Original Article

Evaluation of a novel augmented reality educational tool and its effects on patient experience: A randomized controlled trial

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ABSTRACT

Introduction: Patient education is an essential element of the treatment pathway. Augmented reality (AR), with disease simulations and three-dimensional visuals, offers a developing approach to patient education. We aim to determine whether this tool can increase patient understanding of their disease and post-visit satisfaction in comparison to current standard of care (SOC) educational practices in a randomized control study.

Methods: Our single-site study consisted of 100 patients with initial diagnoses of kidney masses or stones randomly enrolled in the AR or SOC arm. In the AR arm, a physician used AR software on a tablet to educate the patient. SOC patients were educated through traditional discussion, imaging, and hand-drawn illustrations. Participants completed pre- and post-physician encounter surveys adapted from the Press Ganey® patient questionnaire to assess understanding and satisfaction. Their responses were evaluated in the Readability Studio® and analyzed to quantify rates of improvement in self-reported understanding and satisfaction scores.

Results: There was no significant difference in participant education level ($P = 0.828$) or visit length (27.6 vs. 25.0 min, $P = 0.065$) between cohorts. Our data indicate that the rate of change in pre- to post-visit self-reported understanding was similar in each arm ($P \geq 0.106$ for all responses). The AR arm, however, had significantly higher patient satisfaction scores concerning the educational effectiveness and understanding of images used during the consultation ($P < 0.05$).

Conclusions: While AR did not significantly increase self-reported patient understanding of their disease compared to SOC, this study suggests AR as a potential avenue to increase patient satisfaction with educational tools used during consultations.

INTRODUCTION

Augmented reality (AR) is a tool that is used to enhance one's perception of the surrounding environment by inserting virtual objects into the space of the real world.[1,2] AR provides the potential for physicians to better educate patients through enhanced visualization. This may result in improved quality of care, better patient understanding of their disease, and increased patient satisfaction. Research studies have shown that multisensory learning with the incorporation of two-dimensional and three-dimensional (3D) images and diagrams helps improve

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patient comprehension of diagnosis and treatment options, as well as their overall experience.[3-6]

Patient satisfaction has become an important metric for value-based care in the American Healthcare System. In 2010, the Patient Protection and Affordable Care Act and the Health Care and Education Reconciliation Act changed the way hospitals and physicians were evaluated. Factors assessing the quality of health care include both patient experience and satisfaction.[7,8] Furthermore in 2011, the Centers for Medicare and Medicaid Services implemented a new policy that adjusted reimbursement payments based on patient satisfaction scores.[9] The integration of AR in a urologic clinic is novel and could potentially improve patient understanding of complex urological diseases, such as nephrolithiasis and renal cancer. Nephrolithiasis is a common urological condition affecting approximately 10.6% of men and 7.1% of women in the United States, with increased incidence over the past decade.[10] Similarly, renal cell carcinoma is the ninth most common malignancy and is estimated to account for 3% of all cancers worldwide.[11,12] Both urologic illnesses have a variety of treatment options and management plans, which can confuse and frustrate patients. In addition, as both diagnoses are heavily dependent on visualization through imaging, they serve as an ideal candidate for AR-enhanced education.

AR has the potential to improve the quality of shared patient–physician decision-making by improving patient understanding of the diagnosis and treatment. The purpose of this study is to test the efficacy of the novel use of AR models for patient satisfaction and education of two common urologic conditions in new patient consultation visits to a urology clinic.

METHODS

A single-site, prospective, randomized study was employed at our center and approved by the Ethics Committee of Atrium Health (IRB 00083100, approved June 20, 2016). The study adhered to the ethical guidelines of the Declaration of Helsinki and its amendments. Our single study physician is a board-certified, fellowship-trained urologist with over 6 years in practice. Pre- and post-physician encounter surveys were developed, and questions were chosen based on the Press Ganey® patient questionnaire, a commonly used, validated outpatient satisfaction survey in the US and answered on 5-point Likert-type scales ranging from "1-Strongly Disagree" to "5-Strongly Agree."[13] The surveys were analyzed through Readability Studio® software to demonstrate they were completed at an 8th grade reading level. These survey questions were used to assess both patient understanding and post-visit satisfaction [Supplementary Figures 1 and 2].

New patients, who provided written consent before enrolment and were referred to the clinic for an initial consultation for urolithiasis or a new renal mass, were randomized to either the standard of care (SOC) or AR group. For SOC participants, the physician conducted a new patient visit with standard resources. In contrast, in the AR group, the physician used appropriate AR-supported models on a tablet during consults to explain the patient's disease state [Figure 1]. Time spent by the physician in the room with the patient was recorded.

The AR software representing 3D images of kidney cancer and stones was developed in collaboration with Atrium Health and Charlotte Area Health Education Centers (AHEC) [Figure 1]. A tablet was held up to the patient or physician's body to superimpose the AR pictures with the patient's real-world view. These 3D computer models provided a composite image that could be magnified, rotated, and shown in cross-section. This tool demonstrated only kidney anatomy of the presenting problem. Treatment options were not a feature of the software and were instead discussed with patients in reference to the AR model.

The primary objective of this study was to compare the rates of improvement in self-reported understanding from pre- to post-visit questionnaires for each of the five target questions between those receiving SOC or AR educational experience [Figure 2]. The secondary aim was to assess post-visit patient satisfaction between the two conditions [Supplementary Figure 2]. The study was designed to enroll and randomize participants in equal allocation to the study arms. A single-stage design was used to test the hypothesis that the difference in satisfaction-improvement rate is ≤ 0.25, and a sample size of 186 evaluable subjects per question would provide approximately 80% power to reject the null hypothesis, assuming the rate of improvement in satisfaction in the SOC group is 0.5. To preserve an overall Type I error rate of 0.05, each of the five target questions was intended to be

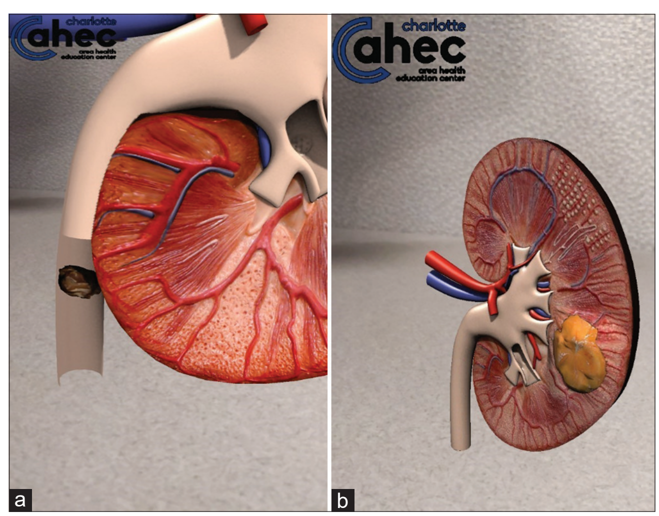

Figure 1: Augmented reality models indicating nephrolithiasis in the urinary system (a) and mass within the renal parenchyma (b)

tested at the two-sided alpha = 0.01 significance level (using the Bonferroni correction).

However, the study was terminated as it became evident that enrolment to full accrual was not feasible before study resources were exhausted. Thus, the study was closed to accrual after complete data for 100 subjects were collected, and the results were presented understanding the enrolment goal was not met [Supplementary Figure 3].

Patients' clinicodemographic factors, time spent with the physician, and survey responses were summarized and described, as well as the rates of improvement (≥1 point increase, where eligible). Comparisons between the arms were performed with Fisher's exact test or Wilcoxon rank-sum test where appropriate. Logistic regression modeling was used to estimate odds of improvement in satisfaction between the arms, adjusted for diagnosis. Statistical analysis was performed using SAS version 14.1 (SAS Institute, Cary, NC USA); $P < 0.01$ and $P < 0.05$ were considered statistically significant for the primary objective and all other analyses, respectively.

Patients' demographics and pre- and post-survey responses were summarized. Gender, diagnosis, and primary language were compared between the study arms using Fisher's exact test. Survey responses were summarized and evaluation of the patient's satisfaction and understanding of the disease were calculated between the pre- and post-visit surveys. Time spent with the physician was reported and compared between the arms with Wilcoxon-rank sum test. Logistic regression modeling was used to estimate odds of improvement in satisfaction between the arms, adjusted for diagnosis. Proportions indicating the highest level of satisfaction on the post-visit questionnaire were compared between the arms with Fisher's exact test. Statistical analysis was performed using SAS version 14.1. The authors confirm the availability of, and access to, all original data reported in this study.

RESULTS

Patient characteristics

In this one-physician study, all 100 analyzed subjects completed the survey both before and after meeting with the physician. Eighty-nine percent of participants were aged 35 or older at the time of the survey; 34% were aged 65 or older [Table 1]. Most patients spoke English as a primary language (98%). Fifty-six percent of diagnoses were renal masses and 44% were stones. No significant differences in gender ($P = 0.317$), diagnosis ($P = 0.522$), or primary language ($P > 0.999$) were evident between the AR and SOC arms.

1	I understand why I am in the office today.
2	I understand my diagnosis.
3	I feel educated on possible treatments for my diagnosis.
4	I am aware of the complications associated with proposed treatments.

Figure 2: Target questions to assess patient satisfaction and understanding

Pre-visit understanding

Figure 3a demonstrates participants' clinic experience and understanding based on the pre-visit questionnaire. In both arms, most patients (AR 76% and SOC 69%) demonstrated strong competency for the purpose of their consultation. Fewer patients (AR 45% and SOC 27%) reported they strongly agree that they understood their diagnoses before physician encounter. Less than a third of patients, in either arm, reported "Strong agreement" in feeling educated on possible treatments for their diagnoses or were aware of complications with the proposed treatments.

Post-visit understanding

Participants' understanding of their disease was assessed again following the physician encounter by revisiting the initial five questions [Figure 3b]. Assessing the difference between pre- and post-visit scores, we found no significant difference between either study arm [Table 2]. Rates of improvement were also calculated and ranged from 54% to 93% in evaluable patients. In both arms, patients experienced the greatest improvement in feeling educated on possible treatments. Odds of improvement were estimated, and no significant difference was observed between the two intervention arms or patient diagnosis of stone versus mass.

Table 1: Subject characteristics

Characteristic	Frequency (%)		
	Overall (*n*=100)	AR (*n*=51)	SOC (*n*=49)
Gender			
Female	49 (49)	22 (43)	27 (55)
Male	51 (51)	29 (57)	22 (45)
Age			
18–24	3 (3)	0	3 (6)
25–34	8 (8)	4 (8)	4 (8)
35–44	13 (13)	8 (16)	5 (10)
45–54	22 (22)	9 (18)	13 (27)
55–64	20 (20)	10 (20)	10 (20)
65–74	23 (23)	13 (25)	10 (20)
75+	11 (11)	7 (14)	4 (8)
English as a primary language			
No	2 (2)	1 (2)	1 (2)
Yes	98 (98)	50 (98)	48 (98)
Level of education			
8th grade or less	2 (2)	1 (2)	1 (2)
Some high school, did not graduate	8 (8)	5 (10)	3 (6)
High school graduate or GED	11 (11)	4 (8)	7 (14)
Some college or 2-year degree	35 (35)	16 (31)	19 (39)
4-year college graduate	23 (23)	13 (25)	10 (20)
>4-year college degree	21 (21)	12 (24)	9 (18)
Diagnosis			
Mass	56 (56)	27 (53)	29 (59)
Stone	44 (44)	24 (47)	20 (41)

AR=Augmented Reality, SOC=Standard of care

Table 2: Odds ratios of improvement in augmented reality versus standard of care and kidney mass versus kidney stones

Questions	AR		SOC		Intervention (AR vs. SOC)		Diagnosis (mass vs. stone)	
	n	Satisfaction-improvement rate (%)	*n*	Satisfaction-improvement rate (%)	OR (95% CI)	*P*	OR (95% CI)	*P*
I understand why I am in the office today	12	67	15	67	1.00 (0.20–5.02)	>0.999	1.00 (0.15–6.88)	>0.999
I understand my diagnosis	22	82	31	74	1.56 (0.41–6.03)	0.516	0.87 (0.22–3.40)	0.516
I feel educated on possible treatments for my diagnosis	30	93	30	83	3.94 (0.75–20.78)	0.106	1.18 (0.27–5.06)	0.106
I am aware of the complications associated with proposed treatments	32	81	27	70	2.01 (0.83–4.86)	0.122	1.17 (0.48–2.84)	0.732
Carolinas HealthCare System uses the most advanced technology to care for patients	26	54	29	55	0.81 (0.34–1.92)	0.628	1.87 (0.76–4.56)	0.172

SOC=Standard of Care, AR=Augmented reality, OR=Odds ratio, CI=Confidence interval

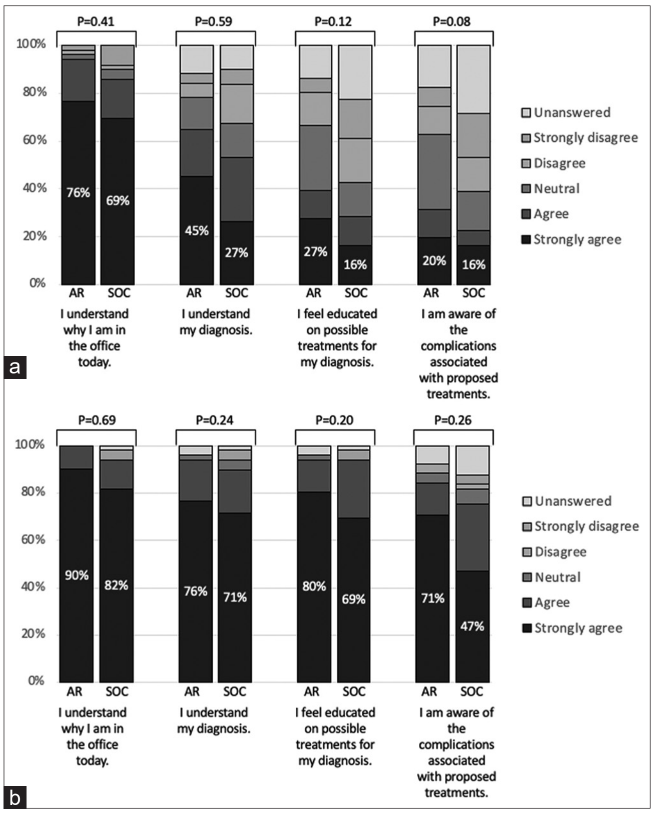

Figure 3: (a) Pre-visit understanding survey questionnaire item-level responses. (b) Post-visit understanding survey questionnaire item-level responses. AR = Augmented reality, SOC = Standard of care

Post-visit satisfaction

Additional satisfaction questions were assessed in the post-visit survey. The greatest proportion of participants over both arms reported high satisfaction ratings on "The doctor answered all of my questions" [Figure 4]. The proportion of participants reporting strong agreement was significantly higher in the AR arm compared to the SOC group on the question "The pictures my doctors used were easy to understand" (AR 84% vs. SOC 57%; P = 0.011). Similarly, rates of agreement were significantly different between the two groups on questions "The pictures my doctor used helped me understand my diagnosis" (AR 86% vs. SOC 59%; P = 0.009) and "The pictures used by my doctor helped me understand why a complication could occur during treatment" (AR 67% vs. SOC 43%; P = 0.049). Finally, patients in the AR group reported significantly higher satisfaction with "The doctor answered all of my questions" (AR 92% vs. SOC 78%; P = 0.042). There were no significant differences observed in rates of strong agreement between the two arms on the other post-visit survey questions.

Duration of visit

We found no significant difference between the average time spent in the AR arm (27.6 min) and time spent in the SOC arm (25.0 min; P = 0.065).

Physician perspective

In a detailed debriefing of our study physician, he indicated an overall preference for the traditional approach; however, this was self-admittedly due in part to his familiarity with drawing pictures out for patients. He indicated the AR tool was easy to use with no significant learning curve. Common difficulties included minor software glitches which were resolved quickly by closing and reopening the application. Anecdotally, he noticed AR patients were more engaged and tended to ask more questions. Some, he added, wanted to explore the tool themselves outside the clinic.

DISCUSSION

The complex pathologies of kidney cancer and stone disease and their various treatment options can lead to lengthy and perplexing discussions. In addition, patients may have a low health literacy which can further contribute to confusion about disease management. We hypothesized that incorporating the AR model into our practice would increase levels of both patient understanding and satisfaction during clinical encounters. The results of this randomized, prospective study demonstrated that the AR group had significantly higher rates of satisfaction compared to the SOC group regarding the understandability and helpfulness of visuals used during the office visit. We found no significant

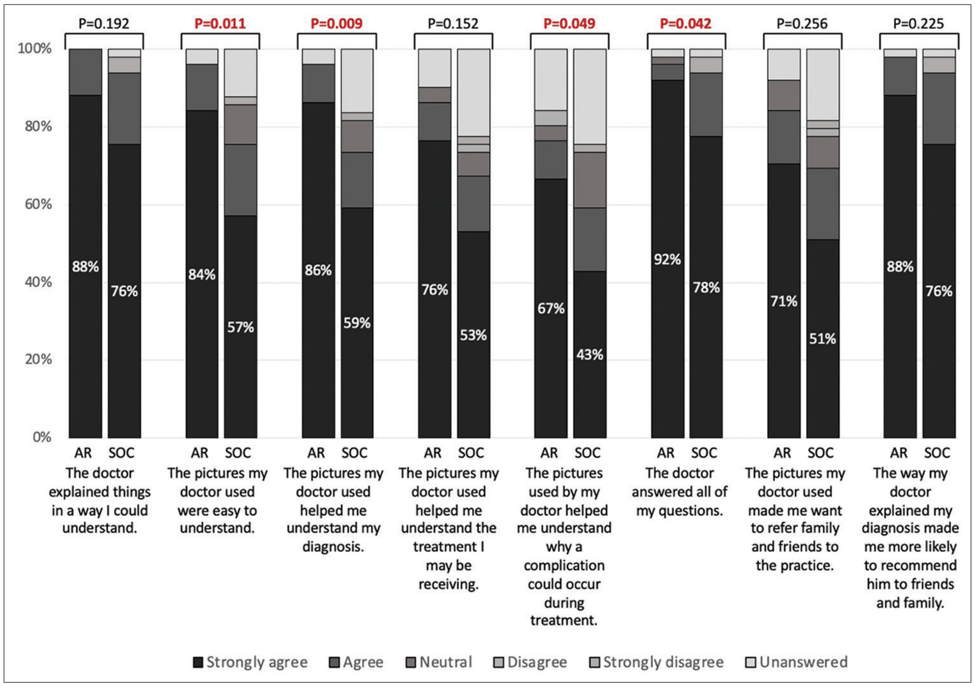

Figure 4: Satisfaction assessed on the post-visit questionnaire. AR = Augmented reality, SOC = Standard of care

difference, however, in the rate of pre- to post-visit improvement in self-reported understanding between either arm.

Previous studies have evaluated the use of AR as a learning tool, specifically in medical training and surgical interventions. Zhu *et al*. reported that 96% of papers reviewed about AR and health-care education reported the tool as useful by improving performance accuracy, accelerating learning, and shortening the learning curve with a better understanding of spatial relationships.[1]

Few studies, however, have explored the relationship between this type of multisensory learning and patient education and satisfaction. In a qualitative study of patients' evaluation of diagnostic images, Carlin *et al*. showed that patients believed images enhanced the understanding of their problem and fostered a more trusting relationship with the physician during the visit.[5] Another study with 187 patients reported the use of digital images in surgical consultation visits not only improved communication between patient and doctor but also resulted in a high degree of satisfaction and understanding.[14]

Similarly, we found AR participants reported significantly higher satisfaction rates regarding the ease of understanding and helpful nature of visual aids compared to SOC patients. In addition, this data demonstrates that significantly more AR participants felt that during their visit, all their questions were answered by the doctor, potentially indicating improved doctor-patient communication. Interestingly, this study did not find a significant difference in the rate of understanding improvement between AR and SOC groups, as suggested by other studies. Our results are similar, however, to a recent review that suggested patient self-reported understanding did not significantly change with AR tools.[15] The review did report, however, that most of the sampled studies concluded that patient's actual knowledge did improve with the use of AR.

Patient satisfaction with the visit was significantly higher in the AR group. This may suggest that while visual aids are helpful for patient education and understanding, the most important aspect of visit satisfaction is the doctor–patient interaction and connection. As previously mentioned, our study physician anecdotally noticed an increase in patient engagement in the AR group; this could help explain why their patient satisfaction scores were higher than the SOC group even though their self-reported understanding was similar. Given that a previous study by Kosa *et al*. found that incorporating AR tools into a community-level disease awareness event increased public engagement as reflected by positive attitudes, there are meaningful links between AR, engagement, and satisfaction.[16] The results of this current study build on this and other existing evidence that multisensory learning, specifically AR, may help improve patient understanding of their disease and consultation satisfaction.[14]

In addition, given that our pre-visit survey indicated that less than a third of our patients reported "Strong agreement" that they were educated on possible treatments and understood treatment complications before their visit, physicians must be sure to fully explain treatment options. Although our study did not find a significant difference in the average time our study physician spent with patients in each arm, there could be significant differences with other providers or in other centers. Given the fixed nature of the protocol for using AR with patients in relation to the SOC methods, implementing AR tools in treatment consultations could help prevent shorter consultation times that impede patient understanding.

This study is not without its limitations. The Press Ganey® survey is dependent on patient participation and is limited by patient cooperation. It is also important to note that there may be factors not included in the survey that may influence patient satisfaction, such as possible personal biases. In addition, as only 100 patients completed the study, the small sample size could introduce bias. There was also an 18% difference in the number of participants that reported strong understanding of their diagnosis in the pre-visit questionnaire, with AR at 45% and SOC 27%. This can most likely be explained by our relatively small sample size. Our limited cohort size may also have limited our ability to detect significant differences between the two arms. Future studies may eliminate possible bias and underpowered statistical analysis by accruing more patients.

Beyond the sample size, the age of the patient population used in the sample could have impacted the results. Over 1/3 (34%) of the subjects in the study were over the age of 65 years, and only 11% of patients were 34 or younger. It is possible that older individuals may be less likely to appreciate and easily learn from AR since they grew up with lower levels of exposure to digital media.

This study augments current research which suggests AR could be a powerful tool to assist in patient satisfaction and interaction with the physician. These tools may also be particularly suited for nontraditional office visits, especially as virtual visits become more commonplace after COVID-19. Alternative methods of integrating AR tools into patient care could also involve their distribution before and/or after office visits to augment traditional learning. Giving these tools out to patients before visits could help to close their health literacy gap. Future research is necessary to elucidate the full potential of AR in patient education and the best mechanism of integration.

CONCLUSIONS

While there was no difference in the rate of understanding improvement, patients in the AR group reported higher levels of satisfaction regarding the usefulness and understanding of visual images and having all questions answered compared to SOC patients. This suggests that AR models may be able to enhance the relationship between patients and physicians. As technology continues to advance, finding ways to integrate it into the health-care system for the benefit of the patient's education and satisfaction has the potential to improve patient experience.

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Pre-Visit Questionnaire

Survey instructions: Answer each question by filling in the circle to the left of your answer.

ABOUT YOU:

1. Your Gender
   - o Male
   - o Female
2. Your Age
   - o 18-24 years
   - o 25-34 years
   - o 35-44 years
   - o 45-54 years
   - o 55-64 years
   - o 65-74 years
   - o 75 years or older
3. I am a:
   - o New patient
   - o Returning patient
4. Is English your first language?
   - o Yes
   - o No
5. What is the highest grade or level of school that you have completed?
   - o 8th grade or less
   - o Some high school, but did not graduate
   - o High school graduate or GED
   - o Some college or 2-year degree
   - o 4-year college graduate
   - o More than 4-year college degree

INSTRUCTIONS: Please rate how strongly you agree or disagree with each of the following statements by circling the corresponding number. If you feel that question does not apply to you, please mark "Does Not Apply".

Rank how much you agree or disagree with the following statements:	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**	**Does Not Apply**
7. I understand why I am in the office today	1	2	3	4	5	N/A
8. I understand my diagnosis	1	2	3	4	5	N/A
9. I feel educated on possible treatments for my diagnosis	1	2	3	4	5	N/A
10. I am aware of the complications associated with proposed treatments	1	2	3	4	5	N/A
11. The nurses and medical staff are friendly and courteous	1	2	3	4	5	N/A
12. The office is clean and well-maintained	1	2	3	4	5	N/A
13. Carolinas HealthCare System uses the most advanced technology to care for patients	1	2	3	4	5	N/A

Supplementary Figure 1: Pre-visit questionnaire

Post-Visit Questionnaire

Survey instructions: Answer each question by filling in the circle to the left of your answer.

YOUR CARE FROM THIS PROVIDER:

1. During this visit, did this provider explain things in a way that was easy to understand?
   - Yes, definitely
   - Yes, somewhat
   - No

2. During this visit, did this provider listen carefully to you?
   - Yes, definitely
   - Yes, somewhat
   - No

3. During this visit, did this provider give you easy to understand information about these health questions or concerns?
   - Yes, definitely
   - Yes, somewhat
   - No

4. During this visit, did this provider spend enough time with you?
   - Yes, definitely
   - Yes, somewhat
   - No

5. Using any number from 0 to 10, where 0 is the worst provider possible and 10 is the best provider possible, what number would you use to rate this provider?
   - 0 Worst provider possible
   - 1
   - 2
   - 3
   - 4
   - 5
   - 6
   - 7
   - 8
   - 9
   - 10 Best provider possible

6. Would you recommend this provider's office to your family and friends?
   - Yes, definitely
   - Yes, somewhat
   - No

INSTRUCTIONS: Please rate how strongly you agree or disagree with each of the following statements by circling the corresponding number. If you feel that question does not apply to you, please mark "Does Not Apply".

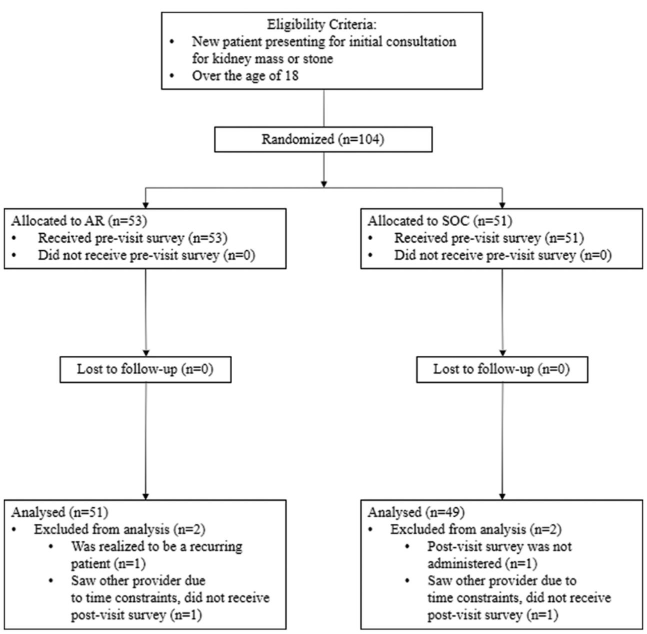
Rank how much you agree or disagree with the following statements:	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Does Not Apply
7. I understand why I came to the office today	1	2	3	4	5	N/A
8. I understand my diagnosis	1	2	3	4	5	N/A
9. I feel educated on possible treatments for my diagnosis	1	2	3	4	5	N/A
10. I am aware of the complications associated with proposed treatments	1	2	3	4	5	N/A
11. The nurses and medical staff were friendly and courteous	1	2	3	4	5	N/A
12. The office was clean and well-maintained	1	2	3	4	5	N/A
13. Carolinas HealthCare System uses the most advanced technology to care for patients	1	2	3	4	5	N/A

Supplementary Figure 2: Contd...

Rank how much you agree or disagree with the following statements:	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Does Not Apply
14. The doctor explained things in a way I could understand	1	2	3	4	5	N/A
15. The pictures my doctor used were easy to understand	1	2	3	4	5	N/A
16. The pictures my doctor used helped me understand my diagnosis	1	2	3	4	5	N/A
17. The pictures my doctor used helped me understand the treatment I may be receiving	1	2	3	4	5	N/A
18. The pictures used by my doctor helped me understand why a complication could occur during treatment	1	2	3	4	5	N/A
19. The doctor answered all of my questions	1	2	3	4	5	N/A
20. The pictures my doctor used made me want to refer family and friends to the practice	1	2	3	4	5	N/A
21. The way my doctor explained my diagnosis made me more likely to recommend him to friends and family	1	2	3	4	5	N/A

Space is provided for you to comment on your experience.

Supplementary Figure 2: Post-visit questionnaire



Supplementary Figure 3: Consort diagram. AR = Augmented reality, SOC = Standard of care