial Surgery	Effectiveness of guiding distraction osteogenesis	20 patients	AR may be helpful for precise positioning of intra-oral distractors in patients with hemifacial microsomia
12.	Suebnukarn et al. (2014)	Cross-Sectional Study	Education/Teaching	Training motor skill acquisition	34 participants	14 novices/14 intermediates/6 experts: improvement of learning curves of manual skills using VR
13.	Fernandez-Alvarez et al. (2014)	Human Cadaver Study	Maxillo-Facial Surgery	Accuracy of alloplastic facial transplantation	5 human cadavers	5 human cadavers: VR displays an equivalent alternative for alloplastic facial transplantation
14.	Eve et al. (2014)	Cross-Sectional Study	Education/Teaching	Training motor skill acquisition	26 participants	12 novices/14 experts: experts removed greater portion of carious lesion on a VR 3D immersive haptic simulator
15.	Urbankova et al. (2013)	Retrospective Cohort Study	Education/Teaching	Training motor skill acquisition	39 participants	39 novices: VR allows to identify dental students with potential learning challenges in pre-clinical education
16.	Zinser et al. (2013)	Prospective Cohort Study	Maxillo-Facial Surgery	Accuracy of computer-aided orthognathic surgery	16 patients	VR/AR provides a precise technique of maxillary positioning with comparable results as the goldstandard

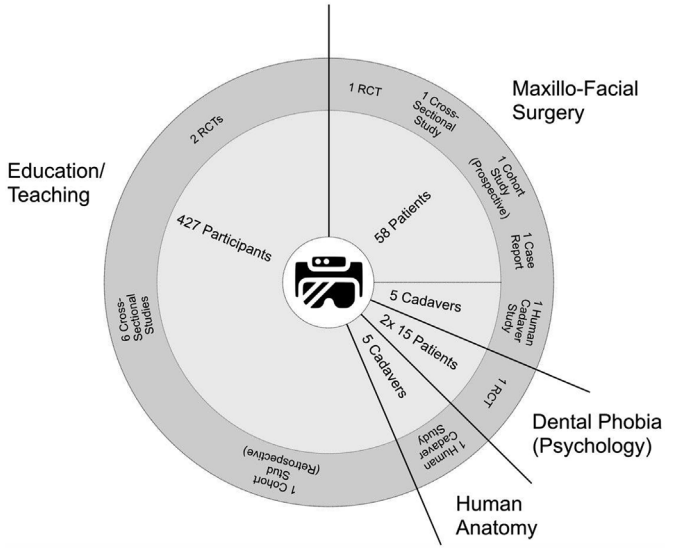

Fig. 5. Pictured summary of included studies related to the dental discipline, the trial design, and investigated number of participants/patients.

4. Discussion

This systematic review focused on clinical research related to AR/VR-technologies in dental medicine, and revealed that these were predominantly used for educational motor skill training in university settings, and for clinical analyses of complex maxillofacial surgical protocols. Furthermore, AR/VR-technology was also applied to investigating human anatomy and treatment of patients with dental phobia. The identified clinical trials in the field of dental AR/VR must be (still) seen as experimental in nature, being used for educational purposes or purely scientific projects with some first applications developed for surgical protocols. Fast computing devices and supporting software are essential for the upcoming translation of AR/VR from the lab into clinical routine [10].

AR/VR-systems are beneficial, especially for pre-operative planning to provide realistic outcome predictions and intra-operative navigation to mitigate potential risks. Here, the overlaid images should be able to coincide three-dimensionally without any lag in real-time and with reliable accuracy and precision [11,12]. As educational tool, AR/VR-simulators can offer enhanced opportunities to undergraduate students and specialized dental residency programs. AR/VR-simulations (including direct feedback and objective evaluation) will become a key function in the future of dental education [13,14]. By blending digital elements with a real learning environment, AR/VR provides new teaching possibilities [15,16]. Clinical dental training is based on serious and constant practice for motor skill acquisition. AR/VR has been shown to positively affect the quality of learning lessons and to promote the joy of knowledge transfer as well as the acquirement of motoric skills, such as with simulated tooth preparation models [17,18].

However, a number of uncertainties limit the widespread implementation of AR/VR-technologies for clinical routine at present. Most of these uncertainties are anticipated to be solved by continuous progress in information technology (IT). In addition, the growing mass of obtained data needs to be smartly managed. Protected data anonymization is crucial, but possible re-identification of individuals poses several challenges: appropriate security procedures (including establishing access permissions to data identifiers) and novel algorithms for statistical analyses and interpretation of generated data need to be developed and implemented [19]. In this context, legal regulations must define clear standards for the directive of patient data. Another issue is the cost-benefit evaluation from the perspectives of clinicians as well as patients since AR/VR-applications are still expensive for daily practice.

Despite the fact that only 16 studies could be included in the current review, the increase of yearly-published articles in MEDLINE demonstrates the huge interest and importance of AR/VR in the healthcare sector. The possibilities (and limitations) of AR/VR are directly dependent on the technical performance and power of the IT-environment. AR/VR are comprehensive technologies that are made up of interacting components: computation machines, operating software, registration techniques, and tracking sensors [20]. Currently, VR still lacks true realism, although immersion is a basic feature of both AR and VR. Unlike VR, AR can be characterized by incorporating additional information into physical reality. Thus, AR seems to be of greater benefit in real operations compared to VR, since AR enables 'seeing through' reality [21]. Nevertheless, both AR and VR are believed to have a wide range of applications in the manually dominated medical disciplines, including dentistry [22]; and it is predicted that the global healthcare AR/VR-market will have an estimated value of 5.1 billion US-Dollar by 2025 [23]. Technological advance is not a linear progression, but it is based on exponential jumps. The developments in IT-technology have fostered a global explosion of digital data. Collected files are anticipated to be more than 4 zettabytes in the computerized nirvana today. Hal Varian (Chief Economist, Google Inc., CA, USA) summarized, "Between the dawn of civilization and 2003, our society only created 5 exabytes. Now, this volume is produced every 48 h" [24]. Moreover, the IT-turnover, affecting both hard-as well as software, has speeded up for new technologies with half-life expectations of less than 2 years [25].

5. Conclusions

In this systematic review, the total number of includable studies reporting on AR/VR-technology in dental medicine was low. Only four RCTS (out of 16 studies) were involved for analysis. Scientifically proven recommendations for clinical protocols cannot be made at the present time. The continuous progress in IT-technology will reveal the full potential of AR/VR-technology in dentistry in the near future.

Nevertheless, AR/VR-applications are of increasing interest and importance in dental under- and postgraduate education offering interactive learning concepts with 24/7-access and objective evaluation. In maxillofacial surgery, AR/VR-technology is a promising tool for complex operations enabling predictable and safe treatment outcomes. Forthcoming research should focus on technological standards generating high data quality, ubiquitously accepted file formats, secure and appropriate data management, and developing approved applications of dental AR/VR-device for clinical routine.

Summary

Augmented reality (AR) and virtual reality (VR) have been applied to various fields of social life such as industrial processing, entertainment, marketing; and medicine is not an exception, especially in the surgically dominated disciplines using minimally invasive approaches such as endo- and laparoscopic surgery. However, the infiltration rate and routine implementation of AR/VR-technologies in dentistry is still unknown. Therefore, the aim of this systematic review was to provide an update on the current knowledge, to report on the scientific progress of AR and VR in the field of dental medicine, and to identify further research needs that will accomplish its clinical translation.

A modified PICO-strategy was performed using an electronic (MEDLINE, EMBASE, CENTRAL) plus manual search up to 12/2018 exploring AR/VR in dentistry in the last 5 years. Inclusion criteria were limited to human studies focusing on the clinical application of AR/VR and associated field of interest in dental medicine. The systematic search identified 315 titles, whereas 87 abstracts and successively 32 full-texts were selected for review, resulting in 16 studies for final inclusion. AR/VR-technologies were predominantly used for educational

motor skill training (n = 9 studies), clinical testing of maxillofacial surgical protocols (n = 5), investigation of human anatomy (n = 1), and the treatment of patients with dental phobia (n = 1). Due to the heterogeneity of the included studies, meta-analyses could not be performed.

The overall number of includable studies investigating AR/VR-technology in dental medicine was low; and scientifically proven recommendations for clinical protocols could not be given at this time. The continuous progress in IT-technology will reveal the full potential of AR/VR-technology in dentistry in the near future. AR/VR-applications are of increasing interest and importance in dental under- and postgraduate education offering interactive learning concepts with 24/7-access and objective evaluation. In maxillofacial surgery, AR/VR-technology is a promising tool for complex procedures and can help to deliver predictable and safe therapy outcomes. Forthcoming research should focus on technological standards generating high data quality, ubiquitously accepted file formats, secure and appropriate data management, and developing approved applications of dental AR/VR-device for clinical routine.

Conflicts of interest

None.

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APPENDIX A. Excluded Full-Texts [n = 16]

No Study In The Field Of AR/VR-Technology (n = 11).

- Schreurs R, Dubois L, Becking AG et al. Implant-oriented navigation in orbital reconstruction. Part 1: Technique and accuracy study. Int J Oral Maxillofac Surg 2018; 47(3):395–402.
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