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Image Quality in Real-Time Teleultrasound of Infant Hip Exam Over Low-Bandwidth Internet Links: a Transatlantic Feasibility Study

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Abstract Evolution of communication systems, especially internet-based technologies, has probably affected Radiology more than any other medical specialty. Tremendous increase in internet bandwidth has enabled a true revolution in image transmission and easy remote viewing of the static images and real-time video stream. Previous reports of real-time telesonography, such as the ones developed for emergency situations and humanitarian work, rely on high compressions of images utilized by remote sonologist to guide and supervise the unexperienced examiner. We believe that remote sonology could be also utilized in teleultrasound exam of infant hip. We tested feasibility of a low-cost teleultrasound system for infant hip and performed data analysis on the transmitted and original images. Transmission of data was accomplished with Remote Ultrasound (RU), a software package specifically designed for teleultrasound transmission through limited internet bandwidth. While image analysis of image pairs revealed statistically significant loss of information, panel evaluation failed to recognize any clinical difference between the original saved and transmitted still images.

Keywords Telemedicine · Image quality analysis · Ultrasound · Teleradiology

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Introduction

Rapid growth and development of information systems that fuel development of telemedicine have enabled a constant increase in quality of telemedical services, primarily exemplified in improved telemedicine interfaces and increased speed of transmissions [1, 2]. Worldwide availability of internet infrastructure has opened the door for exchange of medical information on a global level [3–5].

Without going into a full discussion of the full impact of this process, the authors would like to acknowledge its potential utilities in education and public service.

Imaging-based medical fields, especially radiology, have been utilizing the global internet infrastructure for over 20 years now. Transmission of still radiographic images and cross-sectional imaging has been widely used in both developed and developing world [6–11].

Also, transmission of real-time video streams, from modalities like ultrasound, has been reported and applied for different purposes, such as: remote real-time fetal teleultrasound consultation, real-time remote physician guidance of assessment with sonography for trauma examination, and teleultrasound in emergency situations and humanitarian work [12–17].

Unique features of ultrasound such as its low cost, benign safety profile, and availability of portable ultrasound units enable its easy integration into both primary and secondary care settings in the developed and developing world. In the USA, availability of highly trained sonographers simplifies the interpretation of an ultrasound exam to a review of still images, often without need for the physician to directly examine the patient. However, in the developing world, the lack of trained technologists or physicians would mandate direct supervision of the exam.

In our previous papers we described the development of the Remote Ultrasound (RU) software, a dedicated university-generated package for transmission of ultrasound in real-time set for humanitarian projects [10, 11]. In this paper, we continue to explore the utility of remote ultrasound system for infant hip exam [18].

The objective of this study, previously approved by Ethical committee of General hospital Zrenjanin, was to examine whether there is a statistically significant difference between original and transmitted image based on qualitative and quantitative analysis based on the corresponding pairs of images (original image and transmitted).

Methods

Our teleultrasound setup contained the following components:

1. Compact ultrasound machine (Sonosite 180, Bothel, Washington, USA) connected to
2. A desktop or laptop directly, or via
3. A video capture card
4. Software platform capable of transmitting real-time ultrasound images as well as supporting audio communication (RU and Skype) in teleconference setting.
5. Internet link with (maximum) value of 250 kbps bandwidth to support the software demands including real-time video transmission, audio conference, and intermittent transmission of recorded images in the background.

All imaging was done with a portable ultrasound unit donated by Dartmouth-Hitchcock Medical Center (Lebanon, NH), USA and utilized in General Hospital Djordje Joanovic, Zrenjanin, Serbia (Fig. 1).

Hardware platform used in all teleultrasound screening sessions was a notebook MSI EX610X-082EU (Micro-Star Int'l Co., Ltd. Zhonghe District, New Taipei, Taiwan), with configuration AMD Athlon 64×2 TK55 chip (Advanced Micro Devices Inc., Sunnyvale, CA, USA), Transcend DDRII 3Gb (Transcend Information Inc., Taipei, Taiwan), ATI HD2400 (ATI Technologies Inc., Markham, Ontario, Canada) running MS Windows XP with Service pack 2 (Microsoft Corporation, Redmond, WA, USA).

The ultrasound image was transmitted to the computer via a Pinnacle PCTV Analog USB TV tuner video capture card (Pinnacle Systems Inc., Mountain View, CA, USA).

RU Software application was used for transmission of ultrasound image via low bandwidth (250 kbps) public internet links without security measures between Serbia and the USA (Philadelphia, PA). The software is based on open source libraries and standard video conferencing protocols available in Microsoft Research Group and operates under Windows XP and .NET environment [19]. This unique application enabled us to use ultrasound in the settings of limited resources. More specifically, the software enables:

1. Direct monitoring of ultrasound exam in real-time via teleconferencing module that is in addition to audio link that transmits ultrasound video stream.
2. Recording and review of still ultrasound images, similar to functions available on the ultrasound machine.
3. Remote saving of ultrasound imaging—a function that saves images on local and remote computer and thus enables direct comparison of images by personnel on both locations.
4. Ability to add additional text to images for improved communication between two sites.

Like all other teleconferencing software application, RU uses range of Coding–Decoding software (CODECs) Ffdshow for lossy compression of video and still images. By being exposed to several lossy compression–decompression steps, remote video stream and remotely recorded still images are degraded in quality. Compression ratio is 3.5. By being exposed to several lossy compression–decompression steps, remote video stream and remotely recorded still images are degraded in quality. For all pairs a bit ratio of the original and transmitted images was measured and determination of their relationship was carried out with mean value of 3.5, which is a compression ratio. While some lossy compression is commonly used in PACS systems, the limits of the compression ratios in telemedicine and teleradiology are not clearly established [20–23].

Figures 2 and 3 depict RU interface on sender's and receiver's side, respectively.

The Save function of the RU application was used to record the still images while the ultrasound probe was moved or when the images were captured on the ultrasound

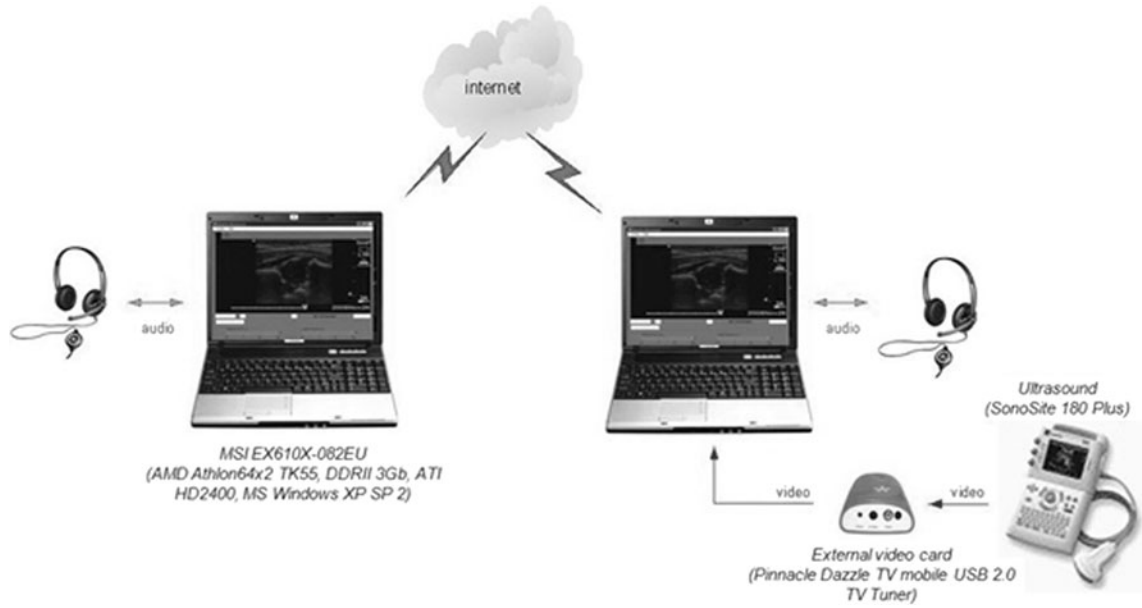

Fig. 1 System structure

machine. Every time the Save function is used, it records a dataset of images on sender's and receiver's computers. Complete datasets on sender's and receiver's computer were used for image analysis.

Fig. 2 Software screen interface NetAVSender: the transmitting interface

For qualitative analysis, the evaluators were asked to rate each image individually, based on identifying by major topographic points described by Graf (Fig. 4) [24–26].

Qualitative and quantitative analysis was performed on 50 ultrasound images pairs original and compressed (transmitted). Each image set contained a locally and remotely recorded image (Figs. 5 and 6). Order of presentation of images for reviewers was randomly selected from a

Fig. 3 Software screen interface remote site: the receiving interface

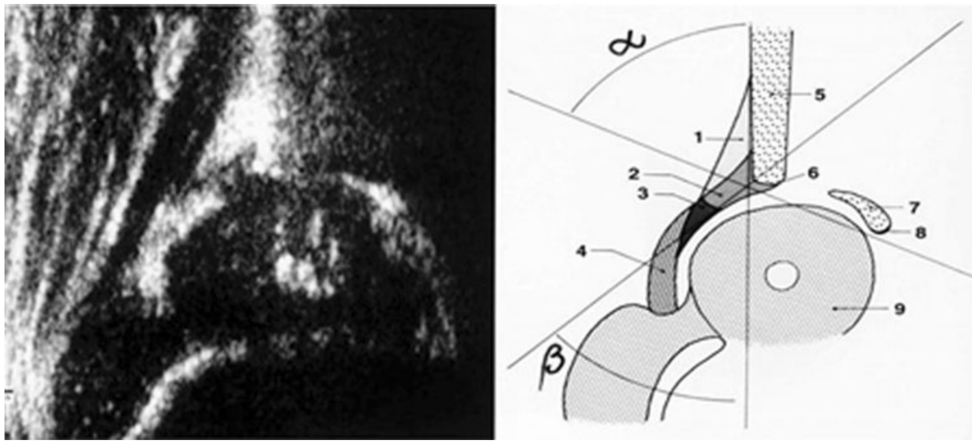

Fig. 4 Ultrasonogram and schematic drawing of a Graf type-I hip. *1* perichondrium and peeiosteum of ilium, *2* cartilaginousacetubular roof, *3* acetubular labrum, *4* joint capsule, *5* ilium, *6* promontory of osseous acetubular rim, *7* iliac bone, *8* inferior margin of ilium, *9* femoral head

complete dataset of all performed teleultrasound. Reviewers were not aware there were paired images and the grading of reviewers was performed in that way that the order of every single image presented was also randomized.

To quantify the difference between original and transmitted ultrasound images dates, we utilized ImageJ software and mean grey value (MGV) function [27]. MGV function represents the sum of MGVs for all pixels in a given image where MGV is calculated as follows: MGV=0.299 red+0.587 green+0.114 blue.

Qualitative Analysis of Image Sets

An image database was created by randomly ordering 100 images from 50 image pairs. Presentation order of every single image was also randomized. Five experienced clinicians (pediatric orthopedic surgeons) from Children's Hospital in Novi Sad, Serbia, assessed the quality of locally and remotely saved images by subjectively grading them from 1 to 5, where 1 was lowest and 5 was the highest grade. The reviewers were not aware of the clinical or imaging findings (hip click or abnormal radiograph). They were not told whether images were normal or abnormal. Their task was to indentify particular imaging targets and to estimate their confidence in doing so. Subjectively grading of reviewers was performed in the same environmental and working conditions in hospital—standard examination room lighting and on the same standard display monitor, notebook MSI EX610X-082EU size 15.4″, screen resolution 1,280×800 pixels, color quality 16 bit, and screen refresh rate 60 Hertz. Calibration of monitor was not done and it was used with basic settings. The display luminance and ambiance lighting were the same for complete image set and for all reviewers.

Statistical Analysis

We applied *t* test for paired samples (repeated measures), and mixed-effect modeling using the individual ratings as dependent (response) variable, which asked for Poisson link-function, appropriate for rank-ordered variables of response. The objective measure was independent variable (covariate), while items and participants (raters) were used as random effects [28].

Results

Complete teleultrasound exams of infant hip in 25 babies were performed. Ultrasound exam of both hips revealed normal findings in all 25 examined babies.

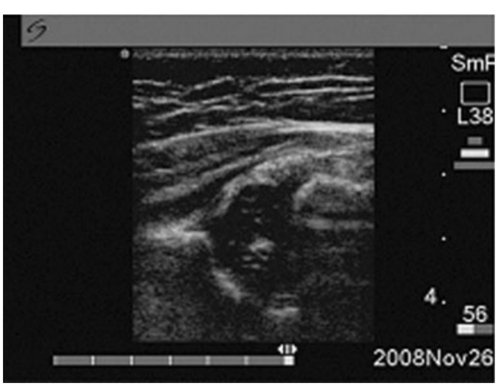

Fig. 5 Original sonogram

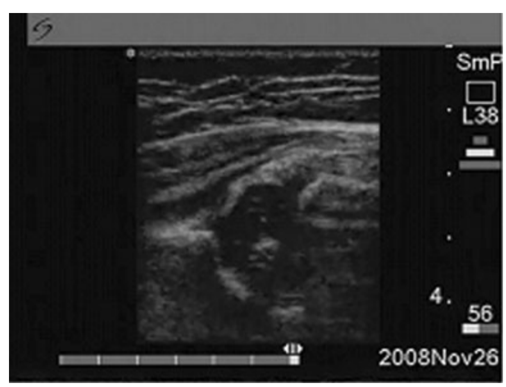

Fig. 6 Transmitted sonogram

General Remarks

Video stream transmitted with Remote Ultrasound software on the aforementioned hardware platform performed largely stable and uninterrupted throughout exams using the Windows Media Video (WMV) coder 9 and transmission rate of five frames per second. This enabled continuous monitoring of the exam from the remote location.

Audio link available within the package was functional most of the time, but occasionally had to be replaced by external link through Skype software [29].

Save Still functionality ensures simultaneous recording and archiving of still images on both sender's and receiver's end without the interruption of exam.

Qualitative Analysis

MGV comparison is a semi-robust way to quantify image degradation that occurs during coding–decoding steps. Figure 7 depicts statistically significant difference in mean MGV values between original (A) and transmitted (B) images (t=76.685; df=49, 1; p<0.0001).

Panel Evaluation

Quality of the image was assessed according to the presence or absence of major topographic points—morphological picture analysis by the Graph [24–26].

Subjective evaluation averages (both median and mean) of the images revealed no statistical difference in ratings of the locally saved and the remotely saved images (t_{Median}= 1.703; df=49; p=0.10; t_{Mean}=1.026; df=49; p>0.10). Median values for original and transmitted images are 2.68 (mean=2.74; SD=0.46) and 2.86 (mean=2.80; SD=0.50), respectively. Original images had higher scores in 26.8 %, transmitted images had higher scores in 30.8 %, and both had equal scores in 42.4 %. In other words, in spite of the statistically significant difference between locally and remotely saved images, the reviewers were unable to notice it clinically, without the ability to differentiate original from transmitted images.

As a last step, we applied mixed-effect modeling at the level of individual evaluations of five raters for 50 image pairs (original and transmitted; 100 images overall). Following recommended procedure, we removed 5 % of extreme residual values and refitted models, thus, testing for their robustness [30]. Results revealed non-significant contribution of the MGV values in predicting individual ratings (Estimate=−0.00630; z=−0.522; df=497; p>0.10). However, the amount of degradation for a given image pair showed marginally significant effect (Estimate=−0.3418; z=−1.907; df=494; p=0.0565). This indicates that the raters were sensitive to the amount of degradation during transmission: the greater the degradation, the lower the rating. In the model, only participants (raters) were attested as significant random-effect (Chi-square=42.861; df=3; p<0.0001), revealing noticeable interindividual differences, as presented in Fig. 8.

Discussion

The trend of continuous growth in internet bandwidth allows a rapid development in image transmission and facile remote viewing of the static images and real-time video stream [5, 30].

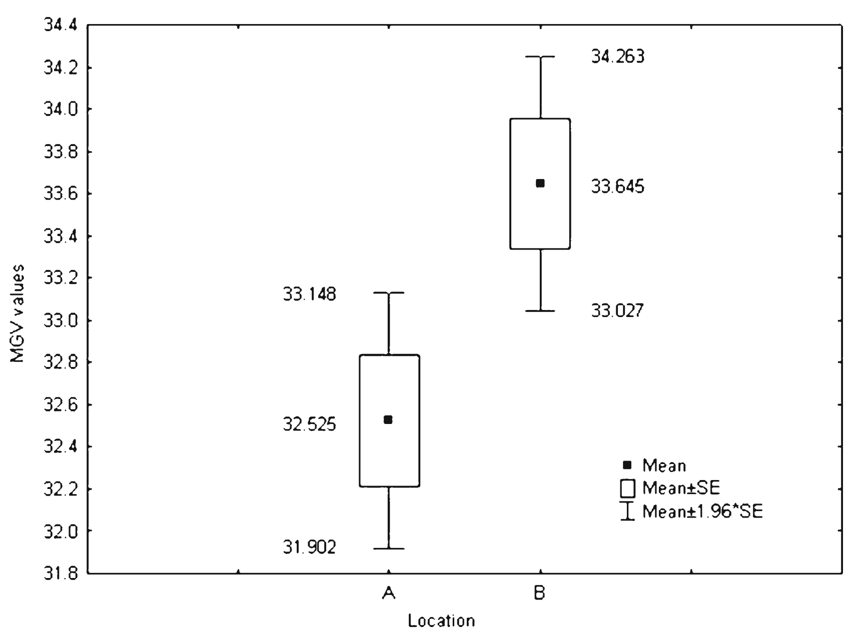

Fig. 7 Average MGV values for original (*A*) and transmitted (*B*) images. *Data points* represent mean values, *lines* represent 2 standard deviations

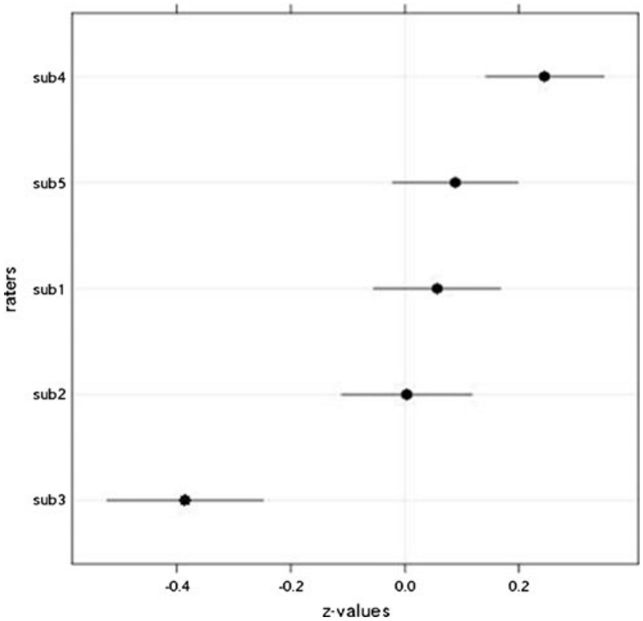

Fig. 8 Standardized ratings per reviewer. Positive *z*-value corresponds to higher grade for original image

Prior reports reveal that teleultrasound examination with limited technical resources could be clinically useful [10, 11, 18, 31]. Likewise, paramedics with no prior ultrasound experience could obtain real-time teleultrasonography images for trauma examination under remote guidance from experienced sonographer [17].

Ultrasound is a powerful tool in infant hip examination as numerous studies have reported and is a major diagnostic tool utilized frequently for screening purposes [24, 32, 33].

Here, we present a model that utilizes teleultrasound in the settings of limited resources. To the best of our knowledge, this is the first report of quality analysis of transmitted real-time images over low bandwidth internet links used for infant hip exam. To be applied in medical practice, teleultrasonography of infant hip should provide a clinically applicable quality of transmitted images, especially in an environment of limited technical resources.

DICOM standard is not applicable to video sequences apart from storage of sequences as separate images [34]. In our study DICOM is not used.

Most studies to date have assessed performance of transmitted images by testing radiologist diagnostic performance and all have proved that diagnostic is possible by application of teleultrasonic systems [35–40].

Earlier research has shown that the normalized mean squared error is a very sensitive test of image degradation but is completely non-specific as it conveys no spatial information [34]. It was also found, with regard to diagnostic quality, that there was mild degradation in gray scale, brightness, and contrast of the images and the main effect is that of loss of high-frequency data [34, 37].

In our study, during teleultrasound infant hip exam in real-time, the frequency of data grows rapidly due to the sudden movements of babies that are frequent, which as a result has a higher data compression. In these conditions, offered model showed adequate quality of transmitted video which is a prerequisite for clinical application.

In this sense, qualitative and quantitative analysis was performed in this study on ultrasound image pairs, original and compressed (transmitted). Beside the fact that image pairs are objectively different (although the difference is small, but systematic), this does not affect subjective estimation, i.e., experienced examiners cannot determine whether it is a compressed (transmitted) or uncompressed (original) image, and ratings between image pairs shows that there is no statistically significant difference.

Potentially, the quality of transmitted ultrasound images may have clinical application, if so, the low-cost structure of the model and the possibility of involvement in paramedics teleultrasonography examination can help to reduce costs, the applicability in places without trained sonographer, no medical infrastructure or remote, rural and prehospital settings, and potentially very widely use in a population to detect a disease, such as strategy screening nap.

Ultrasound screening of developmental dysplasia of the hip (DDH) is not routinely done in most countries but does occur in this region of Serbia (Vojvodina). There are controversial opinions for ultrasound DDH screening [25, 26, 41–47]. The major obstacles to the wide-based ultrasound screening of DDH are the financial cost and the high number of false positives. The consequences of missed diagnosis (false negative) lead to further progression of dislocation and later need for surgical correction that will bring to much worse treatment outcome in patient.

The teleultrasound model we are developing would enable ultrasound screening of wider population (high-risk newborns or all newborns) beside its current use in urgent situations, in regions that lack trained sonologists (M.D.) or sonographers (skilled U/S technologists) or developed medical infrastructure.

In this model, the portable Sonosite 180 ultrasound device offered adequate image quality that made teleultrasound applicable to infant hip exam.

Even though, the current teleultrasound model is designed for the settings of limited recourses, initial testing revealed there were minimal hardware and internet infrastructure requirements necessary to ensure proper software performance. The configuration used for teleultrasound exam is in line with the original paper describing RU which found internet links with maximum upload of 128 kbps to be suboptimal [48, 49, 11]. In our situation, RU showed good performance in real-time transmission of US in an environment of Internet upload of 250 kbps and frame rate with sample rate of five images per second and WMV 9 coder.

During ultrasound examination, lossy compression by the RU software is variable and depends on the quality of internet connection and of the size of incoming video stream. Adjustments of video stream compression to fit less than 250 kbps bandwidth resulted in a steady video stream deemed sufficiently high for a sonologist to follow and guide the exam. Transfer of video stream in DICOM format would require about 200 times larger bandwidth, which is clearly not possible in low resource settings and present technology climate [50, 51].

The possibility of transmission of real-time video streams greatly facilitates the review of infant hip compared with diagnosis based on static US images. Unique aspects of infant hip ultrasound exam, namely high degree of motion during the examination of a baby, results in a highly mobile video stream that needs high rates of compression and therefore lower resolution for transmission. The transmitted video streams were used in continuity without interruption. There was no attempt to correct or reimage the hip after the first pass was done as well as in the cases of extremely restless babies. This non-selective approach ensured more realistic representation of cases in our image dataset.

Our assumption was that the loss of data during transmission would result in the loss of relevant lines and points during morphological image analysis by the Graf. Our results do not support this hypothesis and show that, in spite of the statistically significant degradation of images, the panelists could not clinically differentiate between original and transmitted images.

Conclusion

During the testing, it was ascertained that hardware characteristics significantly affect the quality work of software and that it is important to provide adequate speed values of processor for its successful use, the size of RAM memory and the graphic card, which is essential for the image sender (the computer which sends ultrasound images to remote locations).

The applied model that incorporates hardware elements notebook EX610X-082EU MSI, Pinnacle PCTV Analog USB TV tuner and video capture card Sonosite ultrasound machine and software RU 180 proved to be stable, with no interruption and degradation of video.

Beside the fact that image pairs are objectively different (although the difference is small, but systematic), this does not affect subjective estimation, i.e., experienced examiners cannot determine whether it is a compressed (transmitted) or uncompressed (original) image, and ratings between image pairs shows that there is no statistically significant difference.

Teleultrasound of infant hip through an Internet connection of low transmission bandwidth with open source software package provides adequate ultrasound images, which is a basis for the clinical use of this model.

Further examinations of clinical use of DDH teleultrasound screening through Internet connection of low transmission bandwidth and transmission of video clips is under present investigation as well as upgrading of the software package with the aim of allowing for better navigation with optimal video stream quality in real-time.

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