A Comparative study on the Effectiveness of Augmented Reality on Denture Tooth Selection

Keywords

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ABSTRACT

One of the most difficult aspects of providing removable dentures, for both the patient and the dentist, is the tooth selection process. The aim of this study was to assess the effectiveness of augmented reality (AR) on patient experience of the tooth selection process. Materials and Methods: 3D scanning of upper anterior teeth of various shapes and sizes allowed for the creation of a virtual library that were subsequently used to programme an AR software application, 'ToothPick'. Seventeen participants were recruited to a comparative study at Leeds Dental Institute, over two clinical appointments, to trial the app and complete a 10-question survey to assess the efficacy of AR simulation. The sample size response generated outcome variables for 'perceived usefulness' and 'perceived ease of use' from the perspectives of the patient, dentist and technician. Results: By the second appointment, 86% of participants preferred the app over the conventional methods for selection of denture teeth due to increased ease of use and accuracy that AR simulation had in replicating the wax try-in. Conclusion: The sample population favoured the adoption of AR technology to select denture teeth from the perspective of both the patient and the clinician.

INTRODUCTION

One of the most challenging aspects of providing removable dentures is the selection process of appropriate maxillary anterior denture teeth[8] which occurs at the jaw registration phase. Current conventional methods involve the patient placing artificial teeth of various shapes and sizes against their face or browsing catalogues to determine the aesthetic nature of the prosthetic teeth. Though the patient should be the final arbitrator on the selection with support from the dental team, unfortunately patients are not often engaged in this stage, despite literature expressing the importance of patient involvement for successful treatment outcomes. In some cases, patients may have never had the opportunity to participate in the aesthetic decisions pertaining to their dentures due to assumed clinician time and cost constraints.[2] In other cases where the patient has been involved, they may defer the responsibility back to the clinician in the notion that the clinician's expertise will produce the best results.[2] An aesthetic trial of the denture in wax can provide an analogue solution to allow the patient to view and adjust their 'trial smile'. However, at this stage many key determinants such as the tooth shape, size, position, smile line, midline, embrasure spaces and occlusion are already decided.

Increased evidence of such process limitations in the selection of artificial teeth indicate a gap in the current system and the clinical need for innovation in prosthodontics. Despite the implementation of Computer Aided Design into the manufacturing of prostheses as early as 1987,[17] Canbazoglu *et al*. argue that the field of dentistry still lack the tools and technology to help patients envisage the clinical outcomes of treatment.[6]

The introduction of complete dentures using computer-aided design and computer-aided manufacturing (CAD-CAM) has coined the term 'digital dentures'. The workflow includes scanning the patient's dental arch and the integration of software that determines the tooth shape, size, position, smile line, midline, embrasure spaces and occlusion.[19] Once designed, the complete denture is milled from an acrylic block.[19] The fabrication of digital dentures has eliminated errors in impression-taking, shrinkage/deformation in impression material and has increased denture retention and patient satisfaction.[7,20] Baba (2020) elaborates on the workflow processes of the different digital denture manufacturing systems.[4]

Augmented reality (AR) is a type of interactive digital technology in which a sensory experience is enhanced through the superimposition of computer-generated virtual displays over real structures.[9] Though in its infancy, this technology has attracted interest in various fields and has been applied within dentistry to enhance diagnosis and treatment outcomes.[9] AR has been adopted for pre-procedure simulation and planning within orthodontics for guided placement of brackets onto individual teeth in order to reduce chair time and the need for re-adjustment.[2] To reduce errors in endodontics, AR was introduced on to head-mounted displays to provide audio-visual warning and correction when preparing access cavities.[16] Similarly, head-mounted systems featuring AR have proven to aid maxillofacial bone surgery through improved visualisation of the 3D relationships between anatomical structures.[2,21] Though these current applications of AR have improved clinician performance, AR has rarely been designed for patient use.

Our research investigates patient-centred denture provision by creating a virtual library of artificial teeth for use in our own augmented reality software package called ToothPick. The AR software places virtual maxillary anterior teeth into the patient's mouth in real-time, providing a simulation of the denture aesthetics. Twenty-two alternative setups with different shapes and sizes will allow the patient to virtually 'try on' and compare appearances with the swipe of a finger.

Literature shows that patients place higher levels of trust in practices that are leaders in the field.[4] As such, offering innovative dental technology which has not yet been adopted throughout the industry could increase patient confidence in the profession. In turn, dentists who are willing to adapt to the rapid technological advancements can demonstrate a higher quality of care and service.[4] Currently within the market there are two companies that use AR in cosmetic and implant restorative dentistry. Digital Smile Design,[5] developed by Christian Coachman, enhances the aesthetic smile process by providing visual representation of treatment outcomes to patients. It has been claimed that the implementation of the programme has been shown to improve patient-dentist interaction in a way that meets patients' expectations and encourages patient autonomy in treatment planning.[5] 'IvoSmile', a software application, determines exact teeth positions, shapes, sizes, and even embrasure space distances to produce an output that matches a patient's natural dentition to compare before and after dental implant surgery. Though these companies exist, research to date has not yet determined patients' perspectives on the adoption of AR in the field of prosthetic dentistry.

The aim of this study was to assess the potential effectiveness of AR technology on patient experience during the tooth selection process. Specifically, effectiveness was evaluated by analysing the ease of use of the ToothPick app interface as well as how closely the wax try-in replicated the AR simulation. Lastly, the study compared patient preference between AR and the conventional method (selection of various plastic artificial teeth) of tooth selection within the denture process.

MATERIALS & METHODS

SOFTWARE DEVELOPMENT

As a prerequisite for the software development, the research team was required to 3D scan all upper incisor and canine denture teeth available within the Leeds Dental Institute using the Solutionix Rexcan DS2 3D scanner model (Europac, Crewe, UK) and MeshLab software (www.meshlab.com) (see Figure 1). This allowed for the creation of a virtual library consisting of 22 sets of 6 teeth with various shapes and sizes that were then used to program the software application.

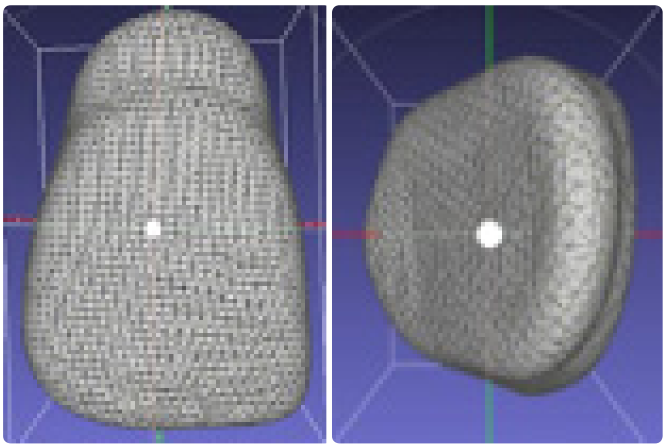

Figure 1: 3D scanning image of upper right incisor using MeshLab software.

Software development was carried out in-house at The University of Leeds. To ensure compatibility of the customised ToothPick software onto a Windows tablet PC (device used in clinic), it was written in programming language C++.[3] Camera calibration was achieved using the OpenCV library (2000), to facilitate real dimensional measurements of the face whilst compensating for lens distortions. Next, a video recording was taken to create a 3D model of the subject's face and was followed by fitting a morphable mesh[16] using facial landmarks.[14] This subject-specific facial mesh was then incorporated into a live video stream in real-time to provide position and expression information, deeming the software useable in clinic.

When augmenting new teeth within the clinical setting, markers were initially placed on the upper wax rim and plaster cast model which allowed 3D scanning through a video recording *(Figure 2)*. The markers were automatically identified in each frame and their 3D positions were determined using non-linear optimisation.[1] The outcome of this procedure indicated the curvature of the labial segment. The aforementioned library of 3D denture teeth was then virtually laid around this arch-form and positioned appropriately in the mouth. Only the mouth region was augmented, with the lips shrouding any parts of the teeth in a realistic way. Individual, customised adjustments to the incisal level and occlusal plane could be made manually in the app *(Figures 3 and 4)*.

CLINICAL METHODOLOGY

In order to carry out a clinical study, the research team underwent Good Clinical Practice (GCP) training to certify that both the members and the research followed international ethical and scientific standards. Compliance with GCP ensures that participants' rights, safety and wellbeing are protected, and that the research data is reliable.[10] An investigator site file containing all research documentation was also created and stored securely within the University of Leeds.

Case report forms (CRFs) were drafted to standardize data entry and to facilitate data analysis. These CRFs were stored within the site file along with other documentation.

This pilot study used a brief 10-question survey as the outcome measure. Due to its ubiquitous nature and its simplicity in facilitating data analysis,[6] 5-point Likert scales were incorporated within the questionnaire. To ensure the validity and reliability of the outcome measure, the questionnaires and patient information sheets (PISs) were assessed three-fold;

1. Supervisors and Clinical Associate Professors reviewed and made amendments to the research questionnaire and PISs.
2. The 'Smile Aiders' Patient and Public involvement (PPI) group at the University of Leeds School of Dentistry consists of members that are actively involved with ongoing research. A thorough review of the questionnaire and PISs were conducted to ensure the research tools were easy to understand. Feedback from the PPI group was used to modify the documents.
3. A National Health Service (NHS) Research Ethics Committee (REC) meeting was initiated in St Luke's Hospital, Bradford, UK on 20 March 2018 where a presentation of intended research and revision of documents took place. Subsequently the research project, with all resource tools in place, was granted ethical approval by the University of Leeds Dental Student REC as well as the NHS Health Research Authority and Health and Care Research Wales (IRAS project ID: 238446, REC reference: 18/YH/0110).

PATIENT SAMPLE

A sample size of thirty was pragmatically determined by the research team based on the expected number of patients available during the research period at Leeds Dental Institute. Within the sample size calculation, a proportion of non-respondents were accounted for.

Within this research study, the 'potential participants' were patients undergoing denture provision within the Leeds Dental Institute that met the inclusion and exclusion criteria below.

INCLUSION CRITERIA

Potential participants were included if:

1. The patient has capacity to give informed consent.
2. The patient has no natural upper anterior teeth.
3. The patient has the ability to read and understand the Participant Information Sheet and questionnaire which are printed in English.
4. The patient is undergoing treatment for dentures within Leeds Dental Institute or the University of Leeds School of Dentistry.

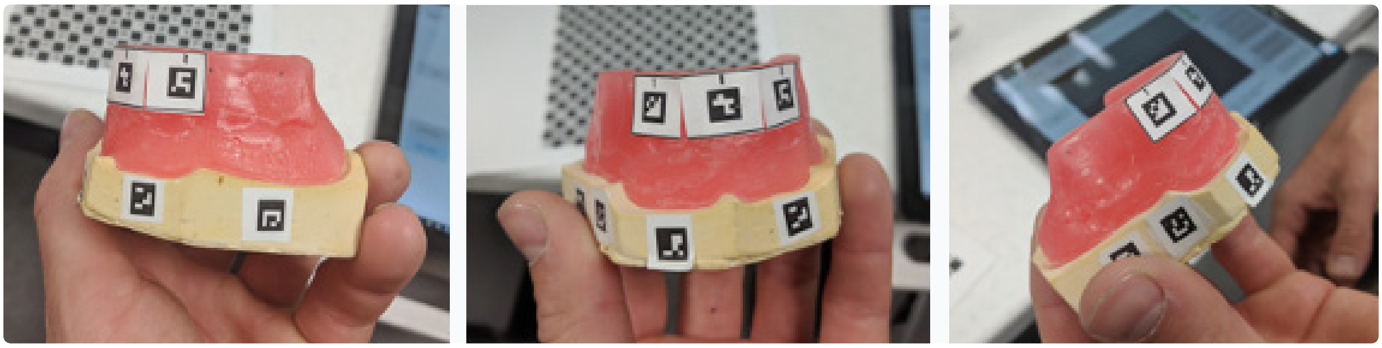

Figure 2: Sticker markers placed on upper wax rim and cast model to allow 3D scanning through a video recording using the Toothpick app.

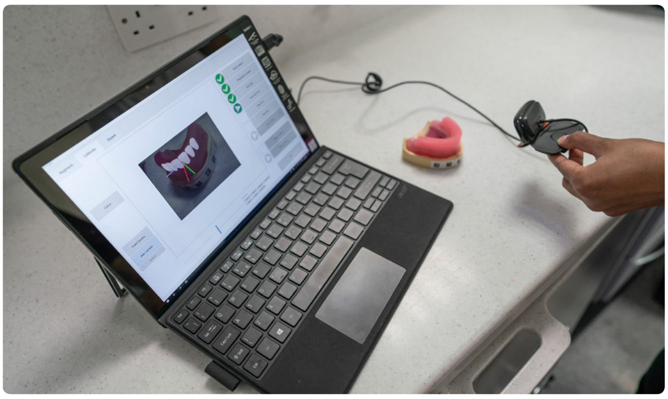

Figure 3: Augmented teeth onto a wax rim

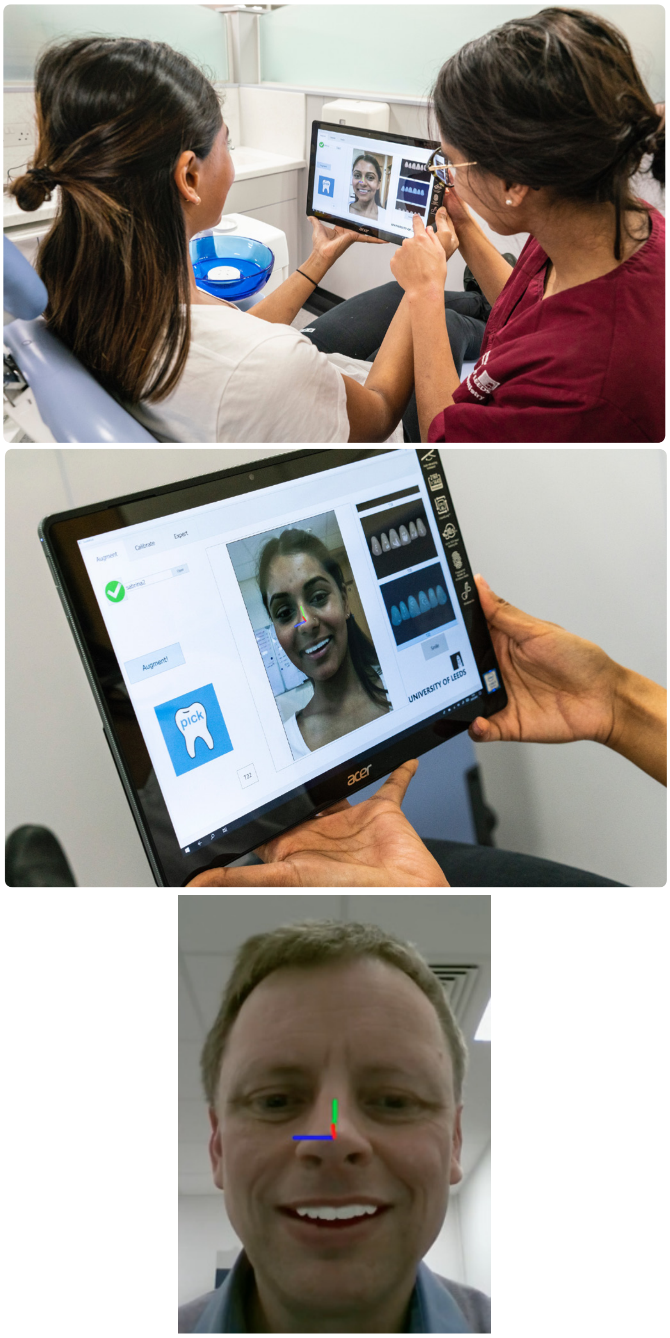

Figure 4: Demonstration of Toothpick app; enabling the user to select and modify from a library of 3D virtual teeth

EXCLUSION CRITERIA

Potential participants were excluded if:

1. The clinical use of a wax 'occlusal record block' is not part of the patient's treatment plan.
2. The patient has a visual impairment and indicates they cannot adequately assess the Augmented Reality (AR) image.
3. Written consent to take part in the research is not obtained from the patient for participating in the construction of the dentures.

DATA COLLECTION & ANALYSIS

The GCP-trained clinical research team had access to the laboratory records which indicated the name of the clinician providing the denture and the date of the next appointment, ensuring no patient details were obtained. The potential participants were approached by members of the research team and the PISs were given as well as being verbally explained. At the next visit the research team answered any questions the potential participants had and if they agreed, they were asked to sign the informed consent form.

After obtaining valid consent, the study followed selected patients over two clinical appointments (2.5 hours each); at the jaw registration and wax try-in stages of the denture-making process. At the first appointment, the patient was given the AR app on a tablet device and was asked to select their desired shape and size of denture teeth. The study involved videotaping and photographing the final selection which was given to the laboratory to process before the next appointment. At the second appointment, the patient was given their wax try-in and once again similar videotaping and photographing occurred. The patient compared videos and images from each appointment and their opinion on the ease of use of the app was recorded. In addition, the extent to which the denture was replicated from the AR app into the physical wax try-in was measured via the questionnaires (*Appendix 1*).

The data collected was analysed using simple descriptive statistics in Excel software, where the results to date are represented qualitatively through graphs and reported quantitatively as percentages. Due to the small number of participants recruited, significance testing was deemed inappropriate at this stage, though the study is on-going to increase the sample size. Results were interpreted, and conclusions were drawn after analysis.

RESULTS

To date, a total of seventeen participants have been approached to take part in this research project, of which eight did not give consent. The study therefore collected data from nine participants that completed the first appointment and seven participants that completed the second appointment,

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giving a response rate of 41% and 53%, respectively. The sample size consisted of three males and four females, all aged 61 years and over.

Most participants (67%) reported that the app was easy to use, with a higher distribution of males ($\bar{x}$=4.25) than females ($\bar{x}$=3.4). 56% agreed that this enabled them to visualise how their front upper teeth would look, giving them a better understanding of the proposed treatment outcomes. With increased understanding, the majority (67%) agreed that the app gave them a more informed choice compared to the conventional method *(Figure 5)*.

The majority of the participants agreed or strongly agreed that the position & alignment (57%), size (71%) and shape (86%) of the wax try-in denture outcome closely represented the AR simulation. Overall, 71% agreed or strongly agreed that their expectations were met in the way that the wax try-in closely replicated what was projected in the AR simulation *(Figure 6)*.

A binary outcome for the final question was assessed. At the first appointment, 78% preferred the app over the conventional method. By the second appointment, this increased to 86% of participants preferring the app over the conventional method for the selection of denture teeth. Before the trial of this study, our research team determined, within our protocol,

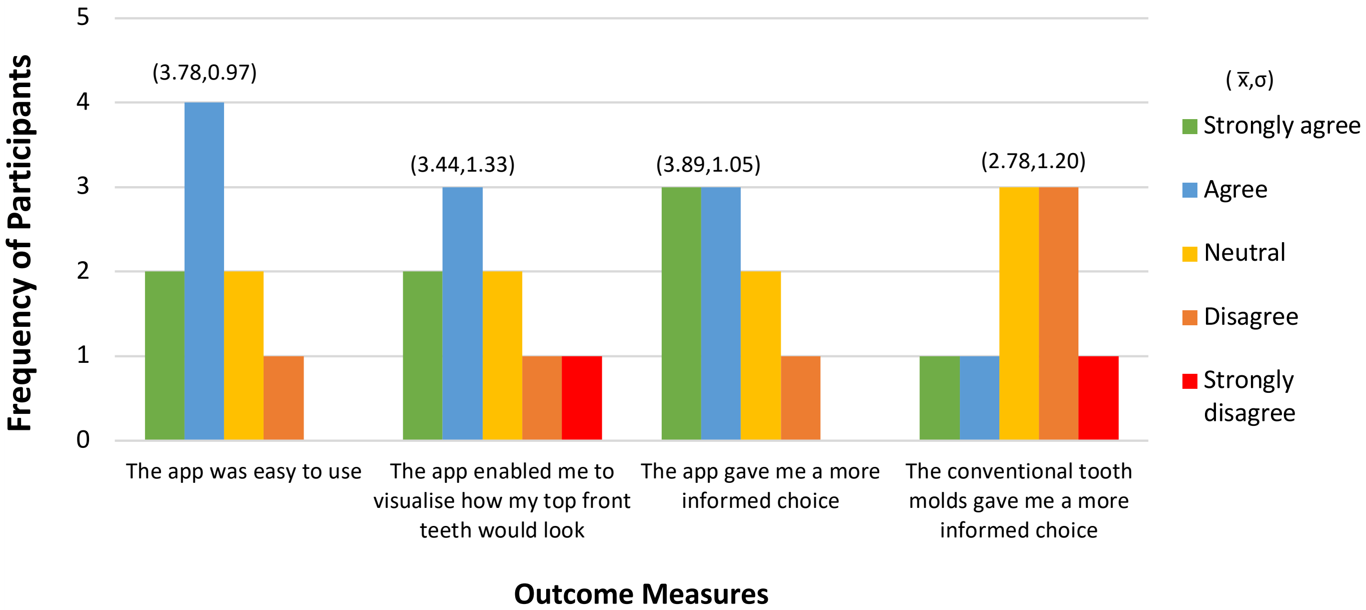

Figure 5: Graph showing Perceived Usefulness and Ease of Use of AR

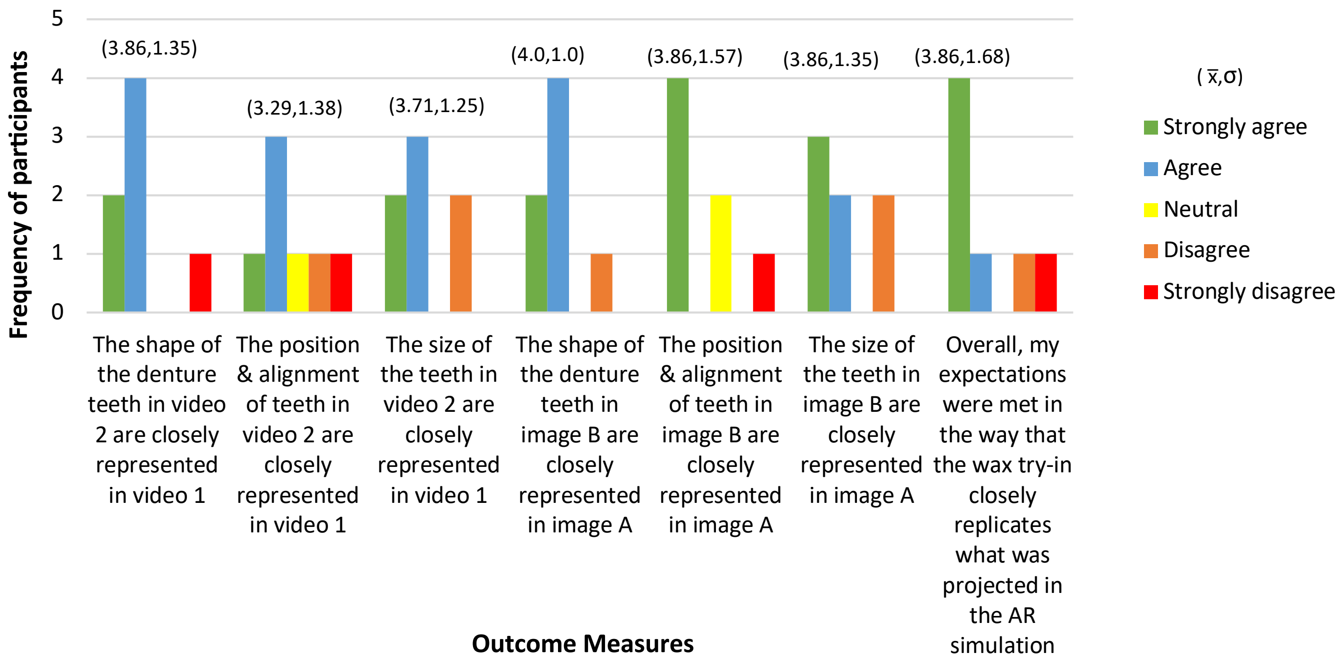

Figure 6: Graph showing Participant views on Representation of AR

that a clinically significant difference would be demonstrated if 70% of respondents indicated one favourable method of tooth selection. For this scenario, a sample size of 30 patients produces a two-sided 95% confidence interval with a width equal to 0.35 when the sample proportion is 0.7. Though 70% was achieved, a sample size of n=30 was unattainable and therefore this statistical testing was inappropriate *(Figures 7 and 8)*.

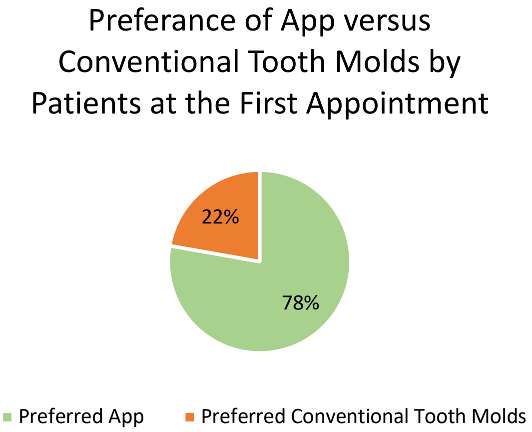

Figure 7: Chart showing preferences of AR versus conventional tooth selection at First Appointment

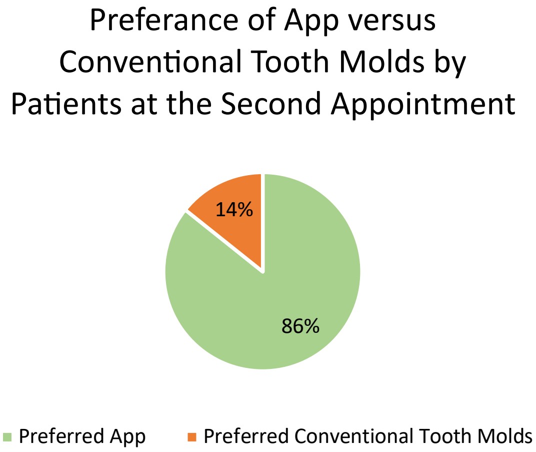

Figure 8: Chart showing preferences of AR versus conventional tooth selection at Second Appointment

DISCUSSION

An application that could accurately determine the desired aesthetic position of 3D virtual teeth to the parameters of the mouth could not only be used to communicate prospective treatment outcomes but also to attain valid patient consent.The main finding of this study was that the ToothPick AR app was well received by patients. The majority preferred the app over the conventional method for selection of denture teeth due to increased ease of use, providing a more informed choice and meeting expectations in closely replicating the AR simulation.

The advantages of AR technologies are clear; it is an appropriate platform that can provide realistic treatment outcomes for patients in the area of prosthodontics and can provide clinicians and technicians better chances of achieving favourable results. The biggest contribution of this research is the development of an application with the participation of actual users. To the author's knowledge, the ToothPick app is the first of its kind to implement AR in the area of prosthodontics. The innovative study design and intricate software user interface with the creation of a virtual library of 3D-printed prosthetic teeth introduces a new method of measuring patient expectations in treatment outcomes. Furthermore, this process allows a virtual confirmation before construction of the final denture. This process of virtual trial-and error will effectively eradicate repeated patient visits, additional labour and material costs and wasted chair time[13] caused by unacceptable tooth selection. Additionally, it improves communication by introducing a visual component through the implementation of its interactive technology. This increases patient autonomy within the clinical setting which in turn meets their expectations of the planned treatment.[18]

However, in order to gain more acceptance in the use of AR technologies, a number of improvements within the software could be made. The ToothPick app tested for replication in the shape and size of prosthetic teeth, however the software exhibited a limitation in the display of one standardised colour. The study of colour is an integral part of denture aesthetics[13] and this limitation may have inhibited patients' ability to visualise treatment outcomes accurately. Another limitation, described in the software methodology, was the inability to augment structures outside the mouth region due to the 2-dimensional markers. This meant that apart from the augmentation of the upper anterior teeth, the app blacked out posterior teeth as well as the lips. This created the illusion of the upper teeth appearing longer and wider, and it drew more attention to the prosthetic teeth than would normally occur in reality. Once again, this could potentially distort patients' ability to visualise treatment outcomes, making the outcome measure of AR replication less favourable. In addition, technical errors did occur during the trial such as software lag in the systems processes, making the use of the software interface more challenging. Within the study, yet another barrier in the usability of the tablet device and AR app may potentially lie within our sample population demographics. Our study sample consisted of all participants over the age of 61 years, though this was expected as the likelihood of tooth loss increases with age.[11] The use of tablet devices in older adults (65-76 years) was explored by Vaportzis *et al.*[17] and negative emerging themes of increased complexity, feelings of inadequacy and scepticism about using technology were highlighted. The effects of this technological barrier may be two-fold. In the first instance, it may have acted as a contributing factor in the high number (58.8%) of participants that refused to consent to this research project. In the second instance, for those that did consent, it may have resulted in a non-response bias whilst skewing the preference of the conventional method over the app for denture tooth selection. Regardless of this possibility, 67% of participants agreed that the app was easy to use.

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The questionnaire itself presented with challenges. Though reviewed by various groups to increase the validity and reliability of outcome measures, more succinct and fewer questions would have likely been better received by patients. Having trialled these questionnaires in this pilot study, appropriate amendments for further research should be made. Additionally, participants filling out questionnaires within the clinical setting may have led to a reporting bias in which participants may have felt obliged to answer in a particular manner either to maintain good relations with their clinician and / or to prevent consequences to their future treatment. This was controlled by stating within the PISs that all subjects have the right to refrain from participation and are free to withdraw consent at any point without any consequences. This can be revised by the research team and can be avoided by having participants complete questionnaires outside of the clinical bay, for example in the dental reception with support from a neutral member of staff if needed.

With a high non-response rate, no statistical significance testing could be carried out. However, the study will continue to be on trial within Leeds Dental Institute to increase the sample population and remedy the statistical analysis to include significance testing. When the appropriate sample size is achieved (n=30), statistical evaluation by age and gender will use a chi-squared analysis and when appropriate, further Fisher Exact Tests would be calculated through subdivision of a 2 X 2 table. The final binary question for preference of AR or the conventional method for tooth selection will be reported using a 95% confidence interval.

The findings of this study were consistent with published literature. This research found that 67% of the participants agreed that the app gave them more informed choice compared to the conventional method. This was supported by Canbazoglu *et al.*[4] who concluded that 3-dimensional applications to illustrate treatment outcomes in implant prosthetics not only improved dentist-patient interactions and behaviour but enhanced the patient's right to make informed decisions. In accordance with these findings, AR in surgery has been shown to improve clinician communication[7] resulting in improved clinical decision making by the dental team.[15] Within this study, 71% of patients agreed that AR met their expectations, which corroborates the conclusions when Digital Smile Design[5] was employed as an auxiliary tool in periodontal surgery.[15]

At the same time, this study differs from similar research in the literature in that most related studies do not present an augmented reality software application with participation of actual patient users. Other research has proved AR to be very beneficial for orthognathic and maxillofacial dental surgeons in the navigation and visualisation of anatomical structures during surgery.[12] The development of ToothPick is novel in the area of denture prosthodontics and is unique in that it encourages a mutualistic relationship by not only offering patients clinical information but supporting them in responding to the information presented.

Although the research aims of this study do not include the clinician perspective, counterpart research questionnaires indicated that 50% of clinicians found ToothPick to be more time consuming than conventional methods of tooth selection. Interestingly, this contradicts related literature where Canbazoglu *et al.*[4] found that dentists claimed their mobile phone application saves clinical time and effort.

Augmented reality technology within the ToothPick app has the potential to positively impact the dentist-patient interface within prosthetic dentistry. It has the potential to save clinical time and cost, increase patient autonomy allowing patients to have more control and make more informed decisions within their treatment. While AR systems are costly for daily use within dental clinics,[7] technological applications in dentistry continues to advance and may even become more imperative as an alternative to the conventional methods of communication with patients.[4]

It should be emphasised that the app was only intended for research purposes, to investigate the potential for AR in this setting. Given the positive outcomes, more effort is warranted in refining the augmentation as noted above, and this is an ongoing aim for future research and development.

The implementation of the app within a clinical setting allowed us to recognise some drawbacks of the research and in turn, continuous developments of ToothPick are ongoing to make the app more effective. Additionally, an increase in patient enrolment would remedy the limitation of a low sample size and in turn increase the validity of the research for future applications. Our virtual library of tooth moulds and digital software may serve as a platform for advancement in research within the University of Leeds School of Dentistry. If successful, the AR app software may become available and distributed to general dental practitioners for a free, open access trial. The app would be added to the LeedsDigitalDentistry website (https://leedsdigitaldentistry.com/) along with other research collaborations.

CONCLUSION

With the advancement in Information Technology, there is no doubt that digital solutions will continue to play an increasing role within the dental setting. In conclusion, a user-focused methodology was successfully implemented to develop an AR dental application. Reported patient preference of AR due to ease of use and accuracy in replicating AR simulation compared to conventional methods is a major advantage in the selection of denture teeth. Nonetheless, there is still much room for improvement. The implementation of this pilot study within the dental setting allowed us to recognize the pitfalls and seek progression with the research and the app itself. A digital design process that becomes more time efficient will improve the ease of implementation within a clinical setting. As ToothPick continues to develop along with our understanding of its capabilities, AR will move towards becoming more accessible,

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affordable and a pivotal part of patient care that will gradually challenge the traditional dental clinical approaches. This study has shown how ToothPick enabled patients to visualise their final treatment outcome, helped to form realistic expectations and enhanced the consent process. Clinical accuracy and data security implications should be further investigated. Supplementary research in this evolving area is welcomed.

ACKNOWLEDGEMENTS

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Ethical approval REC reference: 18/YH/0110

ABBREVIATIONS

AR: Augmented Reality

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APPENDIX 1

PATIENT QUESTIONNAIRE

Research number:

To be filled in by the patient:

Please fill in the questionnaire below. For each question please select the answer that most closely corresponds with your thoughts.

1. Gender (M/F/NB)

   Male: ☐ Female: ☐ Non binary: ☐

2. Patient age:

   <40 | 41-50 | 51-60 | 61-70 | >70

3. The shape of the denture teeth in video 2 are closely represented in video 1

   Strongly agree | Agree | Neutral | Disagree | Strongly disagree

4. The position & alignment of teeth in video 2 are closely represented in video 1

   Strongly agree | Agree | Neutral | Disagree | Strongly disagree

5. The size of the teeth in video 2 are closely represented in video 1

   Strongly agree | Agree | Neutral | Disagree | Strongly disagree

6. The shape of the denture teeth in image B are closely represented in image A

   Strongly agree | Agree | Neutral | Disagree | Strongly disagree

7. The position & alignment of teeth in image B are closely represented in image A

   Strongly agree | Agree | Neutral | Disagree | Strongly disagree

8. The size of the teeth in image B are closely represented in image A

   Strongly agree | Agree | Neutral | Disagree | Strongly disagree

9. Overall, my expectations were met in the way that the wax try-in closely replicates what was projected in the AR simulation

   Strongly agree | Agree | Neutral | Disagree | Strongly disagree

10. Overall, which method of tooth selection did you prefer?

    Augmented Reality (AR): ☐

    Conventional tooth selection: ☐