

# A Novel Approach to Patient Self-Monitoring of Sonographic Examinations Using a Head-Mounted Display

Masaharu Inoue, MD, Kazunori Kihara, MD, PhD, Soichiro Yoshida, MD, PhD, Masaya Ito, MD, PhD, Hideki Takeshita, MD, PhD, Junichiro Ishioka, MD, PhD, Yoh Matsuoka, MD, PhD, Noboru Numao, MD, PhD, Kazutaka Saito, MD, PhD, Yasuhisa Fujii, MD, PhD

**Objectives**—Patients’ use of a head-mounted display during their sonographic examinations could provide them with information about their diseases in real time and might help improve “patient-centered care.” We conducted this prospective study to evaluate the feasibility of a modern head-mounted display for patient self-monitoring of sonographic examinations.

**Methods**—In November and December 2013, 58 patients were enrolled. Patients wore a head-mounted display (HMZ-T2; Sony Corporation, Tokyo, Japan) during their sonographic examinations and watched their own images in real time. After the sonographic examinations, the patients completed a questionnaire, in which they evaluated the utility of the head-mounted display, their understanding of their diseases, their satisfaction with using the head-mounted display, and any adverse events. Until November 26, 2013, patients’ names were requested on the questionnaire; after that date, the questionnaire was changed to be anonymous.

**Results**—Of the 58 patients, 56 (97%) elected to participate in this study. The head-mounted display was reported to have good image quality by 42 patients (75%) and good wearability by 39 (70%). Thirty-six patients (64%) reported they had deepened their understanding of their diseases. There were no major complications, and only 2 patients (4%) had mild eye fatigue. There was no significant association between questionnaire results and patient characteristics. None of the questionnaire results changed significantly after the questionnaire was made anonymous.

**Conclusions**—The use of a modern head-mounted display by patients during sonographic examinations provided good image quality with acceptable wearability. It could deepen their understanding of their diseases and help develop patient-centered care.

**Key Words**—clinical utility; head-mounted display; patient-centered care; sonography

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Address correspondence to Kazunori Kihara, MD, PhD, Department of Urology, Tokyo Medical and Dental University, Graduate School, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8519, Japan.

E-mail: k-kihara.uro@tmd.ac.jp

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The concept of “shared decision making” has been widely advocated as an element of “patient-centered care.”<sup>1,2</sup> If shared decision making is to be implemented, interaction and communication between attending physicians and patients is essential.<sup>3–7</sup> This communication includes sharing diagnostic imaging information to help patients understand their disease statuses so that they can select a treatment from the available options.

Sonography is routinely used in many clinical fields because it provides arbitrary multidirectional cross-sectional images in a noninvasive manner within a relatively short time at an affordable cost.<sup>8–14</sup> Yet the necessity of viewing a fixed sonographic monitor placed on the machine forces examiners to twist their bodies, and specific types of musculoskeletal injuries have been associated with this action.<sup>15</sup> Furthermore, the monitor is generally placed in a position where it is most easily seen by the examiner, making it hard to share diagnostic images with patients in real time.

Some of these difficulties can be overcome through the use of head-mounted displays, which were first introduced for medical purposes around the beginning of this century.<sup>16</sup> The older styles of head-mounted displays were not suitable for clinical use because of their heavy weight and poor image quality. Modern head-mounted displays, however, have become suitable for clinical application due to dramatic improvements in resolution, wearability, and weight. Recently, the novel application of head-mounted displays as imaging monitors has been proposed in many types of medical procedures, including anesthesia management and laparoscopic surgery.<sup>17–19</sup>

One of the modern head-mounted displays is the HMZ-T2 (Sony Corporation, Tokyo, Japan), a 330-g binocular head-mounted display with a 0.7-in organic light-emitting diode screen (resolution, 1,280 × 720 pixels) for each eye, which provides the wearer with sharp, high-contrast images. We have previously reported its efficacy in sonography as a viewing screen for the examiner.<sup>20</sup> The high-contrast image quality of modern head-mounted displays confers high diagnostic ability, and it allows the examiner to assume an ergonomically stable posture during sonographic examinations. Because of its compact size, the display is easily introduced and requires no special equipment; thus, patients can also use the display as a personal monitor during sonographic examinations and share diagnostic imaging information with the examiner in real time. Furthermore, we hypothesized that this new approach would help patients understand their disease statuses better and promote patient-centered care. To confirm this hypothesis, we conducted this prospective study to evaluate the feasibility of using a modern head-mounted display for patient self-monitoring of sonographic examinations.

## Materials and Methods

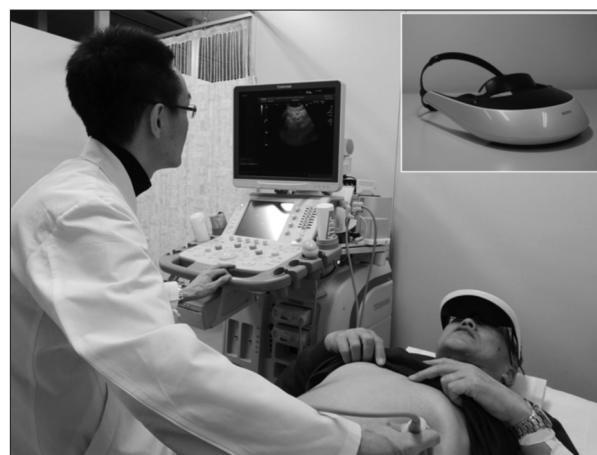
This study was performed with the approval of our university's Ethics Committee. From November 6 to December 18, 2013, patients with genitourinary disease who were newly admitted to our urologic ward were enrolled in this

prospective study. All patients had been provided the diagnosis based on a prior examination such as sonography, computed tomography, magnetic resonance imaging, or cystoscopy before admission. Written informed consent was obtained from all participating patients; patients who refused to take part in the study were excluded from the analysis.

Urologists who were familiar with urologic scanning techniques performed a sonographic screening test, including analysis of the bilateral adrenal glands and kidneys, urinary bladder, and prostate (if male) over about 10 minutes. All ultrasound scanning was performed with an Aplio 500 system (Toshiba Medical Systems, Tochigi, Japan) equipped with a convex 1–5-MHz transducer. During the sonographic examinations, patients wore the HMZ-T2 head-mounted display, which showed sonograms in real time (Figure 1). During the sonographic examinations, the examiners gave explanations of the sonograms and the disease statuses to the patients, who viewed the sonograms with the examiners through the head-mounted display in a real time.

After the sonographic examinations, the patients completed a questionnaire, which evaluated the following aspects: (1) the image quality provided by the head-mounted display; (2) the wearability of the display; (3) the patients' understanding of the states of their diseases; (4 and 5) their satisfaction with their use of the display during their sonographic examinations; and (6 and 7) adverse events caused by the display (Figure 2). Questions 1 and 2 were 5-level questions, and the results were scored on a scale of 1 to 5. Questions 3 through 7 were 3-level questions.

**Figure 1.** Patient wearing the head-mounted display during a sonographic examination. Sonograms were shown on the display.



Until November 26, 2013, the questionnaire requested patients' names along with personal information, including age and final educational background. After that date, the questionnaire was changed to be anonymous and to exclude the possibility of a researcher's identifying any individual who answered the questionnaire. The patients who completed identifiable and anonymous questionnaires were categorized into onymous and anonymous groups, respectively.

Patients were classified according to age, with a median value assigned as the cutoff. The final educational background was divided into a low-education group, including patients who had completed junior high school, high school, vocational school, or junior college, and a high-education group, including patients who had finished college or graduate school. Patients' reasons for hospitalization were classified into benign and malignant disease. Differences between groups were assessed by the Wilcoxon rank sum test and the  $\chi^2$  test for continuous and categorical data, respectively. These statistical analyses were performed with JMP version 8.0 software (SAS Institute Inc, Cary, North Carolina).  $P < .05$  was considered statistically significant.

## Results

### Entire Cohort

Fifty-eight patients were initially enrolled in this study. Of these, 2 (3%) refused to participate in the study because they did not want to see their disease images on sonography. The remaining 56 patients (97%) were eligible for the analysis; 35 and 21 patients were included in the onymous and anonymous groups, respectively. All 56 participants completed the questionnaire.

Of the 56 patients, 15 (27%) reported the image quality of the head-mounted display as excellent, whereas 27 (48%) reported it as good (mean score  $\pm$  SD on question 1,  $3.98 \pm 0.80$ ). Ten patients (18%) reported the wearability of the display as excellent, whereas 29 (52%) reported it as good (mean score on question 2,  $3.79 \pm 0.85$ ). Thirty-six patients (64%) reported that they thought they had acquired a deeper understanding of their diseases. Forty-three patients (77%) hoped to wear the display again if they had another opportunity, and 39 (70%) would recommend the use of the display to family members who were undergoing sonographic examinations in the future.

**Figure 2.** Questionnaire regarding use of the head-mounted display.

Date ( / / )	Examiner ( )
Patient ID ( )	Patient name ( )
Age ( ) years old	Gender 1. male 2. female
Final educational background	
1. junior high school	2. high school
3. vocational school or junior college	4. college
5. graduate school	

**Question 1.**  
How was the image quality provided by the head-mounted display?  
1. poor      2. fair      3. average  
4. good      5. excellent

**Question 2.**  
How was the wearability of the head-mounted display?  
1. poor      2. fair      3. average  
4. good      5. excellent

**Question 3.**  
Were you able to understand the state of your disease?  
1. no      2. neutral      3. yes

**Question 4.**  
Would you want to wear this head-mounted display if you underwent this procedure again?  
1. no      2. neutral      3. yes

**Question 5.**  
Would you recommend wearing this head-mounted display to a family member if they had to undergo this procedure?  
1. no      2. neutral      3. yes

**Question 6.**  
Did you experience any symptoms such as unpleasant feeling, headache, dizziness, nausea or eye fatigue as a result of wearing the head-mounted display?  
Unpleasant feelings: 0. none    1. mild    2. severe  
Headache: 0. none    1. mild    2. severe  
Dizziness/ Nausea: 0. none    1. mild    2. severe  
Eye fatigue: 0. none    1. mild    2. severe

**Question 7.**  
Did you experience any symptoms such as unpleasant feelings, headache, dizziness or nausea as a result of viewing your ultrasound images?  
Unpleasant feelings: 0. none    1. mild    2. severe  
Headache: 0. none    1. mild    2. severe  
Dizziness/ Nausea: 0. none    1. mild    2. severe

There were no major adverse events, and only 2 patients (4%) had mild eye fatigue related to watching sonograms on the display.

### Anonymous Group

Characteristics of the 35 patients in the anonymous group are described in Table 1. The median age of the patients was 64 years. Fourteen patients were categorized into the low-education group, and 21 were categorized into the high-education group. Of the 35 patients, 8 did not have a diagnosis of malignant disease. Of the remaining 27 patients, 19 had untreated urologic cancer (2 with prostate cancer, 5 with bladder cancer, 1 with testicular cancer, and 11 with kidney cancer), and 8 had urologic cancer under treatment (2 with prostate cancer and 6 with bladder cancer).

The questionnaire results obtained from this group are shown in Tables 2 and 3. Of the 35 patients, 11 (31%) reported the image quality of the head-mounted display as excellent, whereas 12 (34%) reported it as good (mean score on question 1,  $3.94 \pm 0.87$ ). Six patients (17%) reported the wearability of the display as excellent, whereas 17 (49%) reported it as good (mean score on question 2,  $3.74 \pm 0.85$ ). Twenty-one patients (60%) reported that they thought they had deepened their understanding of their diseases. Twenty-five patients (71%) hoped to wear the display again if they had another opportunity, and 21

(60%) would recommend the use of the display to family members who were undergoing sonographic examinations in the future. There were no adverse events related to wearing the display or to watching sonograms on the display (Table 4). There were no significant associations between questionnaire results and patient characteristics, including age, gender, final educational background, and reason for hospitalization (Figure 3).

### Anonymous Group

The questionnaire results obtained from the anonymous group are shown in Tables 2 and 3. Of the 21 patients in this group, 4 (19%) reported the image quality of the head-mounted display as excellent, whereas 15 (71%) reported it as good (mean score on question 1,  $4.05 \pm 0.67$ ). Four patients (19%) reported the wearability of the dis-

**Table 1.** Patient Characteristics in the Anonymous Group

Characteristic	n (%)
Male	29 (83)
Female	6 (17)
Age, y <sup>a</sup>	64 (38–87)
Final educational background	
Low-education group	
Junior high school	1 (3)
High school	11 (31)
Vocational school or junior college	2 (6)
High-education group	
College	19 (54)
Graduate school	2 (6)
Reason for hospitalization	
Malignant disease	
Kidney cancer	11 (31)
Bladder cancer	11 (31)
Prostate cancer	4 (12)
Testicular cancer	1 (3)
Benign disease	
Adrenal tumor	1 (3)
Interstitial cystitis	1 (3)
Suspicion of prostate cancer	5 (14)
Benign prostatic hyperplasia	1 (3)

<sup>a</sup>Data are presented as median (range).

**Table 2.** Results of Questions 1 and 2

Result	Anonymous Group, n	Anonymous Group, n	P <sup>a</sup>
Question 1 (image quality of HMD)			
Excellent (score 5)	11	4	
Good (score 4)	12	15	
Average (score 3)	11	1	
Fair (score 2)	1	1	
Poor (score 1)	0	0	
Mean score $\pm$ SD	$3.94 \pm 0.87$	$4.05 \pm 0.67$	>.05
Question 2 (wearability of HMD)			
Excellent (score 5)	6	4	
Good (score 4)	17	12	
Average (score 3)	9	3	
Fair (score 2)	3	2	
Poor (score 1)	0	0	
Mean score $\pm$ SD	$3.74 \pm 0.85$	$3.86 \pm 0.85$	>.05

HMD indicates head-mounted display.

<sup>a</sup>Wilcoxon rank sum test.

**Table 3.** Results of Questions 3 Through 5

Result	Anonymous Group, n	Anonymous Group, n	P <sup>a</sup>
Question 3 (improvement of understanding of the disease)	21/11/3	15/6/0	>.05
Question 4 (desire to use HMD again)	25/8/2	18/3/0	>.05
Question 5 (desire to recommend HMD to a family member)	21/13/1	18/3/0	>.05

Results are presented as yes/neutral/no. HMD indicates head-mounted display.

<sup>a</sup> $\chi^2$  test.



play as excellent, whereas 12 (57%) reported it as good (mean score on question 2,  $3.86 \pm 0.85$ ). Fifteen patients (71%) reported that they thought they had deepened their understanding of their diseases. Eighteen patients (86%) hoped to wear the display again if they had another opportunity, and 18 patients (86%) would recommend the use of the display to family members who were undergoing sonographic examinations in the future. There were no major adverse events, and only 2 patients (9%) had mild eye fatigue related to watching sonograms on the display (Table 4). The questionnaire results did not change significantly after introduction of the anonymous questionnaire.

### Discussion

In this study, we demonstrated the feasibility of the use of a modern head-mounted display for patient self-monitoring of sonographic examinations. To the best of our knowledge, a study in which patients wore a head-mounted display during their sonographic examinations and viewed their sonograms at the same time along with their physicians has not been reported previously. Viewing their own sonograms through the display provided patients with a deeper understanding of their disease statuses as well as great satisfaction. This new approach to information sharing using head-mounted displays could also provide a basis for improved shared decision making and has a potential to promote patient-centered care.

Promoting patient-centered care requires that patients understand their disease statuses.<sup>21–23</sup> Because we initially supposed that patients' levels of desire to share diagnostic imaging information and their satisfaction with having seen it would vary depending on patient age, educational background, and disease type, we requested these details

on the first version of our questionnaire to evaluate the association between patient characteristics and the level of patient satisfaction with the current patient self-monitoring system. Unexpectedly, patient characteristics were not significantly associated with questionnaire results. Furthermore, levels of patient desire for and satisfaction with self-monitoring of their sonographic examinations with the head-mounted display were not significantly different, as reported on the onymous and anonymous questionnaires. These findings showed that it is feasible for patients to use a head-mounted display to share diagnostic imaging information in a variety of disease conditions. However, considering the psychological effects of viewing their disease images, we carefully provided patients a chance to refuse enrolling in this prospective study. As a result, 3% of the patients refused to participate in this study because they did not want to see their disease on sonography. We should take great care to select the patients for whom this display system is used to avoid causing unnecessary alarm to them.

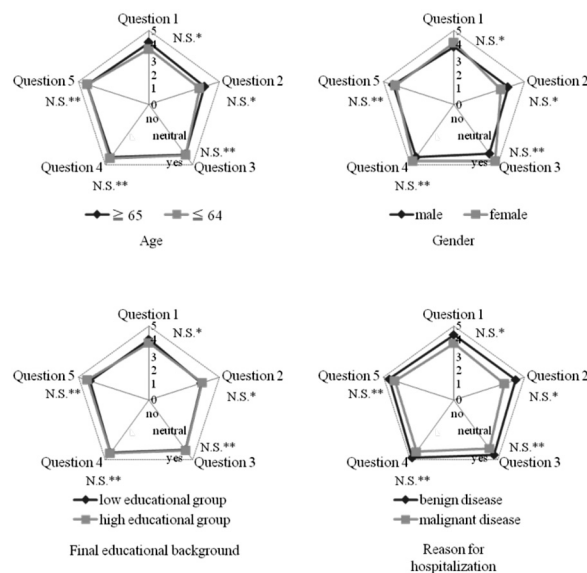
**Table 4.** Adverse Events Caused by the Head-Mounted Display

Type of Adverse Event	Onymous Group, n	Anonymous Group, n	P <sup>a</sup>
Related to wearing HMD			
Unpleasant feelings	35/0/0	21/0/0	>.05
Headache	35/0/0	21/0/0	>.05
Dizziness/nausea	35/0/0	21/0/0	>.05
Eye fatigue	35/0/0	19/2/0	>.05
Related to watching images provided by HMD			
Unpleasant feelings	35/0/0	21/0/0	>.05
Headache	35/0/0	21/0/0	>.05
Dizziness/nausea	35/0/0	21/0/0	>.05

Results are presented as none/mild/severe. HMD indicates head-mounted display.

<sup>a</sup> $\chi^2$  test.

**Figure 3.** Results of the questionnaire in the onymous group. Patients were divided into 2 groups by age, gender, final educational background, and reason for hospitalization. None of the questionnaire results were significantly different between any of the defined groups. Question 1 regarded the image quality of the head-mounted display; question 2, wearability of the display; question 3, improvement of understanding of the disease; question 4, desire to use the display again; and question 5, desire to recommend the display to a family member. Questions 1 and 2 were 5-level evaluation questions, and the results were scored on a scale of 1 to 5. Questions 3 through 5 were 3-level evaluation questions. N.S. indicates not significant ( $P > .05$ ). \*Wilcoxon rank sum test; \*\* $\chi^2$  test.



All patients enrolled in this study had already been provided the diagnosis of genitourinary disease. In this study, sharing the sonographic information through the head-mounted display in real time made 64% of these patients think that they could deepen their understanding of their diseases. We need further studies to evaluate the impact of using a head-mounted display during sonographic examinations and sharing the sonograms with real-time diagnosis on patients who have no information about their diseases.

The image quality, wearability, and weight of head-mounted displays have improved dramatically in recent years. In our previous study, one commercially available modern head-mounted display, the HMZ-T2, provided high-quality images to examiners during sonographic examinations.<sup>20</sup> Therefore, we chose to use the HMZ-T2 display again for this current study. The HMZ-T2 was likewise able to provide patients with high-quality images and acceptable wearability, as shown in this study. As the performance of head-mounted displays continues to improve,<sup>24</sup> we expect that future improvements in head-mounted display technology will further enhance patient satisfaction with these devices during sonographic examinations.

We have used head-mounted displays as imaging monitors for medical providers in various surgical procedures, such as endoscopic surgery, transurethral resection of the prostate, and placement of ureteral stents.<sup>25–27</sup> Depiction of a 3-dimensional view or a multiple-integrated image on the head-mounted display could be advantageous in these urologic procedures. Another advantage of using these displays is the immersive view that they provide, regardless of the wearer's head position. Because sonographic examinations are generally performed in various positions, including supine, prone, and lateral, using a head-mounted display as a personal imaging monitor for the patient is more practical than placing a conventional monitor over the patient's head. Furthermore, head-mounted display systems for patient self-monitoring can be easily introduced in every institution without the need for special equipment because of their compact size and affordable cost.

Although our results show that the use of a modern head-mounted display by patients during sonography has potential to promote patient-centered care and to be a novel way to perform sonographic examinations, there were some limitations to this study. First, the wearability of the display and the incidence of adverse events related to using the display during sonographic examinations were evaluated over a relatively short time. Because comprehensive sonographic evaluations of abdominal organs usually require about 15 to 20 minutes, further evaluation in

sonographic examinations of longer durations is needed. Second, it should be noted that not all patients actually want to view their own sonograms. We provided patients a chance to refuse enrollment in the study after giving enough information. In this study, only 2 of 58 patients refused to view their own sonograms on the head-mounted display, but this low number may have been related to the fact that this study was conducted in an academic hospital, so that most of the patients included could have been expected to have a strong interest in their conditions. It will be necessary to evaluate the usefulness of head-mounted displays during sonographic examinations and patients' perceptions in general hospitals as well.

In conclusion, we have demonstrated that the use of a modern high-definition head-mounted display by patients during sonographic examinations could deepen their understanding of their disease statuses. This novel approach to patient self-monitoring during sonography will help promote patient-centered care.

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