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"Evaluation of a Very Low-Cost and Simple Teleradiology Technique"

Mahdieh Khodaie · Azam Askari · Kambiz Bahaadinbeigy

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Abstract This paper describes and analyzes a proposed solution of fundamental limitative factor of teleradiology to overcome the teleradiology usages problems in underdeveloped and developing countries. The goal is to achieve a very simple and cost-efficient way to take advantage of teleradiology in anywhere even in remote and rural areas. To meet the goal of this study, the following methodology which is consists of two main procedures was done: (1) Using a digital camera in order to provide a digital image from radiographs. (2) Using an image compression tool in order to compress digital images. The results showed that there is no significant difference between digital images (non-compress and compress images) and radiographic films. Also, there was a logic relationship between the diagnostic quality and diagnostic accuracy. Since the maximum percent of diagnostic accuracy can be seen among "Good" quality images and the minimum to was related "Poor". The results of our study indicate that a digital camera could be utilized to capture digital images from radiographic films of chest x-ray. To reduce the size of digital images, a lossy compression technique could be applied at compression percent of 50 or less without any significant differences. The compressed images can be sent easily by email to other places for consultation and also they can be stored with a smaller size.

Keywords Teleradiology · Lossy compression · Store and forward telemedicine · Teleconsultation

M. Khodaie
Research Center for Health Services Management, Institute for Futures Studies in Health, Kerman University of Medical Sciences, Kerman, Iran

A. Askari (✉)
Medical Informatics Research Center, Institute for Futures Studies in Health, Kerman University of Medical Sciences, Kerman, Iran
e-mail: azamaskari@ymail.com

A. Askari
e-mail: azam.askari@hotmail.com

K. Bahaadinbeigy
Kerman University of Medical Sciences, Kerman, Iran

Introduction

Worldwide, people living in rural and remote areas, suffer from problem such as timely accessibility or lack of access to specialized medical and healthcare services because of factors such as few specialist physicians residing in such areas and lack or loss of medical equipment and medical expertise [1]. Moreover, most of these areas are far from the clinical centers thus, there would be some problems related to the transfer of patients. In addition to high cost estimate, there would be inter-hospital risks regarding to inter-hospital transferring of patients [2]. Besides, in most of underdeveloped countries, there is no adequate number of medical specialists compared to the number of population which would result in a decrease in healthcare services. For instance, as reported by WHO in 2012, there were 3.180 physicians per 1000 populations in France, but 1.132 per 1000 in Peru, only 0.204 physicians per 1000 in Indonesia, and 0.04 in Mozambique [3].

During the recent centuries, remarkable progress in computer technology and telecommunication has facilitated providing healthcare services for both the patient and physician that are in different areas. This fact contributed to the advent and advance of provision of healthcare over a distance or telemedicine. Telemedicine is the practice of medicine at a distance; it usually comprises of quick access to remote medical expertise using telecommunication and information technologies [4]. Overall, telemedicine is transferring of medical data by the use of electric methods of communication when the participants are at different locations.

Using telemedicine technologies not only would facilitate and promote the treatment process, but also would be considerably time and cost efficient. Therefore, telemedicine is an effective way of overcoming certain barriers to medical care, especially for communities located in rural or remote areas [5].

Telemedicine applications can be real-time or store and forward. Because of lack of high-bandwidth networks and advanced devices, real-time interactive telemedicine is not usually accessible in developing or underdeveloped countries [6]. Store-and-forward telemedicine (also known as prerecorded or asynchronous) is a telecommunications technique in which information stored and then sent to a consulting provider for interpretation, diagnosis, confirmatory or second opinion, or for any reason that the input of the consulting provider is requested [7].

The requirements for a store-and-forward telemedicine can simply be consisted of two computers in two sides of teleconsultation which are easily completed by low bandwidth Internet for exchanging radiology images with size we achieved. Also, the types of information transferred in store-and-forward telemedicine include text, digital images, audios, and videos.

The point about this form of telemedicine is that the person sending the information and who receiving it does not need to do simultaneously, therefore, viewing the information can be done at some later time. Also, because of the asynchronous transmission of data, the network's delays are less important. Hence, lower bandwidth network can be used for data transmission. Overall, the store-and-forward telemedicine provides simpler and cheaper facilities than real-time telemedicine and in some situations that is the only way for providing medical services for remote areas, or making the most cost-effective services [7, 8].

The common specialties that are conducive to asynchronous telemedicine include radiology, dermatology, and pathology.

Teleradiology is one of the most common types of prerecorded telemedicine that was first used for on-call review. Nowadays, the technology has reached to the point where preliminary diagnoses may be performed remotely. For instance, teleradiology may be used to send medical images from remote clinics to radiologists who are at a professional office or at home [9]. Moreover, this method would contribute to the consultation among radiologists or between other specialists and radiologists. Regarding these advantages and development in teleradiolgy technology, some regions of world, especially developing and underdeveloped countries, are still confronted with limitations.

The two main factors which limit the use of these services include:

1. A need for digital image format, while in many areas conventional imaging is still dominant.
2. Low bandwidth network especially in the most remote or rural areas which would cause some problems in transferring data from them.

The two main outputs of medical imaging devices are digital and analog (non-digital). The advantages of digital images are that they can be processed, reconstructed, reformatted, retrieved, archived, and sent by network. Also, the viewing of digital images such as windowing and zooming is controllable, and they can be printed on radiographic films when needed.

The output of digital medical devices can be direct or indirect. Currently, using direct digital image, acquisition has been increased. Many imaging devices such as all magnetic resonance imaging devices, all positron emission tomography (PET), and single-photoemission computed tomography (SPECT), many computed tomography (CT) scanners, most of modern plain radiography imaging system, and more sophisticated ultrasound machines and angiography catheter laboratories produce images directly in digital form [9–12].

Despite all advantages of digital imaging, because of factors such as socioeconomic conditions in some developing and underdeveloped countries and especially in remote and rural areas, conventional film imaging has been used widely.

In teleradiology, the images must be digital rather than analog format to be transferred. In medicine, the common procedure used to digitalize analog images is digitizer device. There are a variety of digitizing devices, ranging in sophistication from devices which require the radiographer to insert each radiographic film individually to those that automatically process a stack of radiographic films [10]. But most of the health centers in underdeveloped or developing countries and remote areas cannot afford a digitizer to digitize medical images.

In recent years, remarkable development in the technology of photographic cameras also, the advent of digital cameras [13, 14], has facilitated the wide use of these devices in order to provide digital images from analog ones. Considering that digital cameras are widely available and more cost-efficient compared to digitizers, they can be an appropriate substitute to provide digital images of radiographies after the confirmation of the reliability of the results.

As a technique for teleradiology, many images taken by a digital camera can be sent to different geographical areas, and initial studies have shown this technique to be sufficient for many diagnoses [15–17]. To assess the performance of digital cameras, evaluation of diagnostic accuracy between radiographic films (radiographs) and digital images provided with digital cameras has become a part of numerous teleradiology researches [13, 15, 18, 19]. In addition, in some of the studies, a comparison has been made between the quality of digital images obtained from scanners and digital cameras [20].

As previously mentioned, another factor that limits the application of teleradiology in some areas is the difficulty of transferring of images from one point to another because of slow Internet connection. Since the digital images generally occupy more spaces, the necessity of compression emerges.

Image data compression which is the art of representing the information in a compact form rather than uncompressed form is concerned with reducing the size of the images and the number of bits required to represent an image [21, 22]. It can be used in different fields such as text documents, multimedia, and database table [23]. For most of the computerized application, data compression is a common requirement [24].

Reducing the size of images not only decreases the storage space, but also leads to decreasing the time needed to transmitting, retrieving, and processing images. In all different ways used to compress the images, especially in medicine, one important point is avoiding some unwanted changes in the content of data.

Fundamentally, image compression is classified into two primary types: Lossy or irreversible compression and lossless or reversible compression. In lossless compression, compressed image can be recreated and restored to original image without distortion at any time. Conversely, in lossy image compression method, there are always differences after restoration of images from its compressed state. In other words, recreating compressed image is impossible [25].

DICOM (Digital Imaging and Communications in Medicine) is a standard which is applied for the storing and transmission of medical images. According the imaging modality, in DICOM standards, images can be compressed or not. Compressed pixel data in DICOM must use lossless compression standard that contains standards such as JPEG lossless and JPEG 2000.

Lossless compression methods use the algorithms which result in reconstructing an exact original data from the compressed data. It is used in cases such as medical image, image archiving, remote sensing and satellite communications, and so on. Actually, it becomes indispensable when there is no loss of information is tolerable [26]. However, in lossless compression, a remarkable decrease in the size of the images cannot be seen compared to lossy, under this circumstance, whenever there is a requirement for images with low size, lossy method is more preferable than lossless. With lossy compression, data are discarded and removed during compression. In fact, in lossy image compression techniques, content to which the human eye is insensitive is removed. Also, in lossy compression, sometimes data eliminations may produce significant effects which can be noticeable to the human eye or ear that are known as compression artifacts. Although this method compresses images with higher compression ratios without perceptible image degradation, discarded data cannot be recovered. Also, upon decompression, the removed information cannot be recovered. Consequently, the original image is not identical to the decompressed image [27]. Although lossy compression is typically associated with image files, another multimedia type can take advantage of this technique including sounds and videos.

As previously mentioned, the advantage of lossy methods over lossless methods is that size reduction in lossy compression is more than lossless. But according to the mechanism of lossy compression, in some types of files such as data files, lossy compression cannot be applied because they do not have redundant information. In these cases, lossless compression can be helpful. Additionally, in lossy compression, because of permanently elimination of certain information, all parts of the original information cannot be irreversible when the file is uncompressed.

In compression processes, one important thing that must be considered is deciding what element is more important: quality or size of images. In many different image uses, small differences between original and compressed image are acceptable but as the information in the medical images is totally vital, several attempts are performed to prevent the loss of the information during the compression process. It should be noted that losing small image details that might be a sign of pathology could change diagnosis, leading to severe human and legal consequences [28].

Nowadays, in medical imaging, contrary to applications in the consumer market, the use of lossy compression is still in its beginnings. This is attributed to the suspected risk of effects on the diagnostic data. Numerous studies have been carried out, but it was not until 2008 that national activities in different countries lead to recommendations for the safe use of lossy image compression in clinical practice [29]. Nevertheless, the effect of lossy compression on the diagnostic content is still uncertain. Since in lossy compression, in addition to probable loss of data which affects the diagnosis, there is possibility of producing shadows and artifacts on the images following the compression process. Regarding to emphasize on the compression's effect on both content and quality of medical images, many studies have been carried out on this subject [30, 31].

This paper describes and analyzes a proposed solution of fundamental limitative factor of teleradiology to overcome the teleradiology application problems in underdeveloped and developing countries especially in rural and remote areas. In this regard, it is proposed to evaluate the use of digital camera as a very simple and cost-efficient way to organize a communication or teleconsultation among physicians. Additionally, the effect of irreversible (lossy) compression in diagnostic radiology which is required to minimize the images sizes in order to transfer them via a low bandwidth network was evaluated.

Materials and Methods

After consultation by a biostatistics specialist, the number of data was determined. Accordingly, 70 posteroanterior (PA) upright chest x-rays (CXR) were obtained from a database of radiology studies of an educational hospital. These radiographs had common pathologies, and pathology of each radiographic film was previously determined.

The study was carried out in two separated parts. The purpose of the first part was to evaluate the effects of using a digital camera on diagnostic quality and diagnostic accuracy on the taken images. The second part was aimed to evaluate the impact of compression on images taken by digital camera.

In the beginning, two radiologists evaluated every CXR on a light box and reported a diagnosis for each radiograph. Afterwards, a comparison was made between the two radiologists' response, and between the diagnoses, which was made previously for each radiograph with each radiologist's response.

Next, each CXR was placed on a standard light view box and the image was captured by using a digital camera. Details of digital camera specifications are summarized in Table 1. In order to take images from radiographs, the digital camera was placed on a tripod in 63 cm from the standard light view box. The tripod was located as the angel digital camera was perpendicular to the light box in order to reduce the possible distortion. The tripod was used in order to decrease the effect of hand motion and blurring on the quality of image. Furthermore, the mentioned distance was selected according to the fact that the CXR filled the monitor of digital camera in this distance. The images were provided without flash and with auto zoom in a relatively light room in midday, as there was no any lighted lamp and the sun brightness was appropriate to capture radiographies. The resulted images were stored in JPEG format and every image occupied around 1.7 mb. It should be noted that many digital images were captured in different qualities and under different circumstances, and the best image of the quality, distance, brightness, and the applied imaging techniques such as imaging without flash and zoom adjustment was selected after representation and consultation to an expertise of imaging techniques and confirmation of two independent radiologists.

After 8 weeks, as a time interval to decrease the possibility of remembering the former diagnoses, the digital images obtained from CXR were shown to both radiologists to diagnose the pathology of each image. The digital images were displayed in random order. Moreover, the radiologists were asked to evaluate the diagnostic quality (DQ) of each image using a three-point scale: 1, good; 2, adequate; 3, poor. Finally, the responses of question and the diagnoses were analyzed, and diagnostic accuracy (DA) between radiographs and non-compress digital images was evaluated by the use of SPSS software (SPSS version 18). Also, a comparison was made between the two radiologists.

Afterwards, the effect of compression on digital images' content was investigated. According to the recommendation of a biostatistics specialist, the digital images were compressed in the following percentages: 10, 20, 40, and 50. In order to compress digital images, the size of each compressed image was calculated separately as follows: image size (KB) * the compression percentage = compressed image size (KB). Then, the calculated size was given to the software through an option which could compress the image to a desired size. The compression was made by Radical Image Optimization Tool (RIOT version 0.4.4) which is free software with straightforward interface. Then, after 8 weeks as a time interval, the 280 digital images (consisting of images with 10, 20, 40, and 50 compression percentages) were shown to the radiologists. The images were displayed in completely random order, and the radiologists were blinded to image compression percentages. Similar to the previous step, the radiologists were asked to evaluate the diagnostic quality of each compressed digital image using a three-point scale: 1, good; 2, adequate; 3, poor. The data were entered to SPSS and then analyzed.

Local Research Ethics Committee approval for this research was obtained.

Table 1 Specification of digital camera

Model	Canon PowerShot SX120IS
Total/Effective pixel	Approximately 10.3/10.0 Megapixels
Digital zoom	4×
Focusing range	Normal; 1.6 ft./50 cm-infinity (W), 3.3 ft./1 m-infinity (T)

Results

In this study, 70 cases of CXR were selected from a teaching file while a diagnosis was previously reported for each CXR. A comparison was made between each radiologist's comment and the reported diagnosis and there was no difference.

The radiologists' evaluations on diagnostic quality of non-compress digital images show that 90.71 % of all digital images captured by digital camera had "good", 7.14 % "adequate", and only 2.14 % had poor diagnostic quality. Table 2 indicates diagnostic accuracy between digital images and radiographic films. As Table 2 shows, the mean of diagnostic accuracy between non-compress digital images and radiographs is 90.71 %. The relation between the diagnostic accuracy (DA) and the diagnostic quality (DQ) was shown in Table 3.

As previously mentioned, each digital image was compressed in 10, 20, 40, and 50 %. These compressed images were interpreted by the radiologists. Regarding, a comparison was made between the diagnoses of radiographic film and compressed digital images. As Table 2 indicates, in both 10

Table 2 Diagnostic accuracy between digital images and radiographic films in various compression percentages

	0	10	20	40	50
First radiologist	90	90	88.58	82.85	80
Second radiologist	91.42	91.42	91.42	85.7	80
Mean	90.71	90.71	90	84.275	80

and 20 %, the mean of diagnostic accuracy was more than 90 %. As expected, in higher percent including 40 and 50, the mean of diagnostic accuracy decreased to 84.28 and 80 %, respectively.

The diagnostic quality of images for five varieties of digital images (including one non-compress digital image and four compressed digital images) was shown in Table 4.

Also, another analysis was made between the two radiologists' diagnosis in each comparison. The result shows no significant difference overall (P value<0.05).

Discussions and Conclusion

Nowadays, one cannot ignore the role of medical imaging in the diagnosis process of a disease. One of the most common and beneficial radiographies is chest x-ray (CXR), which is highly effective in both diagnosis and treatment process of disease.

As previously mentioned, there are some deprived remote areas in the world which suffer from lack or loss of medical facilities and healthcare services. Moreover, because specialist is more likely to be located in highly populated areas [1], there usually are not any residing specialist physician in these areas. In addition, sometimes it is not possible to transfer a patient from rural or remote area to a health center in cities because there are problems such as lack of sufficient facilities like transportation problems and travels costs. Furthermore, one considerable point in patient transportation is wasting time which sometimes would be followed by some serious consequences. On the other hand, there are cases which are related to unnecessary transportation of patients to a healthcare center. Such occurrences can cause wasting time and patient compulsory costs problems. For overcoming the limited access to healthcare services in mentioned areas, the advised procedure is utilizing teleradiology techniques as a branch of telemedicine technology. To initialize the teleradiology technology system, utilization of digital image is compulsory. The medical digital images can be provided directly by digital imaging systems or indirectly by means of digitizers. Nevertheless, in some areas, any of the mentioned equipment cannot be provided because of financial problems. Additionally, low bandwidth Internet connection causes trouble for transferring digital images for teleradiology utilization in these areas.

Table 3 The relation between diagnostic quality and diagnostic accuracy

	Compression percent	Good	Adequate	Poor
First radiologist	0	96.92	0	0
	10	96.87	16.66	0
	20	95.31	16.66	0
	40	94.82	33.33	16.66
	50	98.11	33.33	25
Second radiologist	0	98.38	60	0
	10	100	50	0
	20	98.33	60	40
	40	96.29	55.55	42.85
	50	96	66.66	18.18

Table 4 Diagnostic quality for digital images for varied compression percentages

	Compression percent	Good	Adequate	Poor
First radiologist	0	65	5	0
	10	64	6	0
	20	64	6	0
	40	58	6	6
	50	53	9	8
Second radiologist	0	62	5	3
	10	61	6	3
	20	60	5	5
	40	54	9	7
	50	50	9	11

Utilizing of an available, convenient, and cost-efficient approach for overcoming the above problems can lead to a wide use of teleradiology not only in remote areas, but also in most of underdeveloped and developing countries.

This paper suggests that teleradiology can be used effectively and simply by a digital camera and an image compression software. To meet the goal of this study, the images of chest radiographs were taken by a digital camera. The DQ of digital images captured by digital camera was almost good as approximately 90 % of all 70 images had "Good" quality (DQ=90.71 %). The DA shows high agreement between radiographs and digital images (mean=90.71). Also, there was no significant difference between two radiologists' interpretations (P value<0.05). As expected, there was a logic relationship between the DQ and DA. Since the maximum percent of DA can be seen among "Good" quality images and the minimum was related to "Poor" (mean=97.65 and 0.00). Overall, our results show that using digital camera for providing digital images is possible.

In the other part of this study, digital images taken by a digital camera were compressed by RIOT software (version 0.4.4) which uses lossy compression algorithms at 10, 20, 40, and 50 %. As expected, by increasing the compression percent, the DQ decreases, yet there is no any significant difference between 10 and 50 % of compression. As the mean percent of difference between images with "Good" quality in 10 and 50 % was only 15.71 %. This difference between "Poor" quality images was 11.43 %. As Table 2 shows, by increasing compression percent, DA between compressed images and radiographs decreases and this trend continues till it reaches to 80 % in 50 compression percent. Also, the mean of DA in 10 and 20 % was approximately similar (about 90 %). As the statistics shows, there was no remarkable difference between the mean of DA from 10 to 50 %. Additionally, no significant difference can be found between two radiologists' interpretations (P value<0.05). Similar to the previous step, a reasonable relationship can be seen between DQ and DA in all compression percent. Since in all percentages, the highest and lowest mean of agreement is related to "Good" and "Poor" quality digital images, respectively. According to our results, compressing digital images through this procedure is possible without any significant impression on both DA and DQ.

Although the investigated procedure is convenient and efficient, there are some limitations in this study which must be considered:

1. The digital images were obtained from chest radiographs so one cannot generalize the result of this study to the all types of radiographs.
2. The image quality and exposure factors of applied radiographies were different. This can affect the diagnostic quality of digital images.
3. This study can be carried out widely as it involves the more number of radiographs, different kinds of radiographs, and more radiologists and other specialists since the human error is not ignorable and it is possible different radiologists have different diagnoses. It should be noted that the study group involved a heterogeneous types of diseases; more accurate results may be obtained by evaluation a homogenous case mix.
4. The images obtained by an amateur individual so the quality can be affected. Although some solutions (for instance the use of tripod) were devised to decrease such effects, imaging techniques may have been not implemented absolutely as professional individuals.
5. This study was carried out in specific compression percentages so the results cannot be attributed to other compression percent.
6. This study was based on using specific kind of digital camera and software while other types of digital cameras and image compression tools (when the reliability of the results has been proved) can be used.

Overall, the following can be concluded from our experimental results:

1. A digital camera could be utilized to capture digital images from radiographic films of chest x-ray without significant degradation. It should be noted that this result is based on using a specific kind of digital camera.
2. The specific lossy compression techniques which are used in this study could be applied to digital images taken from radiographic film of chest x-ray at compression percent of 50 or less without any significant degradation. It should be mentioned that the result is based on using a specific kind of image software.

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