The role and effectiveness of augmented reality in patient education: A systematic review of the literature

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Abstract

Objectives: To provide an overview of the existing research concerning the use and effects of AR in patient education.

Methods: Following PRISMA guidelines four electronic databases were systematically searched. Inclusion criteria: empirical studies using any type of AR intervention in patient education across all medical specialties. Quality assessment of the retrieved literature was carried out.

Results: Ten papers, comprising 788 patients, were identified and included (Randomized controlled trial (RCT) (n = 3), non-randomized controlled trial (n = 3), before-and-after study (n = 3), and qualitative survey (n = 1)). Retrieved literature showed itself to be highly heterogeneous. The studied population included patients suffering from a diverse spectrum of chronic diseases (e.g., prostate cancer, diabetes mellitus, multiple sclerosis, epilepsy). Quantitative results indicated that the use of AR had a positive effect on knowledge retention and patient satisfaction. Qualitative findings suggested that patients liked the technology and felt comfortable with its use for educational purposes. The quality of the retrieved results was shown to be moderate to low.

Conclusion: The limited evidence of this topic suggests the possible potential of AR in patient education.

Practice implication: More research, using high-quality study designs and more evidence-based interventions, is needed to fully appreciate the value of AR on patient education.

Keywords:

Augmented reality
Patient education
Systematic review
Chronic disease
Knowledge retention
Patient satisfaction
AR

1. Introduction

Patient education is an important facet in patient-centered healthcare. Optimal patient education and communication can increase patient satisfaction, improve therapy compliance and result in more favorable health outcomes [1]. By extension, patients who receive effective patient education are more likely to have a better understanding of medical information and have a greater sense of patient empowerment [2,3]. Additionally, interventions focusing on patient education have shown to be an effective tool to reduce medical costs, for example by decreasing treatment duration [1,4].

In order to be effective, information given to the patient by their healthcare provider has to be accurate, timely, complete, and unambiguous [1]. Reports show a general low percentage of information recall in patients [5–7] and widely diversified perspectives between patients and professionals [8]. Causes of low information recall are high levels of anxiety, high age of the patient, low comprehensibility of the information and low perceived importance of the medical information [5]. Improvement of low information recall could be accomplished by using explicit categorization techniques and supporting spoken information with written or visual material [5]. New ways aiding patient-provider communication might improve the effectiveness of patient education.

A possible solution for improving the effectiveness of patient education could be formed by the use of three-dimensional (3D) technologies in patient education, as these technologies can help with visualizing medical information. Using 3D models in patient education may also help patients have a better understanding of their disease and can be utilized as a tool to unite perspectives of patients and professionals on the disease [8,9]. In previous work our group has suggested that physical

Abbreviations: 3D, three-dimensional; AR, augmented reality.

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2. Materials and methods

During the conduct of this systematic literature review the following methodologies were followed to obtain and describe suitable, all empirical, publications.

2.1. Literature search

The Preferred Reporting Items for Systematic Review and Meta-analysis (PRISMA) guidelines were followed during the conduction of this systematic literature review. The PICO strategy was defined as follows: Population as patients or substitutes for patients; Intervention as AR-based educational tools; Control as studies not being selected based on a specific control group; and finally Outcome as effect on patient education (e.g. information recall, perceived knowledge gain, patient satisfaction, health literacy) across all medical specialities. The insights will provide an overview of the currently available AR applications and could provide possible indications for AR in patient education. This overview could form a basis for constructing further research to improve healthcare and information provision.

2.2. Data extraction and synthesis

After papers were considered eligible for inclusion, one of the researchers (JU) extracted data of the included papers using a predefined data extraction sheet, after which the data were cross-checked by another researcher (DH). Extracted data included (a) first author and year of publication, (b) number of included patients, (c) gender distribution of participants, (d) age characteristics of participants, (e) disorder/disease in the study population, (f) study design, (g) intervention group, (h) control group, and (i) measured outcomes. One of the authors (JU) contacted corresponding authors of papers when data were missing or clarification was needed. Up to two reminders were sent out.

Due to a relative sparseness of eligible literature and significant differences between study population, study design, and outcome measures, no meta-analysis could be performed. A narrative synthesis approach was chosen to summarize the findings of the selected studies following the approach as proposed by Eriksen et al. [23]. The AR interventions used were categorized into two categories: studies testing an application with an add-on AR function (4) and studies testing applications with AR as a main function (6). The former category contains applications where AR was a mandatory part of the intervention.

2.3. Quality appraisal of the included study

Quality appraisal of primary quantitative studies was conducted using the Cochrane risk-of-bias tool for randomized trials (RoB 2) for randomized controlled studies [24], and the Risk Of Bias In Non-Randomized Studies - of Interventions (ROBINS-I) tool was used for non-randomized studies [25]. Studies were judged to have high, unclear, or low risk of bias by one researcher (JU). All assessments were cross-checked by another researcher (DH). Qualitative studies were appraised using the National Institute for Health and Care Excellence (NICE) appraisal checklist [26]. Disagreements in quality appraisal were resolved through discussion until consensus was reached.

Three studies showed high risk of bias [27–29] and six showed moderate risk of bias [10,30–34] (Fig. 1 and Fig. 2). The study of Azman et al., presenting qualitative results was considered of low overall quality, with poor quality in terms of research design, context, and rigorous data analyses [35]. A summary of the NICE checklist is provided in the Appendix. Three out of four studies showing high risk of bias were studies using AR as an add-on function [27,29,35].

3. Results

3.1. Results of the literature search

Searches yielded 656 articles, of which we removed 159 duplicates. Through cross-referencing, three additional papers were found. Of the 500 papers left, 475 papers were assessed as irrelevant for the scope of the current review. The remaining 25 papers were selected for full-text assessment. Those not meeting the inclusion criteria were removed, resulting in the inclusion of ten papers (Fig. 3). Synthesis of the results has been performed in the PICO framework [23].

3.2. Overview of the studies

The included papers had the following study designs: Randomized controlled trial (RCT)\(n = 3\), non-randomized controlled trial \(n = 3\), before-and-after study \(n = 3\), and qualitative survey \(n = 1\). Study characteristics are summarized in Table 1.

3.3. Description of patient population

In total, 797 patients were included, 404 of which were female. One paper did not report sex distribution[35]. Participants originated from the United Kingdom \(n = 276\), United States of America \(n = 297\),
Spain (n = 136), Austria (n = 8), Germany (n = 17) and the Netherlands (n = 63). Studied populations comprised patients suffering from prostate cancer, patients with renal masses undergoing partial nephrectomy [30], and patients with multiple sclerosis (MS) [35], diabetes mellitus [28,33,34], epilepsy [32], and glioma [10]. In addition, one study investigated the effects of AR interventions on pregnant women [27]. Furthermore, two studies focused on patients’ experiences when visiting a hospital without specifying their illness [29,31]. Four studies specifically focused on children (mean age of 9.51 ± 0.31) [29,31,33,34]. Four studies focused on adult patients (mean of 42.58 ± 10.9) [10,27,30,32]. The study of Azman et al. only provided the age range of 25–60 years and did not report the mean age with SD [35]. The study of Domhardt et al. reported one patient in the age range of 18–39, three patients in the age range of 40–59, and two patients older than 60 [28].

3.4. Description of used interventions

Details on the applications used can be found in Tables 1 and 2.

3.4.1. Application with AR as an add-on feature

AlemtuzumApp was designed for MS patients to improve the education on Alemtuzumab, a novel disease modifying treatment option. Within the application, an AR feature is used to explain the working mechanism by use of a projected AR animation [35].

The application of Tait et al. is used as an addition to a storybook with generic (i.e., not study-specific) information about children’s involvement in research. The storybook alone provided background information. However, by use of a tablet, additional elements (e.g., animations, a 3D avatar) could be interacted with. Additionally, the AR feature also included quizzes which evaluated understanding of the study materials [31].

Xploro® is a digital therapeutic (DTx) platform that uses AR, gameplay, and artificial intelligence to deliver health information to children about the procedure, environment, and staff, and information on sensory aspects of a procedure as well as information to help a child build coping strategies. The platform includes several serious games with health themes, AR hospital environments, and an AR avatar which children can customize and which acts as a guide and chatbot [29,36].

ServARpreg is a portion-size guidance tool that includes image overlays for eight high-carbohydrate foods equivalent to one AGHE standard serving size. In this study, the women overlaid the virtual food portion images over a dinner plate. ServARpreg also included pregnancy-specific education on six nutrition topics. A summary video with an accompanying voiceover was created for each topic, and web links to additional resources were also provided [27]. For a more complete overview of the characteristics of the AR applications, please see Tables 1 and 2.

3.4.2. Applications with AR as main function

The game developed and studied by Calle-Bustos et al. helped children to learn about carbohydrate content of different foods by use of gamification. The game shows virtual foods on a real dish. The user can observe the food at a 360 degree angle. The game has an information phase followed by a game with three levels, each focusing on a different food group, and a final challenge [33,34].
BEAR smartphone application guides carbohydrates estimation with an AR approach. The shape of different foods on the plate is retracted by the user and the associated amount of carbohydrates is being calculated. Calculations are made based on the volume of the shape of the food in the virtual environment. The calculated carbohydrates are transferred to a diabetes diary [28].

The study of Wake et al. created patient-specific 3D tumor models [30]. The AR model was used to provide patients with pre-operative information.

In the study of Sezer et al., Greymapp (© 2020, Nijmegen, the Netherlands) was used to inform participants about brain tumor location and its relation to surrounding eloquent brain structures [10]. All models could be interacted with [10,37].

House et al. used VSI PE (2021 © Copyrights VSI.health, Hamburg, Germany) to demonstrate the pre-operative planning by use of models and projections [32]. Screenshots and videos from MRI projections could be made to give to the patient afterwards [32,38]. For a more complete overview of the characteristics of the AR application, please see Tables 1 and 2.

3.5. Description of controls

In the control group of three studies, traditional patient education methods consisting of 2D images [10,30] or local hospital practice [29] were used. In one study [32], patients in the control group received information using a rubber brain model. Another study that used AR in addition to a storybook to inform patients used the storybook as the only source of information in the control group [31]. Finally, the three before-and-after studies and the qualitative survey [28,33–35] had no control groups, and in one study the control group received no education from the researchers [27].

3.6. Outcomes

Patient objective and perceived knowledge outcomes were measured using pre- and post-intervention questionnaires [27,28,34,39], post-intervention questionnaires alone [10,35,40], pre- and post-intervention semi-structured interviews [31], and self-report questionnaires at baseline, pre- procedural, and post procedural levels [29]. Three studies used validated instruments to measure outcome [27,
### Table 1

**Study Characteristics.**

<table>
<thead>
<tr>
<th>Author (year), Country</th>
<th>Study design</th>
<th>Population characteristics</th>
<th>Intervention</th>
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<tbody>
<tr>
<td>Tait et al. 2020 USA[31]</td>
<td>RCT</td>
<td>N = 91 children attending to hospital Mean age ± SD Control: 9.5 ± 1.9 Intervention: 9.6 ± 1.9 M/F: 51/46 Drop-out rate: 6%</td>
<td>Printed story book + AR iPad program (n = 45). Trained research assistants to answer any questions.</td>
<td>Printed story book alone (n = 46)</td>
<td>- Understanding of clinical research - Perceptions of information delivery</td>
<td>- Pre-test and post-test on patients' knowledge - Survey to measure perceptions of information delivery.</td>
<td>Both AR and control group demonstrated significant and similar improvements in post-test understanding (P &lt; .05). Understanding of the ability to withdraw participation in research was significantly better in the AR group 1.63 (95%CI: 1.40–1.86) compared to control 1.13 (0.84–1.42). Parents found AR information of significantly higher quality than the control, both parents and children found the AR program very easy to use and 85.0% and 71.2%, respectively, preferred AR information delivery together with a discussion with the researcher in the future.</td>
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<tr>
<td>House et al. 2019 Germany[32]</td>
<td>Cross-over RCT</td>
<td>N = 17 Mean age and range 36.1, 21–61 Disease: Epilepsy M/F: 7/10 Drop-out rate: 0%</td>
<td>VSI Patient Education (VSI PE)</td>
<td>Rubber brain model</td>
<td>- Patient comprehension- Patient anxiety - Feeling of being treated by state-of-the-art information technology</td>
<td>Questionnaire after each intervention</td>
<td>Patients found their patient education significantly more comprehensible (P = .001, r = 0.84) and almost significantly more imaginable (P = .020, r = 0.57) with VSI compared to the control. Patients felt significantly less anxious using VSI (P = .008, r = 0.64). Significantly more patients chose VSI as the preferred patient education tool (P &lt; .001, r = 0.91), and almost significantly more patients decided VSI to be the future standard education tool (P = .020, r = 0.56). Significantly more relatives preferred VSI (P = .002, r = 0.91) and decided it to be the future standard education tool (P = .004, r = 0.83).</td>
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<tr>
<td>Wake et al. 2019 USA[30]</td>
<td>Cross-over RCT</td>
<td>Prostate cancer (n = 151) Renal carcinoma (n = 49) Mean age ± SD 63.7 ± 8.2 M/F: 180/20 Drop-out rate: 0%</td>
<td>2D radiological images in pre-operative planning consultation with one of the following add-on options: 3D printed model (n = 55) AR model (n = 26) 3D computer model (n = 46) ServARpreg + face-to-face sessions including nutrition education and access and training in tool usage (n = 47)</td>
<td>2D radiological images in pre-operative planning consultation with no add-on options (n = 73)</td>
<td>1)Understanding of the cancer and treatment plan 2) Usefulness of the different forms of visualization of the 3D models</td>
<td>A 5-point Likert scale survey determining understanding of the disease and treatment plan. If randomized to receive a pre-operative 3D model, the survey was completed twice, before and after viewing the 3D model.</td>
<td>There was no improvement in understanding for the AR model group as compared to other groups. AR models were reported to be useful, with 3D printed models performing best.</td>
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<td>Brown et al. 2019 UK[27]</td>
<td>Non-randomized controlled trial</td>
<td>N = 186 pregnant woman Mean age ± SD 30.9 ± 4.7 Drop-out rate: 52%</td>
<td>No additional education</td>
<td>- Carbohydrate and standard serve size knowledge - System usability and likability</td>
<td>- Cross-sectional baseline study- follow-up online survey - Process evaluation survey.</td>
<td>Significantly improvement of carbohydrate quantification (1.71 (0.89–2.50) P = .002) and identification knowledge (1.74 (0.65–2.83) P &lt; .001) from baseline to follow-up in (continued on next page)</td>
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Table 1 (continued)

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<tr>
<td>Bray et al. 2020UK [29]</td>
<td>Non-randomized controlled trial</td>
<td>N = 80 children attending to hospitalMean age ± SD 10.4 ± 2.3 M/F: 60/20 Drop-out rate: 0%</td>
<td>Xploro® (n = 40)</td>
<td>Normal care</td>
<td>- Perceived knowledge- Procedural anxiety- Procedural satisfaction- Procedural involvement- Reported experiences</td>
<td>- Self-report questionnaires completed at baseline, preprocedural, and postprocedural- Qualitative semi-structured interviews on experiences</td>
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<tr>
<td>Sezer et al. 2020The Netherlands [10]</td>
<td>Non-randomized controlled trial</td>
<td>N = 63Mean age ± SD 39.6 ± 15.1 Disease: Healthy individuals, similar baseline characteristics as glioma patients M/F: 21/40 Drop-out rate: 3%</td>
<td>- 3D printed model (n = 20)- AR model (n = 20)</td>
<td>2D computer model (n = 21)</td>
<td>Information recall</td>
<td>Two standardized questionnaires (one week apart) testing information recall</td>
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<td>Domhardt et al. 2015Austria [28]</td>
<td>Before-and-after study</td>
<td>N = 8 Age ranges: 18–39 (n = 1), 40–59(n = 3), Older than 60(n = 2)Disease: Diabetes MellitusM/F: 5/1 Drop-out rate: 25%</td>
<td>BE4® + two face-to-face sessions</td>
<td>NA</td>
<td>- Carbohydrate estimation improvement</td>
<td>- Before- and after test - Usability and likability questionnaire.</td>
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intervention group. Significant group × time interaction in favor of the intervention group for carbohydrate quantification knowledge (AR: 1.71 (0.89–2.50), control: 0.12 (–0.46 to 0.70), P = .002). Standard serve size knowledge did not change between groups. The process evaluation survey showed 80% strongly agreed/ agreed that the app made them more aware of how much they ate and 72.5% found it easy to use.

Significant lower anxiety before the procedure for children (AR: 5.82 (5.32–6.32), control: 7.15 (6.32–7.98), P = .008) and parents (AR: 5.10 (4.49–5.71), control: 6.18 (5.28–7.08), P = .05) in the intervention group compared to the control group. Children in the intervention group also reported significantly higher levels of perceived procedural knowledge than before the intervention (before: 5.58 (5.27–6.43), after: 6.75 (6.27–7.23)). Children enjoyed using the intervention, found it fun and easy to use, and felt that it had positively affected their hospital experience.

Both the 3D group (mean Δ 5.66; 95% CI 2.96–8.35, P < .0005) and AR group (mean Δ 3.10; 95% CI 0.41–5.80, P = .025) obtained higher recall scores compared to the 2D group. Highest recall scores were obtained in the 3D group, but difference between the AR and 3D group was insignificant (mean Δ 2.56; 95% CI –0.17 to 5.28; P = .06). Comparing the AR to the 2D group showed a large difference for immediate recall, but a small difference after the 1-week follow-up.

Carbohydrate estimation without technical support improved after the intervention, although not significant (P = .0517). In 44% of the estimations, absolute error decreased by at least 6 g of carbohydrate.
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<tr>
<td>Calle-Bustos et al. 2017 Spain [34]</td>
<td>Before-and-after study</td>
<td>N = 70 Mean age ± SD: 9.2 ± 2.4 Disease: Diabetes Mellitus M/F: 29/41 Drop-out rate: 0%</td>
<td>AR game to support therapeutic education</td>
<td>NA</td>
<td>- Carbohydrate estimation- Satisfaction and usability</td>
<td>- Pre-knowledge questionnaire - Two different post-knowledge questionnaires - Satisfaction and usability questionnaire.</td>
<td>Carbohydrates. Participants identified several problems in systems usability and likability. Statistically significant differences between the scores of the pre- and post-questionnaire, independent of which post-questionnaire was used (Post1: median 7.45; interquartile range 3; P &lt; .001, Post2: median 6.86; interquartile range 2; P &lt; .001). Children were satisfied with the game and considered the game to have a high degree of usability. Younger children gave higher usability scores.</td>
</tr>
<tr>
<td>Calle-Bustos et al. 2019 Spain [33]</td>
<td>Before-and-after study</td>
<td>N = 66 Mean age ± SD 8.9 ± 2.2 Disease: Diabetes Mellitus M/F: 26/40 Drop-out rate: 0%</td>
<td>AR game to support therapeutic education on three devices: BQ Edison 2 tablet (n = 38) (BQ)- Samsung Galaxy tablet S (n = 14) (SGT)- Samsung Galaxy Note II smartphone (n = 14) (mobile)</td>
<td>NA</td>
<td>- Carbohydrate estimation- Satisfaction and usability</td>
<td>Pre- and post-knowledge questionnaire - Satisfaction and usability questionnaire</td>
<td>Statistically significant differences for the knowledge variable before and after using the app for all three devices were found (BQ P &lt; .001; r = 0.617, SGT P = .001; r = 0.625, mobile P = .002; r = 0.618). There were no statistically significant differences among the post-knowledge variable of the three groups. Usability and satisfaction outcomes not reported. Results from the usability questionnaire suggested the application to be highly user-friendly and engaging, improving patients’ understanding of medical information considerably.</td>
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<tr>
<td>Azman et al. 2019 UK [35]</td>
<td>Qualitative survey</td>
<td>N = 10 Age range: 25–60 Disease: MSM M/F: NR Drop-out rate: 10%</td>
<td>Alemtuzum + App + information sheets on AR usage and task description</td>
<td>NA</td>
<td>Usability and likability</td>
<td>Usability questionnaire</td>
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The AR group. It was also found that children participant withdrawal in research, which was significantly better in the objective knowledge gain and/or retention [10,27,28,31,33,34].

Moreover, the two carbohydrate intake. In three before-and-after studies, it was found that using an AR application resulted in gain of knowledge regarding insights in carbohydrate content of different foods [28,33,34]. Moreover, the two AR models based on MRI and CT data

No differences were found between groups, except the understanding of clinical research. Significant improvements in post-test understanding of clinical research. Both patients in intervention and control group demonstrated significantly improved carbohydrate quantification as result in significantly improved carbohydrate quantification as compared to the control group [29,32]. Carbohydrate identification improved significantly from baseline to follow-up in the intervention group compared to the control group [27]. Carbohydrate identification improved significantly from baseline to follow-up in the intervention group.

When looking at the remaining study designs, four studies found significant knowledge improvements in favor of AR [10,27,33,34]. Three of these studies used AR for increasing knowledge on carbohydrate intake. In three before-and-after studies, it was found that using an AR application resulted in gain of knowledge regarding insights in carbohydrate content of different foods [28,33,34]. Moreover, the two studies of the group of Calle-Bustos found a statistically significant difference in knowledge gain between pre- and post-test results [33,34]. The study of Domhardt et al. also found a difference in favor of AR, though it was not significant [28]. In pregnant women, AR education resulted in significantly improved carbohydrate quantification as compared to the control group [35]. Carbohydrate identification improved significantly from baseline to follow-up in the intervention group.

Finally, Sezer et al. found that both the 3D models group and the AR group have significantly higher immediate recall scores compared to the 2D group regarding the factual knowledge questionnaire [10].

Participants’ perceived gain of knowledge.

Three of the ten included papers reported on the participants’ personally perceived gain of knowledge as rated by the participants [29, 30,35]. The RCT testing this outcome showed no improvement in understanding for any of the knowledge measures in the AR group as compared to the control group [30].

Contrasting, the two other studies reported on positive results in favor of AR [29,35]. Only one of these studies reported a significant positive effect of AR on perception of procedural knowledge [29]. Additionally, both studies presenting positive results, showed high risk of bias.

3.6.2. Patients’ satisfaction with AR

Patient satisfaction and related outcomes such as patient involvement and patient comfort were measured in five studies [29–32,35], of which three RCT’s [30–32]. All studies reported relatively positive results, and two found significant beneficial effects [29,32]. Moreover, one RCT showed that patients found their patient education significantly more comprehensible and almost significantly more imaginable when their physician used an AR application compared to a rubber model [32].

A non-RCT found that the mean procedural involvement scores of the intervention group were significantly higher than those in the control group. Participants in the intervention group also had higher procedural satisfaction scores compared to the control group, although not significant [29].

Additionally, the qualitative results of Azman et al. showed that patients considered AR-delivered information as helpful and sufficient to enable them to make an informed decision about treatment [35]. These findings suggest that usage of an AR application made given information more comprehensible for patients [32,35].

Lastly, both an RCT and non-RCT showed that the use of an AR application significantly reduced procedural and pre-operative anxiety in patients when compared to the control group [29,32]. In the non-RCT this effect was strongest for children who had less exposure to a hospital setting [29]. Additionally, in the study of Azman et al., one participant stated that learning from the application was less scary than from brochures they had been given previously [35].

3.6.3. Usability

Eight out of the ten included studies reported on the likability and usability of the used AR application [27,32,34,35]. Most studies [27, 29–32,34,35], and all RCT’s, reported a high usability and likability. Participants stated that applications were easy to use [27,31,34] and chose the AR application over regular patient education methods or wanted to use the application in the future [31,32,34,35]. House et al. substantiated this statement with significantly more participants choosing AR as the preferred patient education tool over the rubber brain model [32]. Five participants in Azman et al. verbally requested that the design of the application be extended to more treatments [35].

Some studies reported concerns on usability [27,28,31,35]. For example, one participant stated that the AR component of the app was not available?
unnecessary [35], and one study reported younger children finding the amount of information in the AR program too extensive [31]. The studies of Domhardt et al. and Brown et al. both reported some interaction problems with their applications [27,28]. Problems consisted of usability difficulties, incompleteness of the applications, and one patient [28] stated that using an application at the dining table is culturally unacceptable.

50% (n = 5) of the AR applications used were commercially available. These applications scored higher in terms of usability with usability complaints in only one out of five applications (versus 3/5 in the non-commercial available applications).

4. Discussion

The present review summarized the available literature regarding the use of AR in patient education. The results indicate AR as a potentially useful tool for patient education. Studies showed positive results in terms of (perceived) knowledge gain, patient satisfaction and usability. When looking at intervention type, applications using AR as a main function scored slightly better with significant results in four out of six (67%) studies versus two out of four (50%) for applications using AR as an add-on. Problems on usability were mostly found in studies using applications with AR as an add-on feature [27,31,35].

However, the available studies on this topic consist of heterogeneous participant groups, relatively small sample sizes, and potential biases. One study described a contrasting finding [30]. Further drawing of sound conclusions regarding the effect of AR in patient education on a meta-study level is hampered by the aforementioned limitations.

Although studies and reviews have been performed on AR in different healthcare purposes, no systematic reviews on the application of AR in patient education have been conducted. One report described the protocol for a scoping review on the use of AR in patient education [22]. This scoping review did not include a quality of evidence assessment. Also, findings, conclusions, and recommendations are not mentioned as it is the protocol of the review. Reviews focused on the use of AR in other educational fields have been published, such as AR in medical education [20,41,42], medical training [12], nursing [43], and anatomical education [44]. These reviews conclude that the teaching potential of AR is promising and that the relatively new technology has a potential for improving a variety of skills, although the pool of evidence is small. This is similar to the findings of this review.

The effectiveness of AR as compared to regular or no education on learning objectives could be explained by several reasons. First, AR has the ability to simulate events on top of reality, creating a hybrid immersive learning environment, that facilitates the development of skills, such as problem solving, critical thinking, and communicating [45].

Additionally, studies testing AR for anatomy education describe how the use of AR applications decreases cognitive load in students [13,46], which might also be the case for patients. Reduction of cognitive load, could cause patients to focus more on the content of the given information and therefore to understand it better. It has been suggested that a decrease in cognitive load was achieved by the use of well-designed AR application [47,48]. Furthermore, AR applications were found to elicit motivation in students when used as study material [48].

The effect of AR on patient satisfaction that emerges from this review could be caused by AR applications improving patients’ understanding of disease characteristics and therefore enabling them to make more thoughtful decisions. This makes the patient feel more involved in the decision-making process and therefore gives a greater sense of empowerment [3,49]. Additionally, using such new technology in the education process is reported to improve learner’s motivation, which we speculate to potentially increase therapy compliance, leading to a better treatment effect and thus patient satisfaction [48].

As mentioned above, AR can make visualizing and understanding concepts easier [19], and therefore could aid to improve doctor-patient communication. This improvement in communication can enhance patient participation in shared decision-making, which is crucial for delivering high-quality healthcare. In addition, patients can also use an AR model to explain their illness to family members, which could increase relatives’ comprehension and involvement.

This review reveals some major limitations of the current literature on the use of AR in patient education. The first limitation is the heterogeneity of the AR applications, devices, outcomes, and outcome measures used in the included studies. As stated before, some of the applications for patient education only used AR as an additional function. For these applications, it remains difficult to determine the exact impact of AR on patient education. Additionally, studies using applications with AR as an add-on function showed higher levels of bias, more usability problems, and fewer significant effects than studies using applications with AR as a main function. The high levels of bias indicate that results found in studies using add-on AR might be less reliable than results found in studies using AR as a main function. The purpose and quality of the AR also differed between the studies. For example, some of the applications were meant for the practitioner in explaining the disease and treatment options [10,32,40], and others seemingly used AR to make learning content more attractive [31,35]. This difference makes it difficult to compare the effects of the AR applications. Furthermore, the majority of the outcome measure tools used were study-specific questionnaires developed by the research team, with limited to no published evidence of validity and/or reliability. Future research regarding AR in patient education needs to be standardized in terms of intervention type and outcome measures in order to be able to investigate the effects of AR in patient education. Standardization of outcome measures can be accomplished by using standardized and validated questionnaires in future studies. Standardization of intervention types can be accomplished by using well-designed AR applications meeting the spatial and the temporal continuity principles of the cognitive theory of multimedia learning [13–15]. Additionally, studies evaluating the effect of AR in patient education should use AR applications with AR as a main function in order to minimize bias of the effect measured.

Another aspect future studies should focus on is the question which AR device is most optimal for patient education. The reviewed studies used two different devices: a tablet/smartphone or the Microsoft HoloLens (© Microsoft, Redmond, U.S.A.). Both devices showed heterogeneous results, which prevents us from drawing sound conclusions on this topic.

A second drawback concerns the relatively limited methodologies used in the included studies. Six of the included studies were controlled trials, with only three of them being randomized. The rest of the studies were uncontrolled studies, which decreases the generalizability of their results. Additionally, small and heterogenous study populations were included. In the future, developers of AR patient education tools should evaluate their interventions using high-quality study designs, such as randomized controlled trials, to minimize bias. Clear research questions, sampling strategies and sample size, inclusion and exclusion criteria, and outcome measures should be taken into consideration.

A third limitation is that patients were rarely involved in the design of the AR applications. However, including patients in this process could help construct patient-friendly, useful, more effective AR applications [50,51]. Prior to clinical implementation patients’ views on AR tools should be investigated. Preferably, patients’ opinions and thoughts should be included when designing a new AR application for patient education. Previous work has shown that conducting qualitative research can result in identified facilitators, barriers, and positive and negative effects of new educational tool usage [9]. Including these insights in application development will ensure that the use of technology will meet the needs of the patient in a more efficient way.

The fourth limitation is that the investigated diseases are selected based on a need for additional education. Probably not every disease needs an AR tool to improve patient knowledge. 3D animations, serious gaming and Virtual Reality applications might also be suitable, but are
outside the scope of this review. Complex and invisible conditions might benefit more from the combination of visible reality and digital augmentation that AR offers [51]. This aspect should be considered in future work.

The final limitation is that the investigators who designed the reviewed AR tools did scarcely describe (1) potential differences in professional and patient agendas, (2) patients’ acceptance of AR, (3) differences in beneficial effects between patients, and (4) negative effects of using AR in patient education. Future clinical studies should address the aforementioned aspects, as these provide relevant information on the subject that is now missing. For example, patients’ capacities with regard to spatial abilities must be incorporated in future studies to assess whether AR can benefit subgroups of patients more than others [52].

Finally, future studies should focus on the implementation process of the AR interventions to increase effectiveness of these applications in practice. This focus is being omitted in current studies. For example, feasibility and adequacy in the clinical setting should be assessed by asking questions: What are the benefits of AR as compared to its 3D alternatives in the specific setting? Do health practitioners require an AR training to give optimal patient education using AR? Are there barriers for implementing AR in the consulting room and what are strategies to overcome these barriers in specific clinical settings? Evaluating these and more questions is necessary to guarantee successful implementation of AR in patient education [51].

A strength of the current study is that it is the first study that systematically reviews the literature on the effects of AR in patient education. However, a limitation of the present study concerns the small number of publications that could be included in this paper, which made meta-analyses impossible.

5. Conclusion

Although research concerning AR in patient education is relatively limited, there are encouraging results regarding the educational potential of AR. Unfortunately, existing literature often contains heterogeneous applications and heterogeneous populations. More high-quality studies are needed in order to draw sound conclusions.

Practice implications

Future research, using high-quality research designs, standardized outcome measures, and more standardized AR interventions based on patients’ wishes and needs is necessary to elucidate whether AR should play a more eminent role in patient education.

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Conflict of interest

The authors declare that they have had no conflict of interest while conducting this research.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jpec.2022.03.005.

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