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Can an Offsite Expert Remotely Evaluate the Visual Estimation of Ejection Fraction via a Social Network Video Call?

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Abstract We aimed to investigate whether an offsite expert could effectively evaluate visually estimated ejection fraction (EF) while watching and guiding the echocardiographic procedure of an onsite novice practitioner using a social network video call. Sixty patients presenting to the intensive care unit and requiring echocardiography between October and November 2016 were included. Sixty novice sonographers without any previous experience of echocardiography participated. Prior to the procedure, the onsite cardiologist completed the echocardiography and determined the EF using the modified Simpson's method (reference value). Then, the novice practitioner performed the echocardiography again with the offsite expert's guidance via a social network video call. The EF was visually estimated by the offsite expert while watching the ultrasound video on the smartphone display. Spearman's rank correlation and Bland-Altman plot analysis were conducted to assess the agreement between the two methods. There was excellent agreement between the two methods, with a correlation coefficient of 0.94 ($p < 0.001$). The Bland-Altman plot showed that the average bias was −3.05, and the limit of agreement (−10.3 to 4.2) was narrow. The offsite expert was able to perform an accurate visual estimation of ejection fraction remotely via a social network video call by mentoring the onsite novice sonographer.

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Keywords Telesonography · Viewing of clinical imaging · Smartphone

Introduction

Due to the increased emphasis on the importance of point-of-care bedside echocardiography for evaluating the hemodynamic status of critically ill patients, this test has been widely adopted in emergency departments and intensive care units. Critical care physicians have focused on the evaluation of contractility function to determine the immediate treatment at bedside [1–3]. Although, the operator-performed border tracing quantitative assessment of ejection fraction (EF) is not complicated, it is still time-consuming. Several clinicians believe that the visual estimation of EF by integrating all information regarding wall motion, atrio-ventricular plane displacement, etc., is highly reliable [4–7]. Thus, the eyeballing EF method has been widely used in emergency point-of-care bedside echocardiography. However, even when used as a bedside point-of-care practice, the sonographers are required to have a certain level of echocardiography experience, including eyeballing EF, because this technique is highly reader-dependent. Considering the rapidly changing status of critically ill patients, immediately available bedside echocardiography is frequently required in the emergency critical care setting. However, onsite physicians providing bedside care are occasionally novices in emergency situations.

To remedy this limitation, several studies have shown that an onsite ultrasound-inexperienced practitioner can acquire interpretative images under the direction of a remote expert [8–10].

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However, these studies were confined to relatively simple practices, such as examining the presence of pneumothorax and intra-abdominal fluid collection, which can typically be performed without detailed guidance from a remote expert. These studies also required an additional image transmission system [8–10], which may not be available at all times and places.

Based on previous research showing that ultrasound images transmitted via freely and always available video calls were non-inferior to those obtained using an ultrasound machine [11], we aimed to speculate whether a commercially available video call could be used by a novice to perform telesonography for eyeballing EF. Compared with the exams used in previous studies [8–10], obtaining the optimal view for eyeballing EF during an echocardiography examination is complex, requiring detailed guidance. We simulated a situation in which the patient's condition took a sudden turn for the worse, so that point-of-care bedside echocardiography performed by a novice was required for evaluating cardiac function. The purpose of this study is to show that novice physicians without any previous echocardiography experience can obtain an optimal view with an expert's assistance using a video call, and then, the remote expert can effectively evaluate the cardiac function using the transmitted video.

Methods and Materials

Study Design and Setting

This prospective experimental study was conducted to compare the remote eyeballing (visually estimated) EF determined by an offsite expert using video call-based, telementored echocardiography and the quantitative EF determined using the modified Simpson's method (MSM) performed by an onsite expert cardiologist.

This study was approved by the Institutional Review Board of our institution and performed in the intensive care unit (ICU) of the tertiary urban teaching hospital from October to November 2016.

Study Participants

Based on a pilot study, at least 55 patients were required to reveal that the eyeballing EF using the novice performed/telementored ultrasonography is not inferior to the EF calculated by MSM. A total of 60 adult patients (>18 years old) were admitted to the ICU and 60 novice echocardiography users participated in this study, considering a 10% dropout rate. Subjects requiring immediate management due to severe symptoms or unstable conditions were excluded from this study. One cardiologist who performed the initial echocardiography participated as an onsite expert sonographer, and two other emergency physicians who were certified as trained echocardiologists by the Korean Society of Echocardiography (KSE) participated as offsite mentors. All study participants completed a predesigned written consent form prior to participating in the study.

Remote Telementored Echocardiography

We used a Logiq S8 with XDclear ultrasonographic system (GE Medical Systems, Milwaukee, USA) and a 1–5 MHz M5S-D broad spectrum sector matrix array probe. It has a diagonal dimension of 23-in. LED monitor with a resolution of 1920 × 1080 pixels. The videos that contain echocardiography images on the monitor of the ultrasound machine or the examiner's practice were transmitted to the remote mentor's smartphone using the freely available social network video calling chat, Kakao face talk, under the 4th generation (4G) network. The Galaxy S7 (Samsung, Suwon, Korea) was used as both an onsite image transmitter and offsite viewer. It has a high-resolution camera (12 megapixels with dual pixel) and can capture 30 frames per second at ultra-high definition (UHD, 3840 × 2160 pixels) in live video capture. It has a super AMOLED display with a diagonal dimension of 5.1 in. and a high resolution (1440 × 2560 pixels). The maximum luminance is 454 cd/m^2. The brightness in this study was set to maximum and auto-adjustment of the brightness was turned off. Furthermore, the screen mode, which was set to adaptive display by default, was changed to the basic mode because it is the best mode for image accuracy. The social network service Kakao talk was downloaded to both smartphones from the Google Play store without charge. Kakao talk includes the video chat Kakao face talk (person-to-person video calling), which is similar to FaceTime and was used during the telementoring in this study.

Intervention

Prior to the novice-performed/telementored echocardiography, the onsite cardiologist completed the echocardiography in advance and calculated the EF by using MSM, regarded as the standard method. Then, the novice sonographers performed the echocardiography again with the offsite expert's guidance via a social network video call (telementored echocardiography; Fig. 1). Sixty novice sonographers and patients were paired, and each onsite novice sonographer performed the echocardiography for each patient assigned. The remote mentors provided real-time instructions to the onsite novice practitioner while watching the echocardiography video on the ultrasound machine and the participant's practice alternately though the smartphone in the adjacent room. They provided verbal instructions over the face talk to obtain the parasternal long and short axis view and additional apical four-chamber view if it was available, and they determined the visually estimated EF with an interval of 5% (e.g., 40, 45%) using the transmitted echocardiography video on the smartphone display. Each remote mentor conducted 30 practices

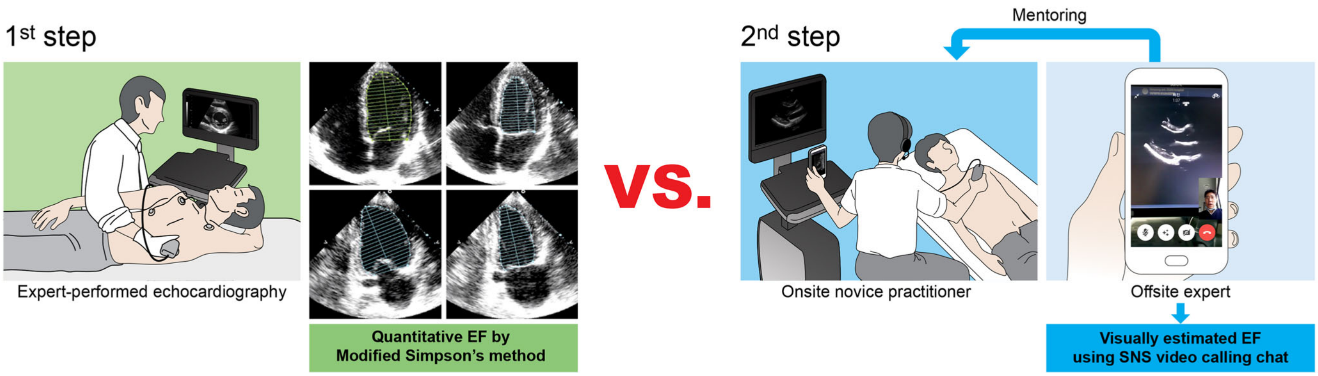

Fig. 1 Study process: An onsite cardiologist determined the quantitative ejection fraction using modified Simpson's method in advance (*1st step*). Then, the remote eyeballing ejection fraction using the telementored echocardiography was determined via a freely available video call (*2nd step*)

each, and they were blinded to the previous result calculated by the cardiologist; they determined the EF according to the following scheme (Table 1). If the wall motion was mildly reduced (45–49%), they recorded the visually estimated ejection fraction as 45%. The movement of the anterior leaflet of the mitral valve (E-point septal separation), the percentage of myocardial thickening, and fractional shortening were mainly used in determining the visually estimated EF. If the apical four-chamber view was presented, the level of ascent of the base of the heart was also applied. The offsite mentors were also asked to rate their subjective image quality assessment scores for the transmitted images displayed on the smartphone on a five-point Likert scale (single stimulus method, 1 = bed, 2 = poor, 3 = fair, 4 = good, 5 = excellent). During the examination, the 8 s of echocardiography videos of parasternal long axis view on the ultrasound machine was recorded in the machine (original video), and the same videos transmitted to the smartphone via face talk were simultaneously saved in the smartphone as an MP4 file using the smartphone application AZ screen recorder, downloaded from Google Play store (Fig. 2). These were matched and numbered from 1 to 60 for future image quality comparisons using a double stimulus impairment scale (DSIS).

After completing these 60 case examinations, the additional subjective image quality for the images transmitted to the smartphone in comparison to the original reference images on the ultrasound machine was analyzed using the DSIS. First, the original video was shown on the monitor of the ultrasound machine for 8 s, and the transmitted video was then sequentially presented on the smartphone display for 8 s, with a 3-s interval of inter-video blackout. The next case followed after a 5-s interval (Fig. 3). Two blinded reviewers were asked to rate the image quality degradation of the transmitted video in comparison to the original video using a five-point Likert scale (1 = obviously annoying, 2 = annoying, 3 = slightly annoying, 4 = perceptible but not annoying, 5 = imperceptible).

Table 1 Values of ejection fraction according to the reduced degree of wall motion

Wall motion	Value (%)
Normal	55–75
Borderline	50–54
Mildly reduced	45–49
Mild to moderately reduced	40–44
Moderately reduced	35–39
Moderate to severely reduced	30–34
Severely reduced	<30

The screen of the mentor's smartphone and the camera lens of the practitioner's smartphone were wiped using a lens cloth prior to use because the touch screen and lens are susceptible to dirt and oil, which could obscure the image and reduce contrast. The echocardiograph examinations were performed under slightly dim ambient lighting with the light around the patient off (intensity of illumination <100 lx) due to the reflection of the light on the monitor of the ultrasound machine if the intensity was more than 100 lx. The offsite mentoring using the smartphone was conducted under general residential indoor lighting (100–500 lx) because the reflection of the light was not problematic when viewing the smartphone display if the brightness of the smartphone was set to maximum. The intensity of illumination was checked by a photometer before the examination. If the intensity of the light at the bedside was greater than 100 lx with the light turned off, then a sunscreen was set up around the monitor and practitioner to prevent the reflection of light on the monitor. The 4G network was used, and its Internet speed was gauged using the smartphone application BENCHBEE at the end of each examination.

Main Results and Statistical Analysis

We compared the values of the visually estimated EF via telementored echocardiography and the EF calculated by MSM. The non-inferiority test was conducted to analyze the remote eyeballing EF via telementored echocardiography, which was not inferior to the quantitative EF by MSM if the

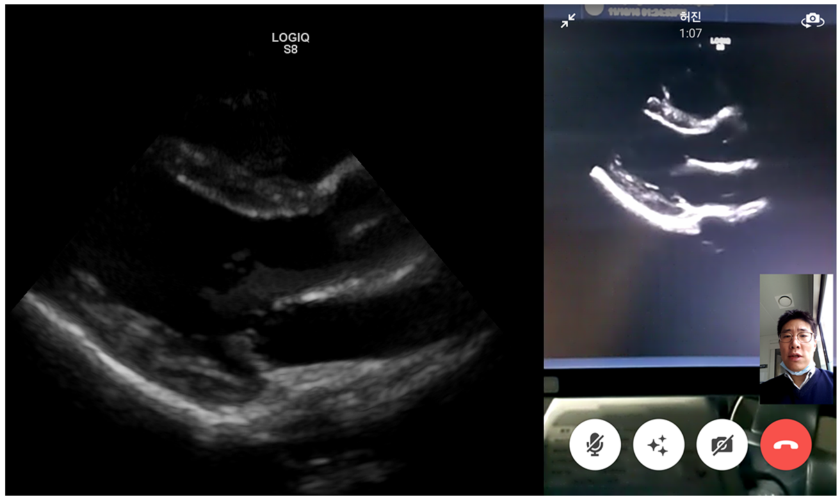

Fig. 2 Original video on the monitor of the ultrasound machine (*left*) and transmitted video to the smartphone via a social network video call (*right*)

non-inferiority margin was set at 7.5%. Spearman's rank correlation and Bland-Altman plot analysis were also conducted to show the agreement of the two methods. We further evaluated the accuracy (sensitivity, specificity, positive predictive value, and negative predictive value) for detecting a low EF when the threshold of a normal value of EF was set at 55% (<55%: low EF, ≥55%: normal EF).

The image quality assessment for transmitted images was evaluated using both single and double stimulus methods. The remote mentors' mean subjective image quality assessment scores were calculated, and a mean score greater than four is regarded as indicative of high quality [12, 13]. The statistical analysis was conducted using SPSS 18.0K for Windows (SPSS Inc., IL, USA). The p value for statistical significance was set at 0.05.

Results

Participants

Of the 60 patients participating in this study, 25 (41.7%) were male, and their mean age was 65.2 years old (SD 15.0) (Table 2). Their diagnoses are shown in Table 2. Sixty volunteers without any previous experience of echocardiography participated as novice practitioners. Their mean age was 29.6 years (SD 4.4), and their occupations are shown in Table 2. Each practitioner performed the echocardiography for each patient assigned with mentoring from a remote expert.

Main Results

The mean values of remote eyeballing EF using the social network service (SNS)-based/telementored echocardiography and quantitative EF by MSM were 49.0 (46.5–51.5) and 52.0 (49.5–54.6), respectively. The mean difference was −3.05 (−6.58–0.48). Given that the 95% confidence interval (CI) of the difference (−6.58 and 0.48) was smaller than the non-inferiority margin of 7.5%, the remote eyeballing EF was not inferior to the quantitative EF.

There was an excellent correlation between the remote eyeballing EF and the quantitative EF (correlation coefficient 0.94; p < 0.001). Bland-Altman analysis comparing two methods is shown in Fig. 4. The average bias was −3.05, and the limit of agreement (−10.3 to 4.2) was narrow.

When the threshold of the normal value of EF was set at 55% (<55%: low EF, ≥55%: normal EF), the remote eyeballing EF had a sensitivity of 94.1% and a specificity of

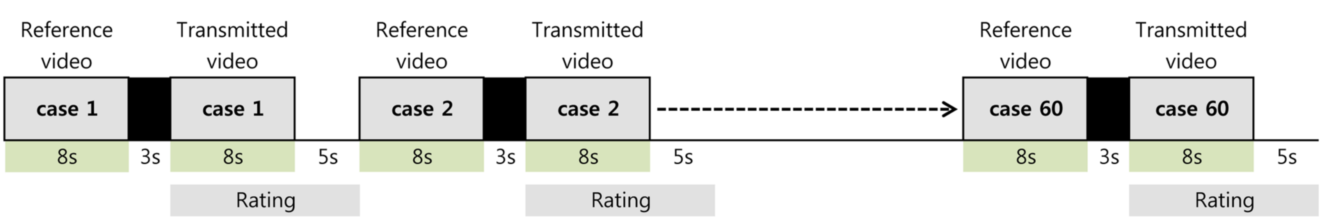

Fig. 3 Process of double stimulus impairment scale (DSIS) evaluation: The original video presented for 8 s prior to the transmitted video, with 3 s of inter-video blackout. Original video: original echocardiography movie played on the monitor of the ultrasound machine. Transmitted video: transmitted echocardiography movie played on the smartphone display that had been transmitted to the smartphone via face talk and was saved as an MP4 file using the smartphone application AZ screen recorder

Table 2 Characteristics of study participants

Characteristics	Values
Patients	
Sex, male, *n* (%)	25 (41.7)
Age, years, mean (SD)	65.2 (15.0)
Diagnosis	
Congestive heart failure	5 (8.3)
Acute coronary syndrome	8 (13.3)
Cerebrovascular accident	10 (16.7)
Chronic obstructive pulmonary disease	2 (3.3)
Pneumonia	8 (13.3)
Acute respiratory distress syndrome	3 (5.0)
Diabetic ketoacidosis	1 (1.7)
Sepsis	7 (11.7)
Cancer	9 (15.0)
Trauma	7 (11.7)
Novice practitioner	
Sex, male, *n* (%)	21 (35.0)
Age, years, mean (SD)	29.6 (4.4)
Occupation	
Medical student	20 (33.3)
Emergency medicine resident	8 (13.3)
Nurse	28 (46.7)
Emergency medical technician	4 (6.7)

SD standard deviation

84.6% for detecting a low EF (positive predictive value 88.9%, negative predictive value 91.7%; Table 3).

Of the 60 novice practitioners, 24 (40%) acquired the acceptable apical four-chamber view with mentoring of the remote expert. Another 28 practitioners (46.7%) acquired the apical four-chamber view, but the images were not acceptable to perform the visual estimation of EF. The remaining eight (13.3%) could not catch the apical four-chamber view.

The mean illumination intensity of ambient lighting during the examination was 63.9 lx (SD 8.6) at the bedside and 389.6 lx (SD 24.9) at the remote mentoring site, and the mean mobile Internet speed at the end of the remote mentoring examination was 52.0 Mbps (SD 6.2).

Image Quality Assessment

The subjective image quality assessment scores by two mentors are presented in Table 4. The mean score rated during the examination (single stimulus method) was 4.1 (SD 0.8). The mean score comparing the transmitted images to the original reference images (double stimulus impairment scale) was 3.8 (0.8).

Discussion

We verified that the visually estimated EF by an offsite mentor using the transmitted ultrasound images obtained by a novice practitioner with guidance from the offsite mentor via a freely available video call greatly agreed with the expert-performed quantitative EF.

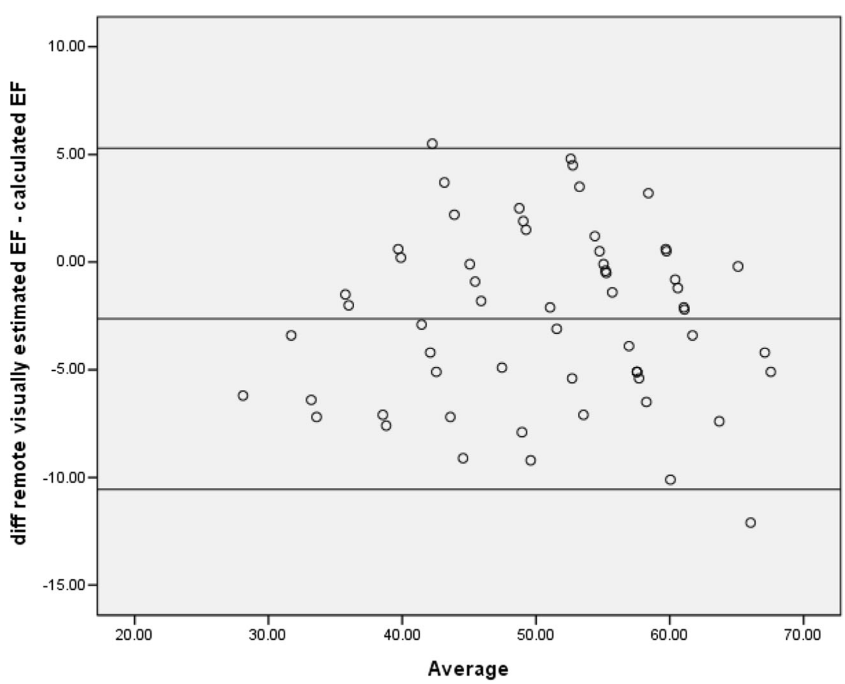

Fig. 4 Bland-Altman plot comparing the remote eyeballing ejection fraction via video call and quantitative ejection fraction by a modified Simpson's method

Table 3 Comparison of remote eyeballing ejection fraction with telementored echocardiography and quantitative EF by a cardiologist using a modified Simpson's method

		EF measured by cardiologist (MSM)		
		Low EF (<55%)	Normal EF (≥55%)	Total
Remote eyeballing EF, *n* (%)	Low EF (<55%)	32 (94.1)	4(15.4)	36 (100)
	Normal EF (≥55%)	2 (5.9)	22 (84.6)	24 (100)
	Total	34 (100)	26 (100)	

EF ejection fraction, *MSM* modified Simpson's method

The mean difference between the two methods above was −3.05, indicating that the remote eyeballing EF using video call had a mean value 3.05% lower than the quantitative EF. This result might be because the offsite expert selected the lower limit of the 5% interval when visually estimating the EF. For instance, in the case of mildly reduced wall motion (45–49%), they recorded visually estimated EF as 45%, not 47.5% (slightly underestimation). This practice might have contributed to the high sensitivity for detecting a low EF (94.1%) in this study. Given that emergency bedside echocardiography is usually considered a screening tool for avoiding false negatives, this remote eyeballing EF using freely available video call with a high sensitivity would be useful as a point of care test for detecting a patient with low EF.

The feasibility of this video call-based telementored ultrasonography depends on several factors. First, the remote mentor's instruction and onsite novice practitioner's hand should be effectively coordinated to obtain optimal scanning. To achieve that performance, the mentors gave easy-to-follow instructions to the onsite practitioners considering that they were complete novices at echocardiography. Nevertheless, it was difficult to take the probe's position to the exact location. The novice practitioners did not easily understand some of the mentor's instructions, particularly related to the probe manipulation (e.g., rotation, tilt, and alignment). When faced with those difficulties, the mentors demonstrated how to manipulate the probe via the video call. The onsite practitioners could follow the practice while watching the remote mentor's demonstration on their smartphone display. This interactive communication by video call between onsite practitioner and offsite mentor might enable a complete novice without any experience of echocardiography to perform the practice in accordance with the mentor's instruction, which is the notable advantage to the one-way video and bidirectional voice communicated telesonographies used in previous studies [8–10, 14, 15]. We did not mark the number on the machine in this study. However, we believe that the practices could be performed more smoothly if specific numbers were assigned to the buttons and probes of the ultrasound machine and instructions were then given by pressing a button and choosing a certain probe with the assigned number.

Second, the transmitted image quality may also be a significant factor. The previous studies equipped their own ultrasound machines with the specific image transmitting systems to directly transmit the image file to the remote display and guarantee the image quality [14, 15]. Thus, they could acquire high-quality lossless transmitted images on the remote display. However, these systems generate additional expenses, which might restrict the availability of teleultrasonography. In contrast, the freely available video call can be used anytime and anywhere as long as both sides have a smartphone. We hypothesize that the transmitted video quality using video call might be decreased compared with those via direct image transmitting systems used in previous studies [14, 15]; however, slightly decreased image quality might not be significant in evaluating cardiac function [11]. In this study, the mentors' image quality scores measured by single stimulus method during the examination and those by double stimulus method

Table 4 Image quality assessment by the single stimulus method and double stimulus impairment scale

	Score, *n* (%)					Total, *n* (%)	Mean (SD)
	1	2	3	4	5		
SSM							
Mentor 1	0 (0)	3 (10.0)	4 (13.3)	16 (53.3)	7 (11.7)	30 (100)	
Mentor 2	0 (0)	1 (3.3)	2 (6.7)	17 (56.7)	10 (16.7)	30 (100)	
Total	0 (0)	4 (6.7)	6 (10.0)	33 (55.0)	17 (28.3)	60 (100)	4.1 (0.8)
DSIS							
Mentor 1	0 (0)	4 (6.7)	12 (20.0)	35 (58.3)	9 (15.0)	60 (100)	
Mentor 2	0 (0)	2 (3.3)	11 (18.3)	41 (68.3)	6 (10.0)	60 (100)	
Total	0 (0)	6 (5.0)	23 (19.2)	76 (63.3)	15 (12.5)	120 (100)	3.8 (0.8)

SSM single stimulus method, *DSIS* double stimulus impairment scale, *SD* standard deviation compared to the original video were 4.1 (SD 0.8) and 3.8 (0.8), respectively. Considering that a score greater than four is regarded as indicative of high quality [12, 13], the remote experts believed that the image quality of the transmitted videos on the smartphone was high when they independently observed a single transmitted video (single stimulus method). However, when they simultaneously compared the transmitted video to the reference video (DSIS), the score was lower than four. The percentage of scores lower than three (slightly annoying) by DSIS (24.2%) was also greater than that by the single stimulus method (16.7%; Table 4). This result means that the image quality of transmitted videos was somewhat decreased, as expected. Nevertheless, users were not significantly annoyed while watching, instructing, and evaluating the dynamic function of the heart using the video call. This finding might be because a frame rate of transmission without interruption in motion is more important for evaluating the dynamic function of the heart than the high-resolution image transmission needed to perceive subtle findings. Transmitted video quality (resolution and frame rate of transmission) is largely dependent on the connected Internet speed between the transmitter and the recipient. The average mobile Internet speed used in this study (4G) was 52.0 Mbps (SD 6.2). Under this speed, the image resolution was somewhat decreased, but the motion was not interrupted. Although availability of the 4G network is not yet universal worldwide, it is rapidly increasing. Akamai reported that 18 of 74 countries included in the report had an average mobile Internet speed exceeding 10 Mbps in the first quarter of 2016, compared with 11 countries in the previous quarter [16]. According to the report, 28 countries had an average peak mobile speed exceeding 50 Mbps, and 55 countries had an average peak speed above 25 Mbps. It was also increased compared with that for the previous quarter. Thus, its use in evaluating cardiac function could be increasingly adopted worldwide.

Other factors affect video quality, including the quality of the hardware used. The latest model of Samsung smartphone (Galaxy S7) with high specifications was used in this study. Thus, the high-quality video could be captured by a high-resolution camera (12 megapixels with dual pixel) and was shown on the high-resolution display (super AMOLED, 1440 × 2560 pixels). It had been thought that the relatively small-sized display of 5.1 in. might interrupt watching the video; however, it did not significantly affect the evaluation of cardiac function. Nevertheless, if a larger display, such as tablet or desktop PC, was applied, it would definitely improve the ease of use. Another factor is image processing and the compression used. There have been subjective reports [17, 18] that FaceTime has better video quality than other third party-based video calling systems, including Skype, Google messenger, and Kakao talk, because Apple controls both software and hardware. Additionally, Apple uses hardware for both encoding and decoding the video. However, there has been no objective evidence supporting these reports. Most experts think, and we agree, that the video quality largely depends on the ambient Internet speed rather than the type of video calling system used.

Kakao talk is an SNS released in 2010 in South Korea, which presents free chatting (one-on-one, or with an unlimited number of friends worldwide), free video and voice call, and text and multimedia messaging services. We used Kakao video calling when the offsite mentor instructed the onsite novice's practice and remotely interpreted the transmitted ultrasound video because it was the most popular SNS in South Korea. It had 49.32 million monthly active users worldwide in the first quarter of 2016; of these, 79% were domestic users [19]. It is available over Wi-Fi and mobile networks, such as 3G/4G. It is operable with the android, iOS, BlackBerry, and Windows operating system-based phones. In addition, it has a PC version; thus, the larger PC monitor can be used as a remote display instead of a smartphone.

Bright ambient lighting can cause reflections in the display and reduce the display contrast [20]. To prevent the light from reducing the image quality of the transmitted video via video call, the light around the patient was turned off when the telementored ultrasonography using the video call was performed. The American College of Radiology recommends conducting the radiologic interpretation under dim ambient lighting (20–40 lx) [20]. However, considering that the dim ambient lighting under 40 lx cannot be generally secured in a real clinical setting, such as in the ICU, we performed those practices under slightly dim ambient lighting (mean 63.9 lx). In our institution, this ambient lighting can easily be achieved by turning off lights around the patient. Under this slightly dim ambient lighting, teleultrasonography using video call was not significantly irritating in this study.

Limitations

The process of acquiring the proper echocardiographic views (parasternal long and short axis views) by remotely mentoring a novice practitioner was easily performed. However, 13.3% of the novice practitioners could not find the apical four-chamber view during the examination, and 46.7% could not acquire an acceptable apical four-chamber view for visual estimation of the EF with remote mentoring. Although visual estimation of the EF may be determined by using only parasternal long and short axis views, this teleradiology system may not always be available in other echocardiographic examinations that require the apical four-chamber view. Furthermore, this process might not be applicable in detecting small structures, such as the appendix and determining the presence of appendicitis, which needs high-resolution image transmission. In addition, the image quality of the transmitted images on the smartphone via video call was exceedingly reduced under the bright ambient lighting because of the reflection of the monitor. Thus, this system could be used under illumination of less than 100 lx of intensity. Lastly, smartphone specifications could affect the quality of the transmitted image.

Conclusions

Remote experts enabled novice practitioners to acquire the interpretable echocardiographic view for visually estimating the EF by mentoring them while watching their practice on the smartphone display transmitted via video call. The image quality of the echocardiography video transmitted using the video call was slightly decreased; however, it did not significantly affect the evaluation of cardiac function. This simple and freely available social network video call-based telesonography would be very useful as a point of care test for evaluating unstable patients with cardiovascular emergency in under-resourced areas where the expert sonographer is not always available.

Compliance with Ethical Standards This study was approved by the Institutional Review Board of Hanyang university guri hospital.

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Conflict of Interest The authors declare that they have no conflicts of interest.

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