DEDICATION

To My Parents,

My Brothers and Sisters,

My Wife,

My Children,

All My Teachers,

And My Colleagues

For giving me a full- support and encouragement, love and patience.

ACKNOWLEDGEMENTS

I take this opportunity to express my profound gratitude towards my great supervisor **Professor Dr. Alsafi Ahmed Abdullah** who has given me great advice and help in the whole process of my thesis, and for providing inspiration, patronizing affectionate guidance and moral support during my graduation. My sincere regards to my co-supervisor **Professor Dr. Abdelmoneim AdamMohammed** for his active support and making facilities available for my study and for his constant encouragement regarding completion of the study.

I express my gratefulness towards my teacher and colleague **Dr.EssameldeenMohamed Tom** whose excellent guidance and dedicated efforts made me think upon and understand a number of problems and solve them sincerely, his keen interest and encouragement serves as a constant support and inspiration during my entire study.

Last but not the least I would like to thank my family and friends, for their unconditional support and guidance towards completion.

TABLE OF CONTENTS

Abstract

The aim of this study was to assess the factors affecting the ultrasound image quality in the real medical practice. Fifty ultrasound machines along with the associated image criteria were assessed in Khartoum state during the period from October 2013 to October 2016. The assessment was carried out using the international standards and guidelines. Clinical referral issues and causes of image degradations were assessed as initial part of this study.

The result of the study showed that the majority of ultrasound rooms had waiting areas for patients with percentage of 70%. The Wheelchair facility was accessible in 28 ultrasound rooms (56%).Standard ultrasound tables were available in 12 ultrasound rooms (24%). While standard ultrasound operator adjustable chair were available in 18 ultrasound rooms (36%).From the aspect of electrical and mechanical safety and cleanliness, the regular maintenance and checkup for ultrasound machines were done in 11 ultrasound machines (22%).

Image quality was evaluated for 846 patients. Quality control (QC) performance tests on the selected ultrasound scanners were performed over a period of 18 months, in order to assess their value. The testing schedule includes the initial tests that relates to noise and sensitivity following the international recommendations. Regarding the System Sensitivity, the maximum depth can be visualize less Than 3cm to 5.5cm in 5ultrasound machines with percentage of (10%),from 6cm to 9cm in 10ultrasound machines with percentage of (20%), between 9.5cm to 12.5cm in 22ultrasound machines with percentage of (44%), from 13cm to16cm in 13ultrasound machines with percentage of (26%).

Regarding the ultrasound quality controls results, depth measurements accuracy (Electronic Calipers), the actual distance 100mm, the measured distance in group(A) was 100mm with error of 00mm in 12 ultrasound machines with

percentage of (24%), the measured distance in group (B) was 88mm with error of 12mm in 23 ultrasound machines with percentage of (46%), the measured distance in group (C) was 67mm with error of 33mm in 10 ultrasound machines with percentage of (20%), the measured distance in group (D) was 45mm with error of 55mm in 3 ultrasound machines with percentage of (6%) and the measured distance in group (E) was 30mm with error of 70mm in 2 ultrasound machines with percentage of (4%).Furthermore, quality assurance program include a mechanism for obtaining outcome data regarding positive sonograms and pathological correlation was included in 14 ultrasound rooms with percentage of (28%).The type of thermal Ultrasound Paper is required by Ultrasound Printers in type of high – end regular paper was used in 6 ultrasound rooms with percentage of (12%), the type of low – end paper was used in 16 ultrasound rooms with percentage of (32%), the type of crap low – end paper was used in 7 ultrasound rooms with percentage of (14%) and was not applicable in 21 ultrasound rooms with percentage of (42%). In accordance to the Image Uniformity, there were 6 ultrasound machines Significant Non-uniformity with percentage of (12%), 5 ultrasound machines were good uniformity with percentage of (10%),18 ultrasound machines were better uniformity with percentage of (36%),13 ultrasound machines were best uniformity with percentage of (26%),and 8 ultrasound machines were Excellent Uniformity with percentage of (16%).

Reviewed results had shown that faults that significantly affect the ultrasound image quality were due to probe faults and noise, inappropriate protocol settings by operators, insufficient clinical guidelines from referring physicians as well as absence of an organized protocol manuals for the various ultrasound procedures and lack of regular QC tests for demonstrating any deterioration in the performance of ultrasound imaging equipment.

In conclusion, applying of planned and inclusive quality control program within these ultrasound departments specifically and within other similar departments with emphasis on developing an ultrasound QA program, does not require test equipment with regular integrity and uniformity assessments of transducers are of an importance as well as establishing an image quality and protocols criteria following the international recommendations is a priority. Finally, the use of the most sophisticated technology in ultrasonography besides the staff training is essential as a basic part of the quality process in ultrasound imaging.

ملخص البحث

تهدفهذهالدراسةإلىالتحقيقفيالعواملالتيتؤثرعلىجودةصورةالموجاتفوقالصوتيةفيالممارسةالطبيةالحقيقية.
تمتقييمخمسينماكينةللتصوير بالموجاتفوقالصوتيةفي هذه الدراسة جنباإلىجنبمعتقييم معاييرالصورةالمرتبطةبهافيخمس وثلاثينقسماً من أقسام التصوير بالموجاتفوقالصوتيةفيالمستشفياتالحكوميةبولايةالخرطومفي الفترة من أكتوبر 2013م إلى أكتوبر 2016م. أجريالتقييمباستخداممالمعاييروالمبادئالتوجيهيةالموصىبهادوليا.حيث أن معظم غرف الموجات فوق الصوتية بها مناطق انتظار للمرضى حوالي (35 غرفة موجات فوق الصوتية) بنسبة 70٪ والبعض الآخر لا توجد حوالي (15 غرفة موجات فوق الصوتية)بنسبة 30%.وكما أثبتت الدراسة أن وسيلة الكراسي المتحركة كانت متوفرة في 28 غرفة للموجات فوق الصوتية بنسبة (56٪) وغير متاحة في 22 غرفة للموجات فوق الصوتية (44٪)،وكانت طاولات الموجات فوق الصوتية القياسية متوفرة في 12 غرفة للموجات فوق الصوتية بنسبة (24٪) وغير متوفرة في 38 غرفة للموجات فوق الصوتية بنسبة (76٪).في حين أن كرسي الموجات فوق الصوتية القياسية قابل للتعديل والذي يجلس عليه مشغل الجهاز كانت متاحة في 18 غرفة للموجات فوق الصوتية بنسبة (36٪) وغير متوفرة في 32 غرفة للموجات فوق الصوتية بنسبة (64٪).ومن ناحية السلامة الكهربائية والميكانيكية والنظافة، تم إجراء الصيانة الدورية وفحص أجهزة الموجات فوق الصوتية في 11 جهازا للموجات فوق الصوتية وبنسبة (22٪) ولم يتم ذلك في 39 جهازا للموجات فوق الصوتية بنسبة (78٪).

تمتقييمطلبات الفحصوالإحالةالسريريةوأسبابتدهورصور الموجات وتقييم جودةالصورةلمامجموعه 846 مريضاكجزءأساسيمنهذهالدراسة. أجريتاختباراتمراقبةالجودةعلىأجهزة الموجات فوق الصوتيةالمختارةعلىمدىفترة 18 شهرا،منأجلتقييمحالتها حيث يتضمنالجدولالزمنيالاختباراتالأوليةالمتعلقةبالضوضاءالحساسية بناءً علىالتوصياتالدولية. ووفقا لحساسيةأجهزة الموجات فوق الصوتية،أثبتت الدراسة أن أقصىعمق تم تصويره كان أقل من 3 سم إلى 5.5 سم في 5 أجهزةللموجات فوق الصوتية بنسبة بلغت (10٪)، وبين 6 سم إلى 9 سم في 10 أجهزةللموجات فوق الصوتية بنسبة (20٪)، وكان بين 9.5 سم إلى 12.5 سم في 22 جهازا للموجات فوق الصوتية بنسبة (44٪)، ومن 13 سم إلى 16 سم في 13 جهازاللموجات فوق الصوتية بنسبة (26٪).

وفقا لنتائج ضبط جودة أجهزة الموجات فوق الصوتية، فإن دقة قياسات العمق عند المسافة القياسية 100 ميليمتر حيث كانت المسافة المقاسة في المجموعة الأولى 100 مليمتر ونسبة الخطأ صفر مليمتر في

12 جهازا للموجات فوق الصوتية بنسبة مئوية بلغت 24% وفي المجموعة الثانية 88 مليميتر ونسبة الخطأ 12 مليميتر في 23 جهازا بنسبة مئوية 46% وفي المجموعة الثالثة 67 مليميتر ونسبة الخطأ 33 مليميتر في10 أجهزة بنسبة مئوية 20% وفي المجموعة الرابعة 45 مليميتر ونسبة الخطأ 55 مليميتر في 3 أجهزة بنسبة مئوية 6% وفي المجموعة الخامسة 30 مليميتر ونسبة الخطأ 70 مليميتر في 2 جهاز بنسبة مئوية 4%.كما تضمن برنامج ضمان الجودة آلية الحصول على بيانات النتائج المتعلقة بصور الموجات فوق الصوتية الإيجابية والصور ذات الإرتباط المرضي في 14 غرفة للموجات فوق الصوتية وبنسبة (28٪) ولم يتم تضمينها في 34 غرفة بالموجات فوق الصوتية وبنسبة (68٪) ولم تكن قابلة للتطبيق في 2 غرفة للموجات فوق الصوتية وبنسبة (4٪). نوع أوراق الموجات فوق الصوتية الحرارية الموصى بها من قبل طابعات الموجات فوق الصوتية ذات الجودة العالية استخدمت في 6 غرف للموجات فوق الصوتية بنسبة (12٪)وذات الجودة المتوسطة استخدمت في 16 غرفة للموجات فوق الصوتية بنسبة (32٪)أما ذات الجودة المنخفضة فاستخدمت في 7 غرف للموجات فوق الصوتية بنسبة (14٪)ولم تكن قابلة للتطبيق في 21 غرفة للموجات فوق الصوتية بنسبة (42٪).ووفقا لتوحيد الصورة، كانت هناك 6 أجهزةللموجات فوق الصوتية غير موحدة الصورة عالية الدلالة بنسبة (12٪)، وكانت 5 أجهزة للموجات فوق الصوتية جيدة التوحيد 10٪، و13 جهازاللموجات فوق الصوتية كان توحيد الصور فيها أفضل بنسبة (26٪)، و8 أجهزة بالموجات فوق الصوتية كانت ممتازة التوحيد بنسبة (16٪).

أظهرتنتائجالدراسةأنالعيوبالتيتؤثربشكلكبيرعلىجودةالصور في التصوير بالموجاتفوقالصوتيةترجع إلى عدة أسباب تشمل عدم كفاءة الأجهزة وما يصاحبها من شوائب أو لإعداداتبروتوكولالفحص الغيرمناسبةمنقبلالمشغلين للجهاز،عدمكفايةالمعلوماتالسريريةبطلبات فحوصات الموجات فوق الصوتية،فضلاعنعدموجودأدلةوبروتوكولاتمنظمةلمختلفهذه الفحوصاتبالإضافة إلىعدموجوداختباراتلمراقبةالجودةمنتظمة لإثباتأيتدهورفيأداءمعداتالتصويربالموجاتفوقالصوتية.

إن تطبيقبرنامجمنتظم وشامل لضبطوضمان الجودةداخلوحدات التصوير بالموجاتفوقالصوتيةالتي أجريت عليها هذه الدراسة علىوجهالتحديدوفيالوحدات الأخرىالمماثلة،معالتركيزعلىتطويرإختباراتضمانالجودةالتيلاتتطلبمعدات، بالإضافة إلى الإختباراتالمنتظمة لسلامةوكفاءةمبدلات الطاقة المستخدمة في التصوير، كما أنإنشاءمعاييرللبروتوكولاتللمستخدمة وفقاً للتوصياتالدوليةيعتبر أولوية.

وأخيرا،فإناستخداماالتكنولوجياالأكثرتطورافيالموجاتفوقالصوتيةإلىجانبتدريبالعاملين يعتبر ذو أهمية قصوى كجزءأساسي منعمليةالجودة في التصوير بالموجات فوق الصوتية.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Abbreviations	Name
A	Symbolof attenuation coefficient.
ACR	American College of Radiology.
D	Distance.
dB	Decibels.
E	Elasticity.
F	Frequency.
Hz	Hertz.
I	Intensity.
$\mathbf{I_{SPPA}}$	Spatial-Peak, Pulse-Average Intensity.
$\mathbf{I_{SPTA}}$	Spatial-Peak and Temporal-Average Intensity.
KHz	Kilohertz.
MHz	Megahertz.
m/se	Meter per Second.
m/s	Meter per Second.
mW	Milliwatts
P	Density.
QA	Quality Assurance
RA	Relative Amplitude.
SDMS	Society of Diagnostic Medical Sonography.
TGC	Time Gain Compensation.
US	Ultrasound.
V	Velocity.
WL	Wave Length.

X	Symbol thickness of material.
Y	Symbol of material density.
Z	Symbol for Impedance.
λ	Lambda.

CHAPTER ONE

Introduction

1.1. Introduction:

The purpose of ultrasonography quality assurance (QA) testing is to adequately characterize specific performance parameters for imaging equipment. The results are compared to vendor specifications, published values, or previous measurements to determine if the image quality is adequate. In most x-ray modalities, performance tests are well defined and typical values and tolerances are suggested(Vitikainen et al., 2017). If the measured values differ significantly from the reference values, corrective action must be taken while performance testing in x-ray modalities is almost universally practiced, in ultrasound, performance testing remains somewhat controversial in the medical physics community and proliferation of Quality Assurance of Ultrasound Imagers: Procedures, Expectations, and Philosophies. Quality assurance programs in ultrasound have not yet been realized (Thijssen et al., 2002).

There are several reasons commonly given by those who oppose initiating quality assurance testing for ultrasound imaging equipment, including the following:

1. Ultrasound is considered to be an established and safe modality; therefore, no Quality assurance is necessary.
2. Ultrasound scanners are very stable; therefore, no quality assurance is necessary.
3. Not all practitioners really know what to test, how often to test, what measured values to expect, or what equipment to use in an ultrasound quality assurance program. Consequently, performance testing of ultrasound scanners is more trouble than it's worth.

4. There are no regulations requiring a well-defined quality assurance programin Sudan; therefore, allocating the resources and expenses to a quality assurance Program is not justified.

Optimization in diagnostic sonography means finding the imaging protocol that maximizes the perceived information content with reasonable cost and maximum safety for the patient. The assessment of image quality depends on the diagnostic task, the system performance and the person who perform the procedure.(Thijssen et al., 2007a)

A Quality Assurance (QA) program, which includes quality control tests, helps to ensure that high quality ultrasound images are consistently produced. The QA program covers the entire system from ultrasound machine, to the process of obtaining the ultrasound image, where the operator actually needs to adjust several basic parameters of the system that image quality is sensitive to their values. This will enable to recognize when parameters are out of limits, which could result in poor quality images and affect the final diagnosis with putting in mind performing the quality control tests is not sufficient. When quality control test results exceed established operating parameters, appropriate corrective action must be taken immediately and documented (Lee et al., 2006)

On the other hand and with considering the common argument, “Ultrasound imaging has been around for about 50 years, no biological effects have ever been shown at diagnostic levels, and nothing ever goes wrong with the machines. No physics support has been used in the past, and no one has ever complained.” Now consider this: ultrasound has changed dramatically in just the past few years, and the cost-effectiveness of ultrasound is driving a frenzy of competition among the ultrasound scanner vendors. Although clinicians and patients ultimately benefit from the competitive efforts of the vendors, new technologies continue to emerge at nearly a blinding rate challenging physicists and institutions to keep pace.

Ultrasound scanners are no longer the simple devices that they are often thought to be. Comparing a modern scanner to the early clinical scanners is like comparing a calculator to a desktop computer. Ultrasound practices are being re-defined as technology provides more echo information and processing options. In this respect, the need for physics support has become twofold: quality assurance to verify that the scanners are operating properly, and technical consultation to assure that the scanners are used appropriately, both of which have implications on patient safety. (Kofler and Madsen, 2001). For that potential biological effects should be considered as part of optimization protocols. The essential Clinical Practice Standards as recommended by SDMS are justification of practice, optimize image quality, and improve patient safety and care includes:-

1. Patient Information Assessment & Evaluation which is essential in providing appropriate diagnostic ultrasound information. Therefore, pertinent data regarding the patient's medical history, including familial history as it relates to the diagnostic ultrasound procedure, shouldbe collected whenever possible and evaluated to determine its relevance to the ultrasound examination.(Thijssen et al., 2007b)

Patient education and communication are necessary to establish a positive relationship with the patient and/or the patient's representative, and to elicit patient cooperation and understanding of expectations.

Analysis and Determination of Procedure Plan for Conducting the Diagnostic Examination to optimize patient safety and comfort, diagnostic ultrasound quality and efficient use of resources, while achieving the diagnostic objective of the examination.

1. Implementation of the procedure plan that falls within established protocols
2. Careful evaluation of examination results in the context of the procedure plan is important in order to determine whether the procedure plan goals have been met.

3. Clear and precise documentation of the diagnostic and patient data according to the policy and procedure of the facility.

These basic Standards are designed to reflect behavior and performance levels expected in clinical practice for the Diagnostic Ultrasound Professional that are common to all of the specialties within the larger category of the diagnostic ultrasound profession. Individual specialties or subspecialties may adopt standards that extend or refine these general Standards and that better reflect the day to day practice of these specialties (Tome and Orton, 2008)

1.2 Importance of the Study

Study the current ultrasound departments in Khartoum state concerning the design of departments, type of ultrasound machines and their specifications, protocol of scanning, care of machine and patients and quality of ultrasound images in order to diagnose the problems and stating the international solutions.

1.3 Problem of the Study

The ultrasound images depend on the operator performance and all the consequences of the treatment decisions depend on these outcomes so if the environment concerning the machine capabilities and operator efficiency is not proper the patient will suffer a lot.

1.4 Objectives of Project:

- **General Objectives:**

To assess andoptimizing the ultrasound images in order to reduce the treatment errors.

- **Specific Objectives:**

1. To assess the function and quality of the ultrasound monitor.

2. To check the working of the transducer elements, scan line correlation, and detection of the size of the active scanning area.

3. To compare Grey-level between Monitor and Hardcopy-unit (printer).

4. To calculate the spatial resolution of ultrasound machines.
5. To measure the depth of penetration of ultrasound machines.

CHAPTER TWO

Literature review

2. Ultrasound Equipment Quality Assurance:

2.1 Introduction and overview:

Ultrasound quality control (QC) testing is often over-looked in ultrasound imaging practice because there are few regulations requiring regular QC of these systems. Many sites rely on the manufacturer's preventive maintenance program to ensure these systems are functioning optimally. However, the regulatory climate is changing, placing emphasis on safe and effective imaging practice. Regular QC testing of ultrasound equipment is a valuable tool that helps ensure proper function and good image quality in ultrasound imaging.(Sipilä et al., 2011)

In an imaging facility, quality assurance is a process carried out to ensure that equipment is operating consistently at its expected level of performance. During routine scanning every sonographer is vigilant for equipment changes that can lead to suboptimal imaging and might require service. Thus, in some ways, ultrasound equipment quality assurance is carried out every day, even when it is not identified as a process in itself.

Quality assurancesteps to be discussed heregо beyond judgments of scanner performance that are made during routine ultrasound imaging. They involve prospective actions to identify problem situations, even before obvious equipment malfunction occur.Quality assurance testingprovides confidence that image data, such as distance measurements and area estimations, are accurate and that the image of the best possible quality from the imaging instrument.(Tome and Orton, 2008)

2. 2Components of an Ultrasound Quality Assurance Program:

2.2.1 Quality Assurance and Preventative Maintenance:

Various approaches are used by ultrasound facilities when setting up a quality assurance program for their scanners.

Sometimes these programs include both preventative maintenance procedures performed by trained equipment service personnel and in-house testing of scanners with phantoms and test objects. Some facilities rely on only one of these measures. For preventative maintenance, emphasis is usually given to invasive electronic testing of system components, such as voltage measurements at test points inside the scanner. Sometimes preventative maintenance also involves an assessment of the imaging capability by scanning phantom.(Hedrick et al., 2005)

In-house scanner quality assurance programs usually involve imaging phantoms or test objects and assessing the results. In-house tests may be performed by Sonographers, Physicians, medical physicist, clinical engineers, or equipment maintenance personnel. Detailed recommendations from professional organizations and experts in ultrasound on establishing an in-house quality assurance program are available elsewhere.(Papp, 2014)

2.2.2Tissue-Mimicking Phantoms:

In-house scanner quality assurance tests are most often performed with tissue-mimicking phantoms. In medical ultrasound a **phantom** is a device that mimics soft tissues in its ultrasound transmission characteristics. Phantoms represent "constant patients," and images can be taken at different times for close comparison. Image penetration capabilities, for example, are readily evaluated for changes over time when images of a phantom are available for comparison.

Phantoms also have targets in known positions, so images can be compared closely with region that is scanned. Examples include simulated cysts, echogenic structures, and thin "line targets."

2.2.3 Tissue Properties Represented in Phantoms:

Tissue characteristics mimicked in commercially available phantoms are the speed of sound, ultrasonic attenuation, and, to some degree, echogenicity, that is, the ultrasonic scattering level. Phantoms cannot exactly replicate the acoustic properties of soft tissues. This is partially due to the complexity and variability of tissues. Instead, phantom manufacturers construct these objects to have acoustic properties that represent the average properties of many different tissues.

Sometimes the term tissue-equivalent is used when phantoms are described. However, this term should not be interpreted literally because most phantoms materials are not acoustically equivalent to any specific tissue.

2.2.4 Typical Quality Assurance Phantoms Design:

An example of a general purpose ultrasound quality assurance phantom is shown in Figure 15-1. Such phantoms are examined with scanner settings that are similar to those used when patients are being scanned. The phantom images have gray-scale characteristics that are analogous to characteristics of organs, although the actual structures are not anatomically represented.

Figure 15-1**,** B,showsthe internal structure of this phantom. The tissue- mimicking material within the phantom consists of a water-based gelatin in which microscopic particles are mixed uniformly throughout the volume(Tome and Orton, 2008).

The speedof sound in this material is about 1540m/sec, the same speed assumed in the calibration of ultrasound instruments. The ultrasonic attenuation coefficient versus frequency is one of two values: either 0.5 dB/cm per megahertz or 0.7 dB/cm per megahertz (Box 2-1). Some users prefer the lower-attenuating material because they find it easier to image objects in the phantom. However, standards groups recommend the higher attenuation because it challenges machines more thoroughly (Tome and Orton, 2008).

Box 2-1 Tissue Attenuation Coefficients

Attenuation coefficients are normally specified in decibels per centimeter. To include the dependence of attenuation on frequency, phantom manufacturers divide the attenuation coefficient by the frequency at which the measurement is done. This yields units of decibels per centimeter per megahertz. Strictly speaking, this approach should be used only when attenuation is directly proportional to the frequency, as we often assume for tissues. The value of 0.7 dB/cm per megahertz is representative of the attenuation coefficient in difficult-to-penetrate fatty liver.*

The depth that structures can be visualized within tissue-mimicking material having this amount of attenuation more closely correlates with clinical penetration.

***** Lu ZF, Lee FT, Zagzebski JA: Ultrasonicbackscatter and attenuation diffuse liver disease, Ultrasound Med Biol25:1047, 1999.

Attenuation in the gel-graphite material in the phantom is proportional to the ultrasound frequency and mimics the behavior in tissues.(Simpson, 2009)Other types of materials have been used in phantom, but only water-based gels laced with powder have both speed of sound and attenuation with tissue-like properties.(Papp, 2014)

Small scatterers are distributed throughout the tissue-mimicking material. Therefore the phantoms appear echogenic when scanned with ultrasound imaging equipment (Figure 2-1**,** C). Many phantoms have simulated "cysts,"

Which are low –attenuating, nonechogenic cylinders. These should appear echo free on B-mode images and should exhibit distal echo enhancement. Some tissue phantoms provide additional image contrast by having simulated masses or test objects of varying echogenicity. Such objects are evident in Figure 2-19**,** C

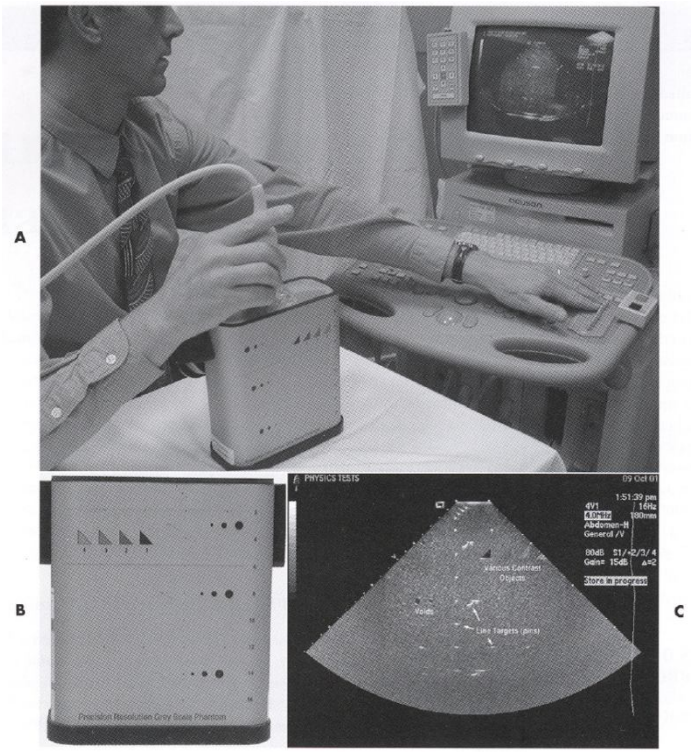

Figure 2-1 Exampleof a general –purpose quality assurance phantom.**A**, phantom being imaged with an ultrasound scanner.**B**, Close-up of phantom, with diagram of interior contents. **C**, B-mode image of the phantom.

Image source :(Ultrasound Equipment Quality Assurance James A. Zagzebski and James Kofler).

Most quality assurance phantoms also contain discrete reflectors, such as nylon-line targets, to be used mainly for evaluating the distance measurement accuracy of a scanner. Tests of the accuracy of distance measurements rely on the manufacturer of the phantom to have filled the device with a material with a sound propagation speed of 1540 m/sec or at least close enough to this speed that no appreciable errors are introduced in calibrations. These phantoms also rely on the manufacturer having defined the reflector positions accurately. With the correct speed of sound (1540 m/sec) and precisely known distances between point like reflectors, it is easy to check the accuracy of distance measurements with calipers, as described later.

Phantom often contain a column of reflectors, each separated by 1 or 2 cm, for vertical measurement accuracy tests. One or more horizontal rows of reflectors are used for assessing horizontal measurement accuracy. Additional sets of reflectors may be found for assessing the axial resolution and the lateral resolution of scanners.

2.2.5 Cautions about Phantom Desiccation:

When a phantom made of water-based gels is used, loss of water (desiccation) may become a problem as the phantom ages. If this occurs, the speed of sound in the phantom may have changed. A scanning surface that has become concave is an indication of severe desiccation. Occasionally, water losses become so problematic that air entering the phantom window leads to the inability to image the phantom effectively. Users should follow the instructions given by the phantom manufacturer to avoid significant desiccation. For example, some manufacturers recommend storage in a humid, air tight container, and this practice should be adhered to if so stated(Merz and Batzel, 2009).

Desiccation is not a problem with rubber-based phantom materials (Figure 2-2) produced by some manufacturers. Storing these phantoms with the tissue-mimicking material directly exposed to the environment can be an advantage compared with water-based gels. The main disadvantages of rubber materials are that their speed of sound is lower than 1540 m/sec (about 1540 m/se in some rubber-based phantoms) and that their attenuation is not proportional to the ultrasound frequency.[14] Therefore they may be not be as effective as water-based gel phantoms when imaging over a large frequency range(Merz and Batzel, 2009).

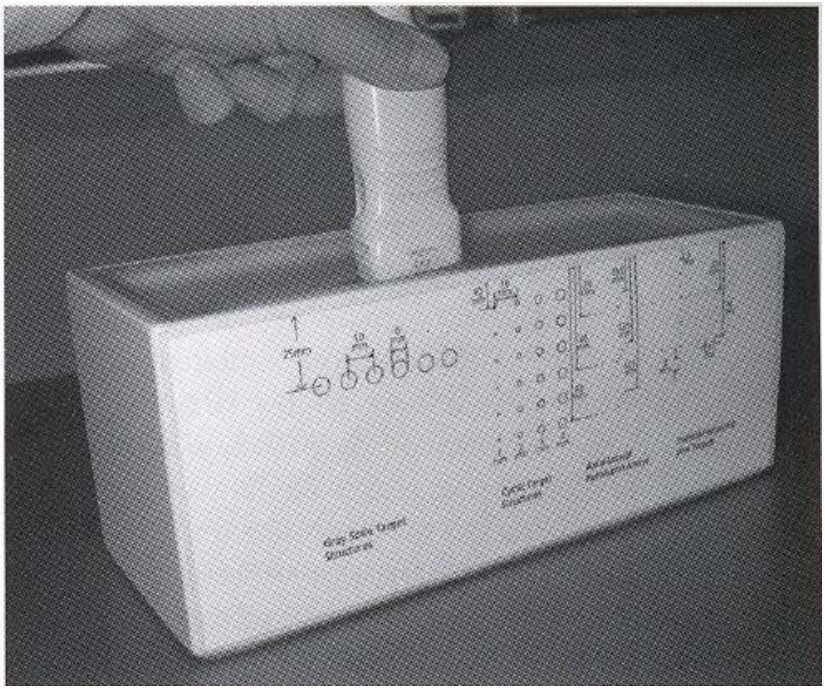

Figure 2-2A phantom with rubber-based, tissue-mimicking small parts. Although the acoustic properties are not as precise as water-based phantoms, less care is required during manufacturing and with on-site storage to minimize changes over time.

Image source :(Ultrasound Equipment Quality Assurance James A. Zagzebski and James Kofler).

2.3 BASIC QUALITY ASSURANCE TESTS:

A recommended set of instrument quality assurance tests includes checks for the consistency of instrumentsensitivity,evaluation of image uniformity, the assessment of gray-scale photography or image workstation brightness levels, and where necessary, checks of vertical and horizontal distance measurement accuracy.(Dudley et al., 2001) This group of tests can be performed by a sonographer in 10 to 15 minutes, which includes the time for recording the results on a worksheet or in a notebook.

2.3.1Transducer Choice:

Results of some test produces depend on which transducer/frequency combination is used with the instrument.

On systems in which several transducers are available, tests should be done with two transducers.(Brendel et al., 1977) Choose the most common transducer that is used in most examinations; additionally it is preferable to test another transducer that has a different frequency range and a different scan format. For example, with a general - purpose scanner, a low-frequency (2-5 MHz) curvilinear or phased array and an intermediate –frequency (5-8 MHz) or even a high-frequency linear array are appropriate. This transducer combination should be used for all subsequent test procedures. Be sure to record all necessary transducer assembly identification information, including the frequency, size, and serial number, so that future test will be conducted with the same probe. If several identical scanners are available, make sure that the same transducer/scanner pairs are used for all subsequent testing(Choi et al., 2011).

2.3.2 System Sensitivity:

The **sensitivity** of an instrument refers to the weakest echo signal level that can be detected and displayed clearly enough to be discernible on an image. Most scanners have controls that vary the receiver amplification (gain) and the transmit level (e.g., output or power). These are used to adjust the sensitivity during clinical examinations. The maximum sensitivity of the instrument occurs when these controls are at maximum practical settings. Often the maximum sensitivity is limited by electrical noise that appears on the display when the receiver gain is at maximum levels. The noise may be generated externally, for example, by electronic communication networks or by computer terminals. More commonly the noise arises from within the instrument itself such as in the first preamplification stage of the receiver amplifier(Choi et al., 2011).

Concerns during quality assurance tests are usually centred on whether notable variations in sensitivity have occurred since the last quality assurance test. Such variations might result from a variety of causes, such as damaged transducers, damaged transducer cables, or electronic drift in the pulse-receiver components of the scanner. Questions related to the sensitivity of a scanner sometimes occur during clinical imaging; a quick scan of quality assurance phantom and comparison with results of the most recent quality assurance test help determine whether there is cause for concern.

A commonly used technique for detecting variations in maximum sensitivity is the measure of the maximum **depth of visualization** for signals from scattered echoes in the tissue-mimicking phantom.(Goodsitt et al., 1998) The technique includes the following:

1. Adjust the output power transmit levels and receiver sensitivity controls so that echo signalare obtained from as deep as possible into the phantom. Now the output power control is positioned for maximum output, and the receiver gain is adjusted for the highest values without excessive noise on the display. (Experience helps in establishing these control settings; they should be recorded in the quality control worksheet, which is described later.)
2. Scan the phantom and estimate the maximum depth of visualization of texture echo signals (Figure 2-3).
3. File a digital or hard copy image of the phantom. In the examples in Figure 2-3, the maximum depth of visualization is 16.8 cm at 4 MHz With a 2-MHz mode, the maximum depth of visualization is at least deep as the length of the phantom, so it cannot be measured with this phantom. The lower frequency results in a lower attenuation and therefore greater maximum depth of visualization.

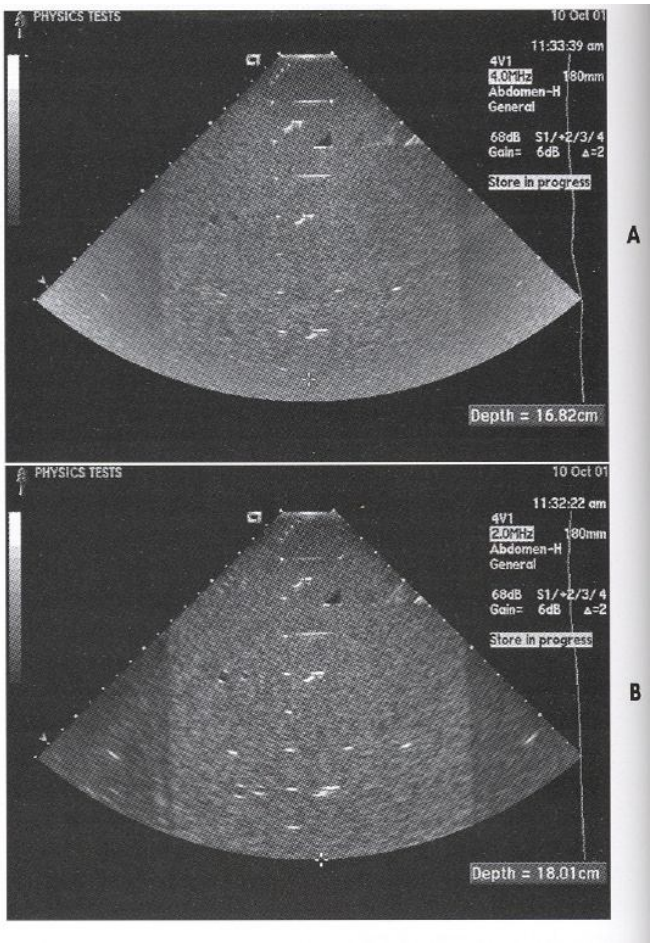

Figure 2-3 Images obtained for the maximum depth of the visualization quality assurance test with a multifrequency array transducer. The phantom has an attenuation coefficient of 0.7 dB/cm per megahertz. **A**,At 4 MHz the maximum depth of visualization is 16.8 cm. **B**, At 2 MHz the maximum depth of visualization cannot be determined wit this phantom because visualization remains excellent all the way to the bottom of the phantom.

Image source :(Ultrasound Equipment Quality Assurance James A. Zagzebski and James Kofler).

For the test results to be interpreted**,** a comparison is made with maximum visualization results from a previous test, perhaps 6 months earlier. Results should agree within 1 cm. Normal trail-to-trail variations in scanning and interpretation

prohibits closer calls than this. However, with digital or hard copy images and records of maximum depth of visualization tests, ascertaining whether a scanner/transducer combination has drifted significantly over time in echo detection capabilities should be possible.

In addition to this measurementbeing made with the standard transducer, occasionally performing the test with different transducers is useful. For example, the test can be performed with all of the transducers that are available for each instrument when quality control tests are first established and semiannually thereafter. This method helps pinpoint the source of any decrease in the maximum sensitivity. If the maximum depth of visualization decreases on all of the transducers tested on a specific scanner, the problem is most likely associated with the scanner and not the transducer assemblies(Choi et al., 2011).

2.3.3 Photography and Gray – Scale Hard Copy:

Perhaps the most frequent source of ultrasound instrument variability over time is related to image photography. Too often, drifting the imaging instrument**,** in the hard copy cameras, or in film processing reduces image quality to the point that significant amounts of detail related to echo signal amplitude variations are lost on hard copy B-mode images.

However, if image viewing monitors and recording devices are set up properly and if sufficient attention is given to photography during routine quality control, these problems can be reduced. The advent of laser printers with automatic (or semiautomatic) calibration has greatly reduced much of the variability of producing a hard copy image. However, even laser printers have problems.

2.3.4 Monitor Setup and Recording Devices:

Most instruments provide both an image display monitor, which is viewed during scan buildup, and an image recording device. As a general rule the display monitor should be setup properly first, and then adjustments should be made, if necessary,

to the laser printers or other hard copy images. The establishment of proper settings is expected only during the installation of a scanner, during major upgrades, or during the detection of image problems. Changes made to the display settings are not automatically reflected in the printed image. Changing the display settings requires adjustment of the hard copy device to properly match the printed image to the display image. Therefore image display settings should not be shifted routinely. Many facilities go so far as to remove the control knobs on image monitors once the contrast and brightness are adjusted to an acceptable level; thus the temptation to change settings casually is removed.

An effective method for setting up both viewing and hard copy devices has been described by Gray.(Üstüner and Holley, 2003)

It is recommended that adjustments be done with an image that contains a clinically representative sampling of gray shades.

1. First attend to the display monitor viewed during scanning. With the contrast seeing of the monitor initially set at minimum settings, adjust the brightness to a level that just allows television raster lines to be discernible.
2. After the adjustment, increase the monitor contrast until just before the text on the display begins to become distorted (the text, which is typically displayed at a maximum brightness, begins to smear to the left and right if the contrast is too high). Verify that the settings are adequate with a clinical image. After the viewing monitor is properly adjusted, make provisions to prevent causal changes in settings by department personnel.
3. Adjust the image recording device to obtain the same gray shades that appear on the display monitor. This adjustment may require several repetitions, varying the contrast and overall brightness, until satisfactory results are obtained. Many manufacturers provide gray-scale test patterns, such as a pattern by the society of Motion Picture and Television Engineers (SMPTE) (Figure 2-4), that can be

displayed on the scanner. These patterns are useful for matching the hard copy image to the display image. If such a pattern is unavailable, a small gray-scale bar is usually presented on the real-time image.

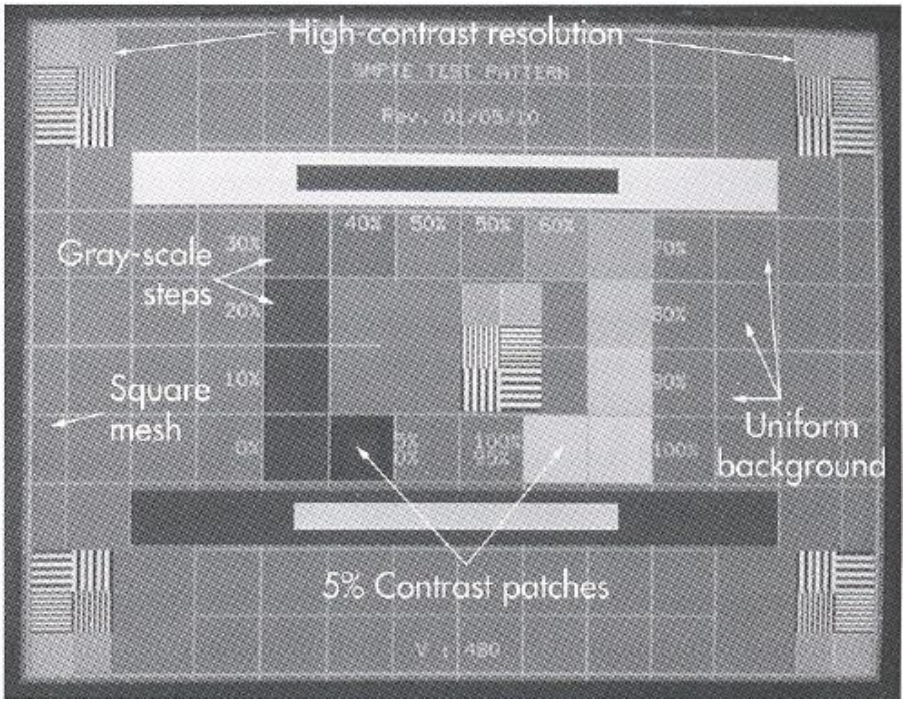

Figure 2-4 Atest pattern of the Society of Motion Picture and Television Engineers (SMPTE). The pattern contains a gray-scale range in increments of 10% video level. There are also 5% contrast patches at the 0% (black) and 100% (white) levels, a mesh pattern to check for spatial distortions, and several resolution patterns.

Image source :(Ultrasound Equipment Quality Assurance James A. Zagzebski and James Kofler).

2.3.5 Routine Quality Assurance of Image Recording:

Routine checks should be performed on the quality of gray-scale photography or other hard copy recording media. Detailed analysis performed in some installations includes film sensitometry and film-emulsion batch crossovers. These processes are well established and documented[5] and are not explained in detail.

Images of a tissue-mimicking phantom, along with the gray-bar pattern that appears on the edge of most image displays, can be used for routinely assessing photography settings. In photography and processing, all brightness variations in the viewing monitor or image should be successfully recorded on the hard copy image.

A quick check of gray –scale recording can be done as follows:

1. On an image of a tissue-mimicking phantom (or of a patient), check to see whether weak echo signal dots appearing on the viewing monitor are successfully recorded on film.
2. Determine whether the entire gray bar is visible bar is visible and whether all gray levels are distinguishable. For example, for a scanner whose gray bar includes 15 levels of gray, along with the background, the hard copy image should portray distinctions among all of the different levels. Continuous gray bars are compared with printed gray levels. In this case, focus attenuation on the light and dark ends of the patterns and compare the differences in the extent of white and black areas on the bars.
3. The entire length of the gray bar pattern display on the viewing monitor should be visible on the final image (see Figure 2-3, B). For multiple images on a single sheet of film or paper, all of the images should have the same background brightness and should display the gray-bar pattern in the same manner. These images can be verified from clinical images taken on the same day the quality assurance tests are taken or from the quality assurance films themselves.
4. Some laser printers offer features for settings other characteristics of the printed image, such as border width and background density. These settings should be decided, usually by trial and error, by all of those involved in reading the images. Once a conclusion has been reached the settings should be installed in all printing devices used for ultrasound and documented for future reference.

Many imaging facilities now use digital images achieved on computer systems and image workstation displays require periodic evaluation to ensure optimum performance. The displays should be cleaned periodically and before any quality assurance testing. Ideally, a lint-free cloth should be used for wiping the surface of display. Cleaning solution should be applied to the cloth and not sprayed directly on the display. Some displays, especially flat-panel displays, many require specific cleaning products because of antiglare or other special coatings on the screen surface, so check the manufacturer's cleaning instructions before applying any chemical product to the display. Storing a cloth and cleaner solution next to the workstation display is a convenient practice to promote a dust-free clean display screen.

TheSMPTEpattern (Figure 2-4) is useful for routine quality assurance of displays. The large square on the SMPTE patterns are used to note any distortions caused by the display; they should appear as an array of perfect squares over the entire screen. Degradation of monitor resolution can be noted by viewing the high-contrast resolution patterns and the text on the SMPTE pattern. These should appear well-defined, not blurry or smeared. The 5% contrast patches should be visible in the 100% video (white) and 0% video (black) squares. The gray background of the SMPTE pattern should be uniformly gray across the entire display.

The following are characteristics that should be noted when performing display quality assurance:(Dudley et al., 2014b)

Monitor cleanliness. The display screen should be free of dust or other markings (e.g., pen markings and finger-prints).

Spatial distortion. Have the display serviced if the squares on the SMPTE pattern are distorted at the corners or if their aspect ratios (width/height) are not correct

(e.g., a square shape that appears to be rectangular). Some displays provide controls that allow the user to correct monitor spatial distortions.

Monitor resolution.(Edge definition). Any high-contrast boundary, such as white text on a dark background, should be well-defined.

Gray-scale uniformity. The intensity on the display should be consistent over the entire screen. This requires a test pattern that contains a constant gray level over the entire screen or at least at all four sides and in the center. Moving a small uniform image from one side of the screen to the other is typically an ineffective alternative to a single large image.

Low contrast visibility. The 5%difference in video level (on black and on white) of the SMPTE pattern should be noticeable on the display. Room lightening should be minimal when viewing low-contrast objects. Alternatively, the entire gray bar pattern seen on the scanner monitor should be visualized on the workstation monitor.

Display artifacts. The display should not contain streaks, lines, or dark/light patches. If a test pattern of uniform brightness is unavailable, the brightness pattern available should be used. In this case, the observer has to "look through" the test objects at the background of the image. A few nonfunctioning (dropped) pixels, which appear as small black dots, may be tolerable. However, a group of dropped pixels or several dropped pixel scattered over the screen warrants replacement of the display(Civale et al., 2015).

2.3.6 Scan Image Uniformity:

Ultrasound phantoms typically contain a background material that is distributed throughout the phantom. However, with most phantoms it is impossible to acquire a view that does not contain any test objects. In these cases, scan image uniformity can be assessed by focusing attention solely on the background material of the phantom. Ideally, when a region within a phantom is scanned and the machine's

gain settings are adjusted properly, the resultant image has a uniform brightness throughout (Figure 2-5, A). Nonuniformities caused by the ultrasound imager can occur because of the following situations:

Bad elements in a linear or curved array or loose connections in beam former board plug-ins can lead to vertically oriented Nonuniformities (Figure 2-5, B). (Boards can be loosening if the scanner is wheeled over bumps or if it is transported by a van to other hospitals.)

Inadequate side-to-side image compensation in the machine can lead to variations in brightness from one side of the image to another.

Inadequate blending of pixel data between transmit and receive focal zones can lead to horizontal or curved streaks parallel to the transducer surface. Quality assurance testing is an ideal time to assess whether such faults are noticeable. An image is taken of a uniform region in the quality assurance phantom, and the image is inspected for these problems.

A uniformity image is useful in the detection of subtle artifacts that may not be readily evident on the clinical images.

Care should be taken to inspect the image thoroughly for any streaks, any dark or light patches, or any gray-scale gradients in the axial or lateral directions. Occasionally a swirling pattern with the background texture may be noticed. However, this pattern is typically a result of the phantom manufacturing process, which can be verified by comparison with uniformity images from other transducers(Civale et al., 2015).

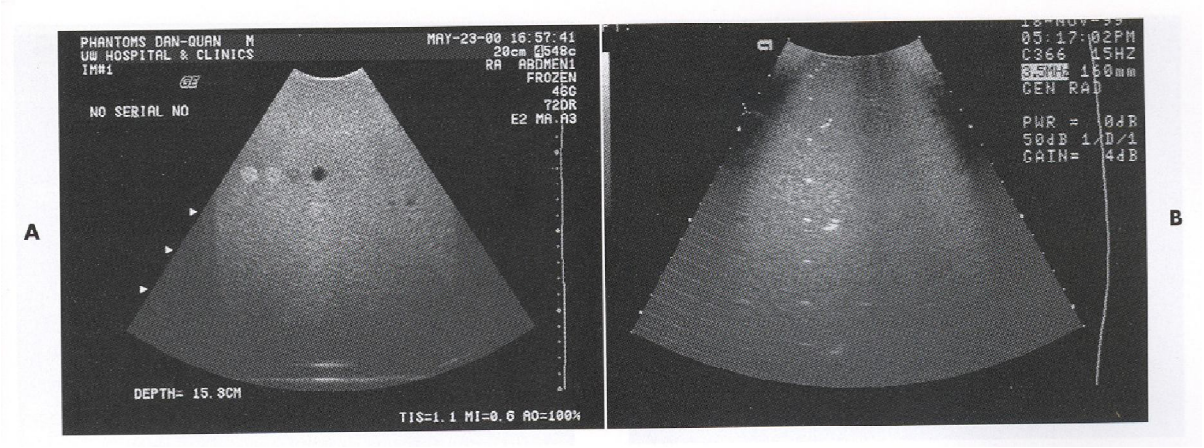

Figure 2-5 Image uniformity test **A**, Good uniformity. **B**, Results with a transducer that should be repaired or replaced. Note the vertical streaks that are evidence of element dropout for this linear array transducer.

Image source :(Ultrasound Equipment Quality Assurance James A. Zagzebski and James Kofler).

2.3.7 Distance Measurement Accuracy:

Instrument used for measuring structure dimensions, organ size, and areas can be tested periodically for accuracy of distance indicators. However, many individuals think that routine distance measurement accuracy checks are not useful because digital measurement systems on scanners exhibit satisfactory stability over time.(Nagy et al., 2008)

Distance indicators usually include 1-cm-deep markers on M-mode and B-mode scanning displays and electronic calipers on B-mode scanning systems. Calipers on workstations that are part of computer archiving systems should also be checked for accuracy. The principal distance measurement tests are separated into two parts: one part is for measurements along the sound beam axis, which is referred to as the vertical distance measurement test or the axial distance measurement test, and the other part is for measurements taken perpendicular to the sound beam axis, which is called the horizontal distance measurement test(Slade and Slade, 2011).

2.3. 7.1 Vertical distance measurement:

Vertical distance measurement accuracy is also called depth calibration accuracy in some texts.

1. To evaluate a scanner's vertical distance measurement accuracy, scan the phantom, ensuring that the vertical column of reflectors in the phantom is clearly imaged (Figure 2-6).

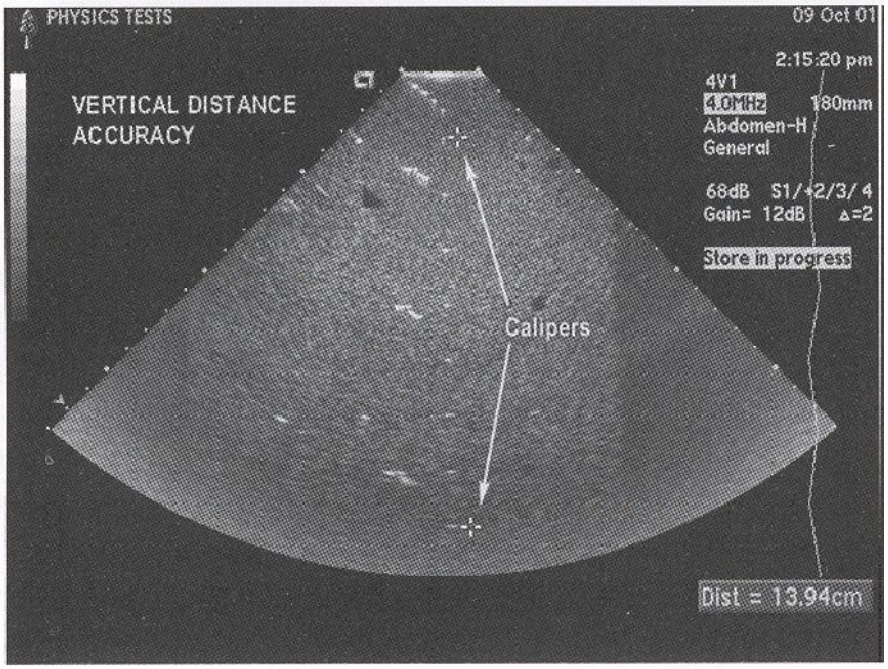

Figure 2-6 Vertical distance measurement check. The caliper reading (13.94 cm) is compared with the actual separation (14 cm) between pins positioned along a vertical column in the phantom. Shorter distances should be used when high-frequency transducers are evaluated.

Image source :(Ultrasound Equipment Quality Assurance James A. Zagzebski and James Kofler).

2. Position the digital calipers to measure the distance between ant two reflectors in this column.

Correct caliper placement is from the top of the echo from the first reflector to the top of the echo from the second reflector or from any position on the first reflector to the corresponding position on the second reflector.

When testing general-purpose scanners, choose reflectors positioned at least 8 to 10 cm apart for this test. Most laboratories also measure a smaller spacing, such as 4 cm. For small-parts scanners and probes, use distance of 1 or 2 cm. In general, the largest separation allowed by the transducer/frequency combination and the target placement in the phantom is appropriate for the distance accuracy test.

Determine that the measured distance agrees with the actual distance given by the phantom manufacturer to within 1 mm or 1.5%, whichever is greater. If a larger discrepancy occurs, consult with the ultrasound scanner manufacturer for possible corrective measures(Slade and Slade, 2011).

2.3.7. 2 Horizontal distance measurement:

Horizontal measurement accuracy shouldbechecked in a manner similarto vertical distance measurement. Measurements obtained in this direction (Figure 2-7) are frequently less accurate because of beam width effects and scanner inaccuracies. Nevertheless, results should agree with the phantom manufacturer's distances to within 3 mm or 3%, whichever is greater. Correct caliper placement for this test is from the center of one reflector to the center o the second reflector. For the example in Figure 2-7, measurement results are within 1 mm of the actual distance between the reflectors examined. This is well within the expected level of accuracy(Slade and Slade, 2011).

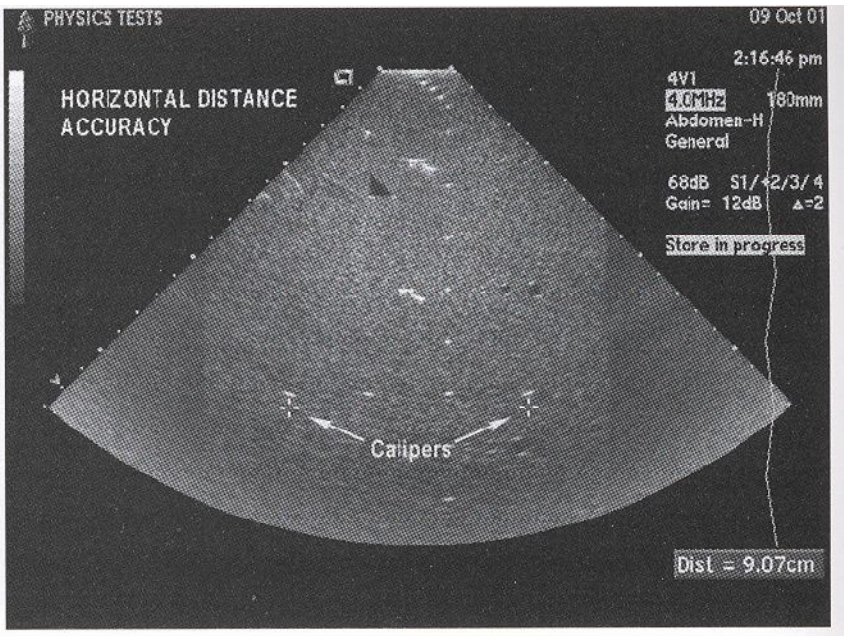

Figure 2-7 Horizontal distance measurement check. The caliper reading (90.7 mm) is for a measurement taken horizontally on the image and compared with the actual pin separation (90 mm).

Image source :(Ultrasound Equipment Quality Assurance James A. Zagzebski and James Kofler).

2.3.8 Other Important Instrument Quality Assurance Tasks:

During routine performance testing it is a good idea to perform other equipment – related chores that require occasional attention. These include cleaning air filters on instruments that require this service(most do), checking for loose and frayed electrical cables, looking for loose handles or control arms on the scanner, checking the wheels and wheels locks, and performing recommended preventive maintenance of photography equipment, which may include dusting or cleaning of photographic monitors and maintenance chores on cameras(Slade and Slade, 2011).

2.3.9 Documentation:

An important aspect of a quality assurance program is keeping track of the test results. Most laboratories want to adopt a standardized worksheet on which to

write down the test results. The worksheet helps the user carry out the tests in a consistent manner by having enough information to facilitate recall of transducers, phantoms, and machine settings. It is also includes blank spaces for recording the results.

2.3.10 Spatial Resolution Tests:

Some laboratories include spatial resolution intheir quality assurance testing. Measurements of spatial resolution generally require more exacting techniques to achieve results that allow intercomparisons of scanners. Therefore many centers do not do such performance tests routinely, but may do so only during equipment acceptance tests.Common methods for determining axial and lateral resolution are discussed in this chapter.

2.3.11 Axial Resolution:

Axial resolution is a measure of how close two reflectors can be to one another along the axis of an ultrasound beam and still be resolved as separate reflectors. Axial resolution is also related to the crispness of the image of a reflector arranged perpendicularly to the ultrasound beam.

Axial resolution can be estimated by measuring the thickness of the image of a line target in the quality assurance phantom. Alternatively, some phantoms contain sets of reflectors for axial resolution testing. Both approaches are shown in Figure 2-8. The axial separations between successive targets in this phantom are 2 mm, 1 mm, 0.5 mm, and 0.25 mm. The targets are offset horizontally to minimize the effects of shallow targets shadowing the deeper ones. The pair most closely spaced yet clearly distinguishable in the axial direction indicates the axial resolution. This implies that to be considered resolved, the axial extent one below, even though the two pins may be distinguishable because of their lateral separation. Often, as in this phantom, the target pair separations are not finely spaced enough to allow a good measure of axial resolution; that is, the 0.25-mm pair in this example is not clearly

resolved, whereas the 1-mm pair certainly is and the 0.5 mm is almost resolved. The vertical thickness of a single target(0.6 mm in this case) is sometimes used[3] to obtain more detailed indication of the axial resolution(Method 2 in Figure 2-8).

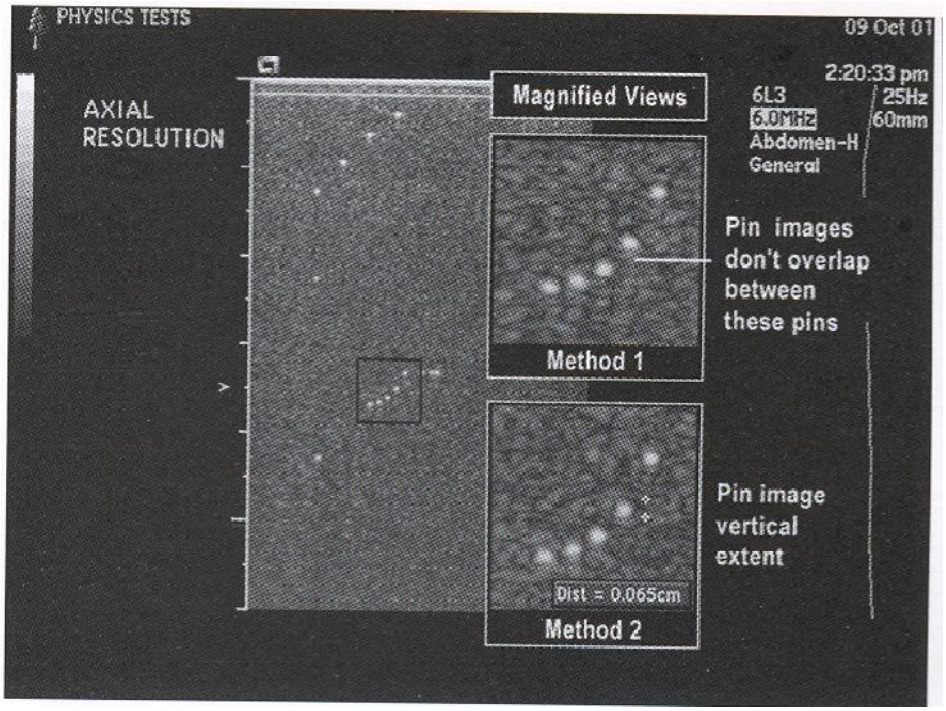

Figure 2-8 Axial resolution measurement. The thickness of the pin target is 0.65 mm. In the axial resolution target set (vertical separation 2 mm. 1 mm, 0.5 mm and 0.25 mm), the 1-mm pair is separated a sufficient distance vertically so that there is no vertical overlap the images of these two targets, whereas the 0.5 –mm pair overlaps if the two targets are on a vertical line. The axial resolution is just over 0.5 mm, in agreement with the estimate made from the thickness of the single target image.

Image source :(Ultrasound Equipment Quality Assurance: James A. Zagzebski and James Kofler).

2.3.12 Lateral Resolution:

Lateral resolution is a measure of how close two reflectors can be to one another, be perpendicular to the beam axis, and still be distinguished as separate reflectors on an image.

One approach that is used for lateral resolution tests is to measure the width on the display of a point like target, such as a line target inside a phantom. For example, Figure 2-9 shows such a measurement. The cursors indicate that the displayed width is 0.7 mm for this case. The displayed response width is related to the lateral resolution at the depth of the target. Through the imaging of targets at different depths, it is easy to see that the lateral resolution usually varies with depth for most transducers(Tradup et al., 2003). Additionally, the lateral resolution measurement is sensitive to any focal zone placement.

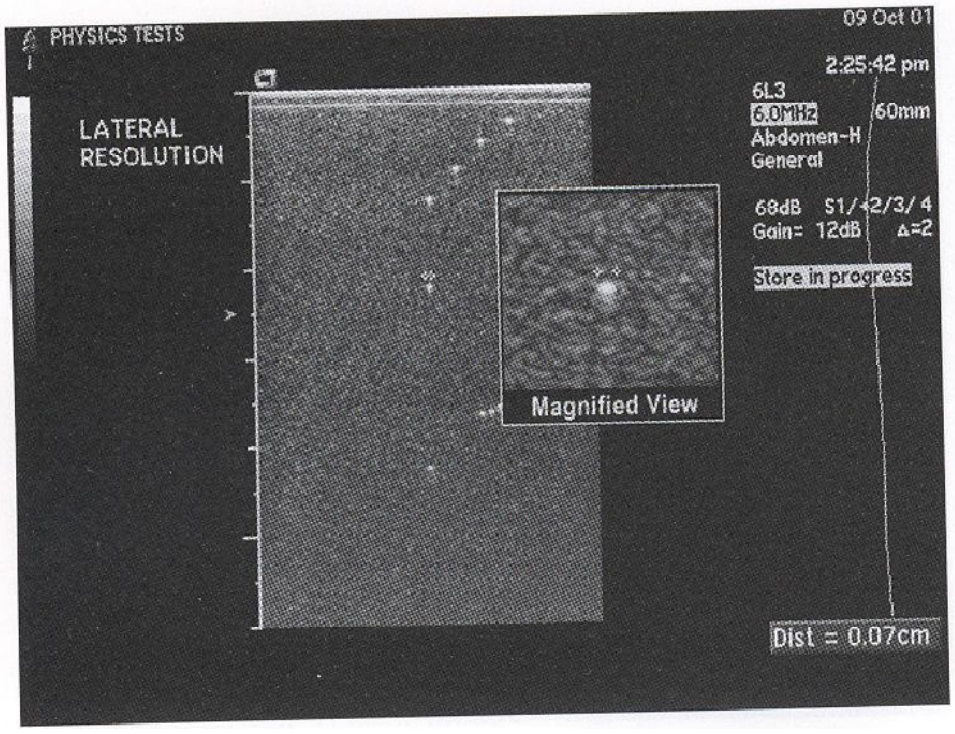

Figure 2-9 Lateral resolution measurement.The horizontal size of the pin target is 0.7 mm.

Image source :(Ultrasound Equipment Quality Assurance: James A. Zagzebski and James Kofler).

2.3.13 Cautions about Resolution Tests with Discrete Targets:

The lateral and axial dimensions of the displayed image of a point like target depend on the power and gain settings on the machine. Such dependency is one of the difficulties of adopting such tests in routine testing. Quantitative results for axial and lateral resolution have been obtained by measuring the dimensions 0f point like targets when they are imaged at specified sensitivity levels above the threshold for their display.(Hedrick et al., 2005)

1. Obtain an image with the sensitivity of the scanner set so that the target is barely visible on the display.
2. Next, obtain a second image; with the scanner sensitivity increased 20 dB above the setting for display threshold.
3. Set the callipers to measure the lateral resolution at this scanner setting. Additional information is available elsewhere.(Hoskins et al., 2010)

2.3.14 Other Test Objects and Phantoms:

Most general-purpose phantoms contain additional objects for the evaluation of image performance. Although these tests are not considered as essential to a routine quality assurance program, they may be useful for testing or optimizing specific imaging configurations. These tests are subjective; therefore the comparison of results with those acquired previously is essential.

2.3.14.1 Anechoic Voids:

Many phantom designs include cylindrical anechoic voids (Figure 2-10). These voids appear as dark circular objects on an ultrasound image and can yield a wide range of information about the performance of a scanner. The void depictions can be inspected for spatial distortion; the voids should not be elliptical. The edges of the voids should be relatively sharp, and the interior of the voids should be echo free. If voids of different sizes are available, the smallest visualized void can be noted.

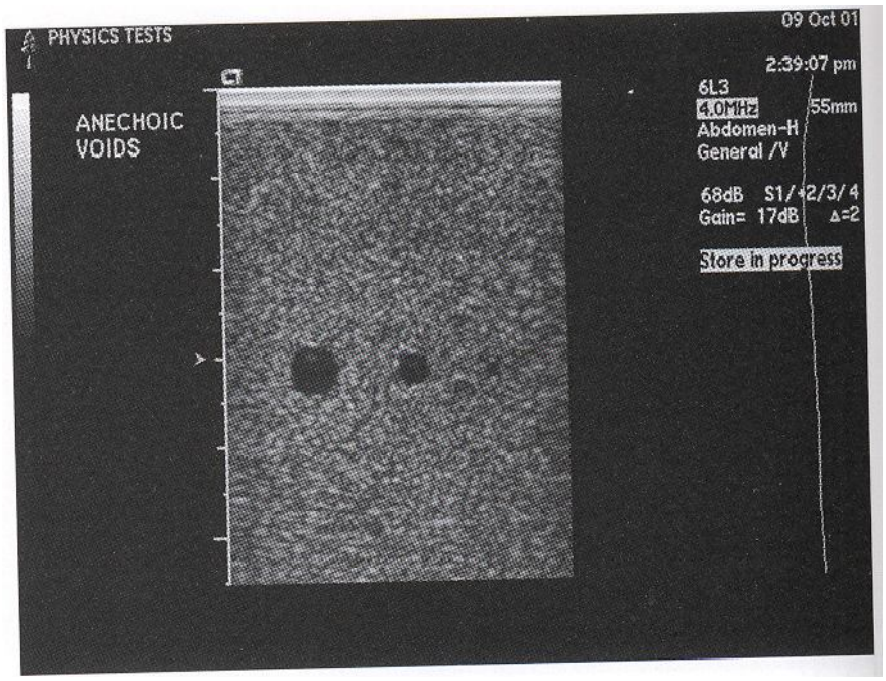

Figure 2-10B-mode image of a phantom containing 3 anechoic cylinders of different sizes (6, 4, and 2 mm diameter) acquired with a 4-MHz linear transducer. Some echoes are evident within the voids, and the edges are well-defined. The smallest void is easily detectable.

Image source :(Ultrasound Equipment Quality Assurance: James A. Zagzebski and James Kofler).

2.3.14.2 Objects of Various Echogenicity:

Many phantoms also include a set of objects with different inherent contrasts(Figure 2-29) these objects can be visually assessed as a means of comparing one scan configuration with another or the performance of a specific scan configuration over time. For example, these objects may be useful to demonstrate the effect of changing the log compression. However, there must be caution when the impressions obtained by the set of various contrast objects are extrapolatedintotheclinicalenvironment because the entire clinical range of inherent object contrasts may not be completely represented by the test objects. As with the anechoic voids, the perimeter of the objects can be inspected for edge definition.

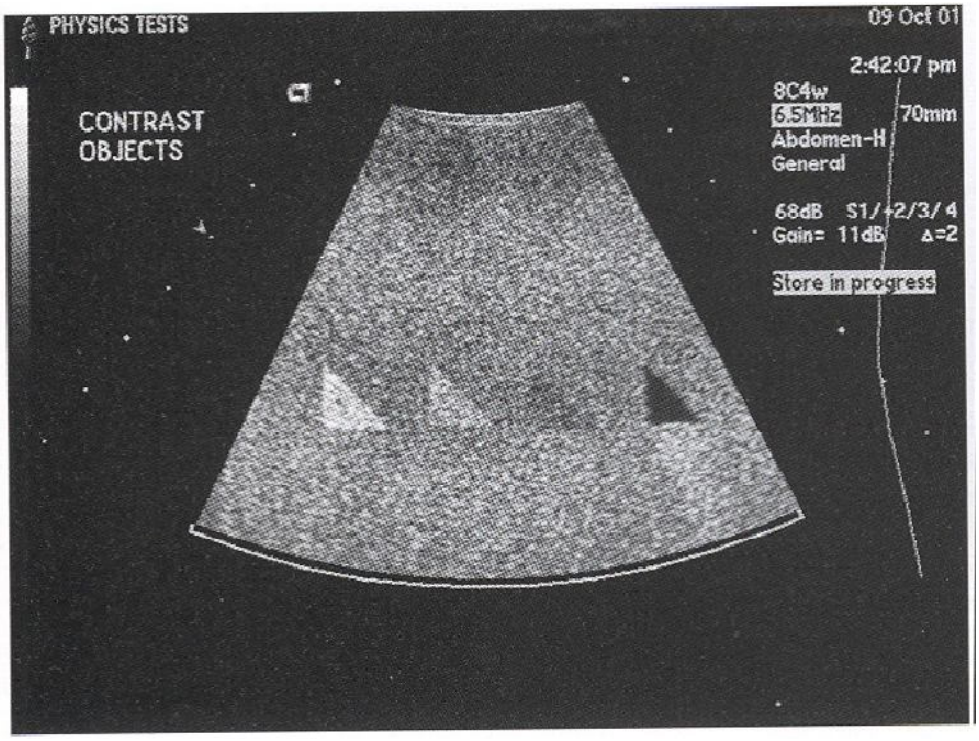

Figure 2-11 Image of a phantom containing four triangular-shaped objects of different contrast values acquired with a 6.5-MHz curvilinear transducer. The higher contrast objects (the outer two) are clearly visualized. The second object from the right is barely visible. The corners of two inner objects are poorly defined.

Image source :(Ultrasound Equipment Quality Assurance: James A. Zagzebski and James Kofler).

2.3.14.3 Spherical Object Phantom:

Another phantom becoming increasingly popular for spatial resolution tests is one that has simulated focal lesions embedded within echogenic tissue-mimicking material.Different simulated lesion sizes and different object contrast levels(e.g., relative echogenicity) have been tried.An example is shown in Figure 2-11, in which the phantom imaged contained 4-mm-diameter, low-echo masses. The centers of the masses are coplanar and distributed in a well-defined matrix.

A test of the ultrasound imaging system is used to determine the "image zone" for detection of masses of a given size and object contrast.The 5-MHz phased array transducer used for Figure 2-1 can successfully detect the masses over a 5.0-to12-cm depth range. The **slice thickness**is too large for this transducer to pick up these structures at more shallow depths.

A particularly useful aspect of spherical mass phantoms is that they present realistic imaging tasks that readily demonstrate resolution capabilities in terms of resolution. For spherical targets the resolution is a combined, effective resolution, made up axial, lateral, and slice thickness. If cylindrical objects are used as phantoms, only two dimensions, usually axial and lateral, are involved in their visualization. Because slice thickness is usually the worst measure of spatial resolution with array transducers, cylindrical objects can be misleading in terms of translating minimum sizes resolved into resolution of actual focal masses. The spherical lesion phantom is superior in this regard(Tradup et al., 2003).

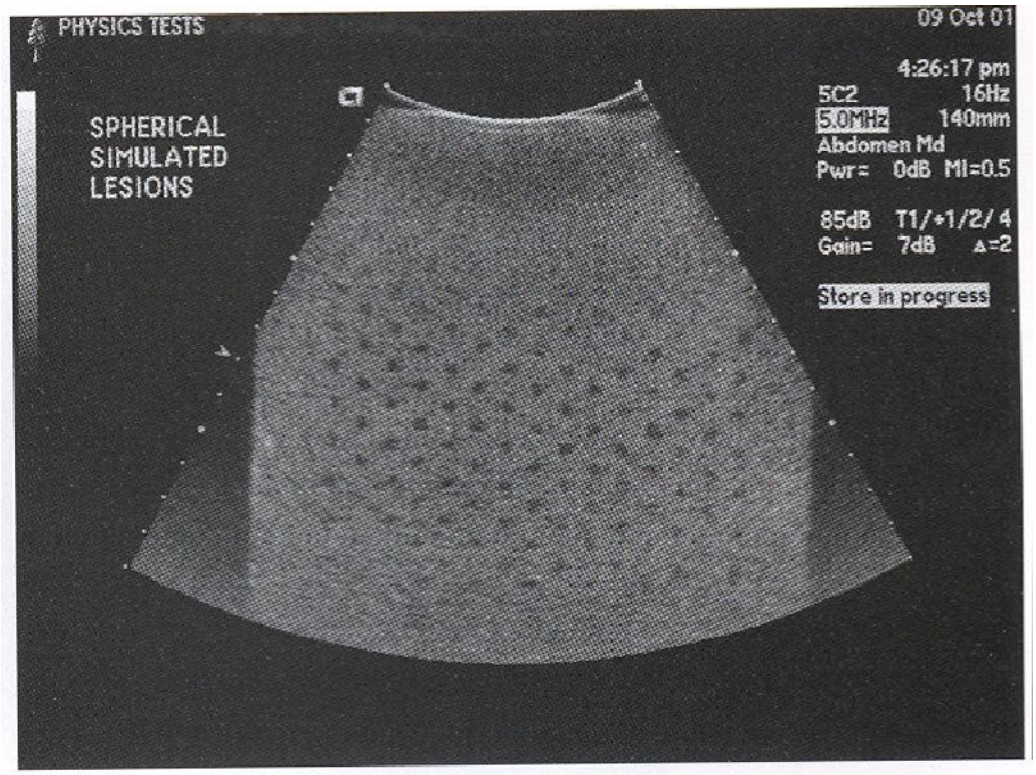

Figure 2-12 B-mode image of a phantom containing 4-mm low –scattering spheres that mimic cysts. The spheres are centered in a regular array within a plane, and the scanning plane is carefully aligned to coincide with the plane containing the spheres. They can be visualized from depths of 5.0 through 12.0 cm with this transducer.

Image source :(Ultrasound Equipment Quality Assurance: James A. Zagzebski and James Kofler).

2.3.15 Doppler Testing:

Limited evaluations of Doppler and color flow equipment can also be made in the clinic. A number of devices, including string test object, flow velocity test objects, and flow phantoms, are available to clinical users for carrying out tests of Doppler equipment (Dudley et al., 2014b).

CHAPTER THREE

Materials and Method

3.1 Type of study

This is a prospective hospital-based study. We assessment and test the level of quality assurance in ultrasound machines.

3.2 Area of study

This study was done in the governmental hospitals, Diagnostic Medical Ultrasound Departments, Khartoum State, Sudan.

3.3 Duration of the study

From 2013 to 2016.

3.4 Sample of the study

This study included 35 governmental hospitals containing 50 ultrasound Machines.

3.5 Apparative Quality Assurance of Ultrasound Imaging Equipment Test Methods for daily check (5min-check)

The methods used in the following checks are able to give the user a rough survey of the status and function of the ultrasound device („5-min Check“). These checks should be performed daily before the first patient is examined to get to know potential damages or deteriorations of the device including the transducers, the monitor and the hardcopy-unit (printer) to guarantee an optimal image quality.
The listed tests are

- Fast to perform(ca. 5 min),
- Easy-to-handle,
- Need only simple availablelab-tools,butnospecialtestobject.

And are effective and suitable!

It is possible after performing these tests to quantify the following performance-parameters of an ultrasound device:

▪ mechanical damages of the device	* element losses of the transducer
▪ scan line correlation	* size of active element area
▪ function of monitor	* grey-level comparison monitor/hardcopy-unit

It is allowed to use and copying these test methods and concepts for testing purposes as long as the origin source is named within final publications or within oral announcements (author, institution etc.)
For possible mistakes, errors or consequences, which result out of these methods, no liability will be given.

Upon request we are sending you information or advice you about suitable test devices for Quality Assurance or about further procedures to quantify and measure

- Aperture
- Dead zone
- Axial/lateral/functional resolution
- Depth- & Measurement calibration
- Scale /Coursor-consistency
- maximum penetration depth
- Contrast range
- Uniformity
- Sensitivity
- Noise limit etc.

Figure.3.1 Quality assurance Test Tools

Tools are needed for these checks?

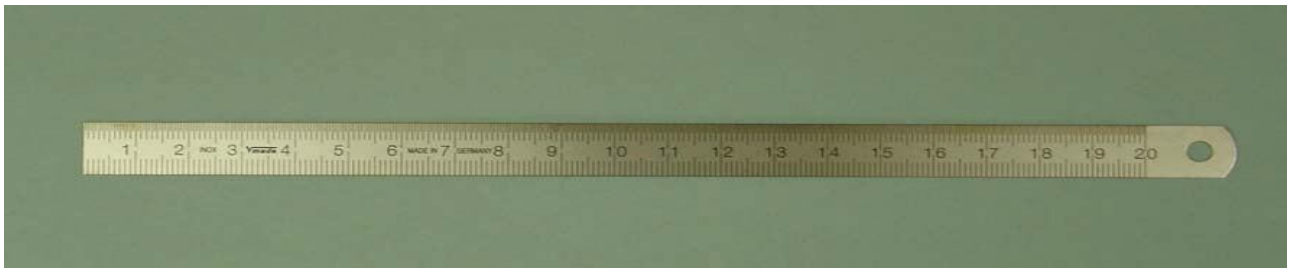

Figure 3.2 Ruler (Test2)

Figure 3.3 Non-permanent marker (Test2)

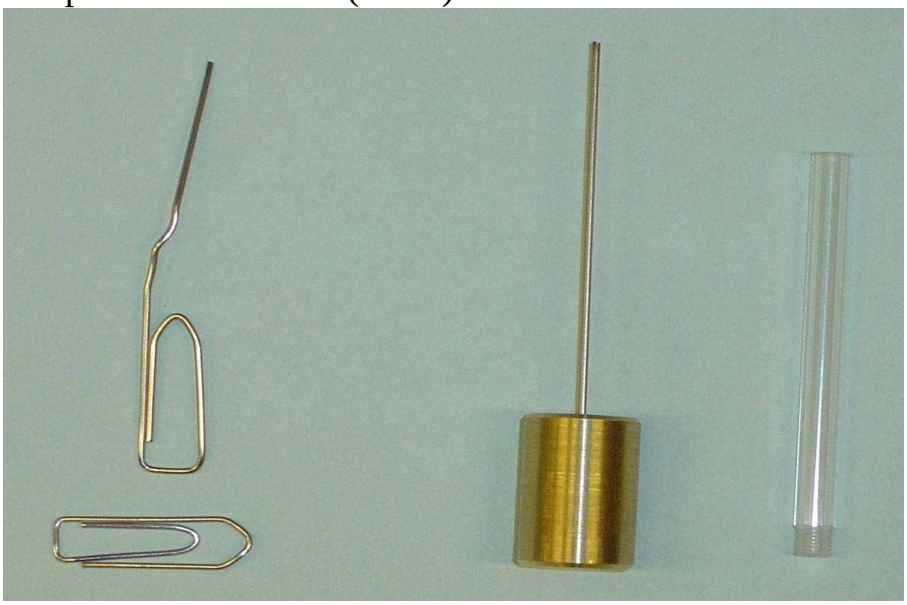

Figure 3.4A paperclip or a thin wire (diameter ca. 1 mm)

The„5-minTests“

1 Visual Inspection (images)

(This test isperformed before each other check!)

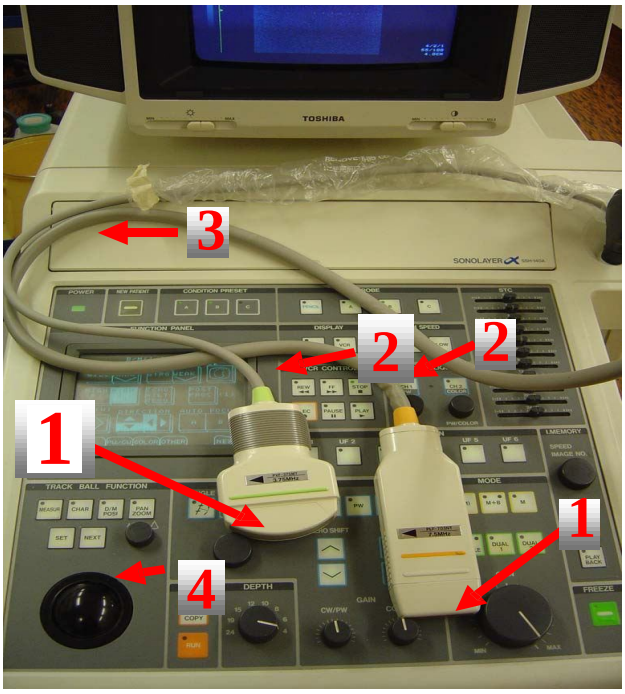

Figure 3.5: Essential items of thevisualinspection

Image source :(http://www.meduniwien.ac.at/zmpbmt/fileadmin /zbmtp/Dateien/Arbeitsfelder /Ultrasound/science/austr_testkit_basic_v1engl)

Visual Inspection

(This test isperformed before each other check!)

Test devices : None
Pre-Settings : None
Procedure :

1. Check cables of transducers and other units (printer etc.) for damages
2. Are the cables connected faultlessly?
   Are some connections damaged?
3. Look for cracks or split-offs at the transducer housings and at the active transducer zone (colored protection foil on the transducer surface).
4. Is the transducer clean/ free of coupling gel or other substances (Otherwise, clean it!)
5. Are the keyboard and trackball working faultlessly?
6. Are the air filters of device cleaned (at the back of the device)?

Tolerance:	None
Test interval:	Daily
Evaluation:	Note down errors or problems in a data sheet
Remarks:	Method listed in [1, 10, and 11]

Technical Relevance: To protect patient and user of electrical risks. Relevance: opt. check of status and usability of the device.

Clinical Relevance: To protect patient and user of damaged cables or housings and infections.

Checking the working of the transducer elements, scan line correlation,and detection of the size of the active scanning area (images)

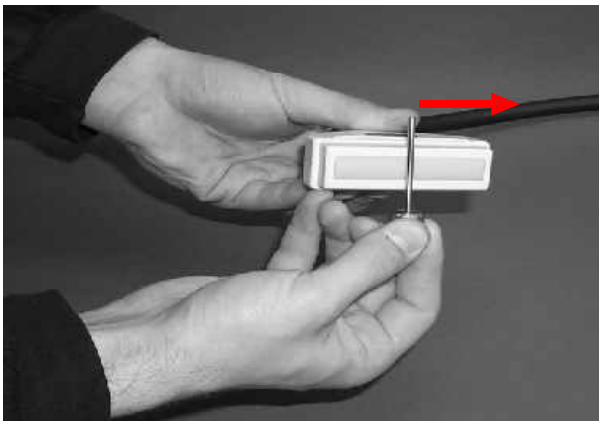

Figure 3-6: Representationof the transducer elements test procedure

Image source :(http://www.meduniwien.ac.at/zmpbmt/fileadmin /zbmtp/Dateien/Arbeitsfelder/Ultrasound/science/austr_testkit_basic_v1engl).

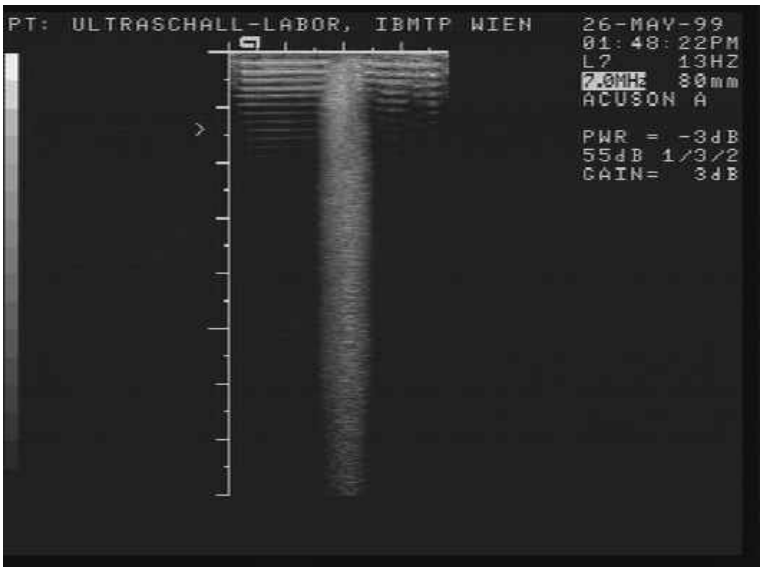

Figure3-7: Resulting ultrasoundimageofthetestperformedabove

Image source :(http://www.meduniwien.ac.at/zmpbmt/fileadmin /zbmtp/Dateien/Arbeitsfelder /Ultrasound/science/austr_testkit_basic_v1engl).

Test devices	Paperclip or thin wire, coupling gel
Pre-Settings	None
Procedure :	
1.	Turnontheultrasounddevice. repeat (2-3 times)
2.	Take the thin wire or paperclip and move it along the active scanning zone of the transducer (optionally with gel, Fig.3-32 and Fig-3-33). Be aware of the scanning order direction of the transducer (arrow marking on the housing to prevent re- versed display of object). Move the object along the
3.	Look for losses or changes of echo display within the B- Mode image (Reverberations of the wire) or changes in moving. A good coupling should be guaranteed (Fig..3-33) !
4.	4.If the thin wire reaches the edges of the transducer (left and right), look at which location the image is displayed and where not (mark these positions
5.	Note down changes of widths within the displayed object, flickering or losses of representation together with the object´s position in a protocol.
6.	Measure the length of the active scanning area with a ruler according to the marks set by the colored marker and note it down in the protocol.

Tolerance:	None
Test	Daily
Evaluation:	Note down errors or problems and size of active scanning length
Remarks:	Definition in [7]; Method in [5;8]; procedure& test interval new
Technical Relevance: Testing the scanning order and detection of separate element losses with the transducer.	
Clinical Relevance: If elements are lost that are at the edges of the transducer the resulting active scanning area is reduced.	

3. Function&Qualityofthe Monitor (images)

Figure3-8: Photo ofthe monitor beingin setting<ext. Video-Input>, noerrors are detectableinthis example; onlythesmallersizeofimageisseenattheloweredge ofthedisplay.

Image source:

(http://www.meduniwien.ac.at/zmpbmt/fileadmin/zbmtp/Dateien/Arbeitsfelder/Ultrasound/science/austr_testkit_basic_v1engl).

Test	None
Pre-	None
Procedure :	
1.	Turn on the ultrasound device or press “new patient”
2.	Set Monitor-input to < ext. input > or < VCR-input >
3.	Are diagonal white lines visible?
4.	Are flickeringsvisible?

5.	Are horizontal / vertical movements of the image detectable?
6.	Minimize brightness and contrast of the display. Are burned-in (dark) areas
7.	Note down changes in a protocol.
8.	Finally adjust brightness and contrast of the display correctly: the frame of the ultrasound image and the frame of the otherinformation given should not be visible any longer (equal in brightness).
Tolerance:	if the monitor is flickering objectionably -> call the service or maintenance
Test	and after maintenance check,
Evaluation:	hly: additional checking with SMTPE-Test pattern (Option).
Remarks:	riptions partly given in DIN 6868-57, SMTPE (www.smpte.org)

Technical Relevance: Strong flickering or local changes in brightness can indicate ageing or damage of the monitor.

Clinical Relevance: An optimal diagnosis cannot be obtained by using an sub-optimal image quality of the monitor.

4. Grey-level comparison between Monitor and Hardcopy-unit (printer) (images)

Abb. 4: Ultrasound images / Example of a visual evaluation.
Middle: image of the monitor.
Left: a „good "representation of a Hardcopy (rating factor: 1), right: a „bad “representation of a Hardcopy (rating factor: 3)

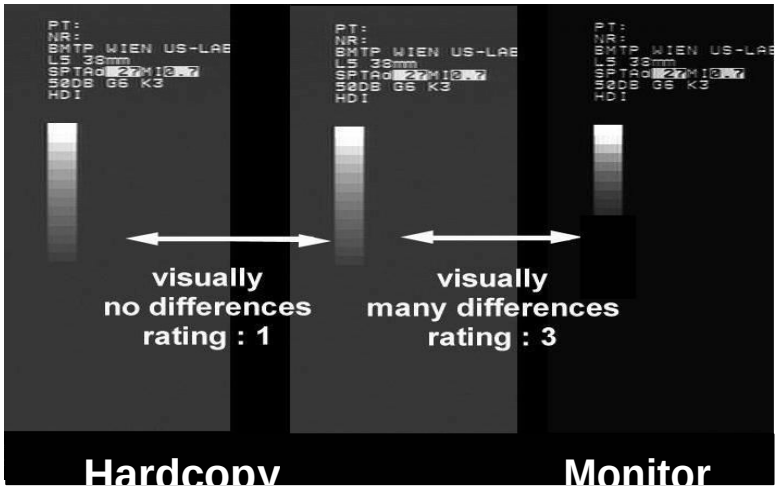

Fig.3-9 Grey-levelcomparisonbetween Monitor and Hardcopy-unit (printer).

Image source :(http://www.meduniwien.ac.at/zmpbmt/fileadmin /zbmtp/Dateien/ArbeitsfelderUltrasound/science/austr_testkit _basic_v1engl)./

Test	None
Pre-	None
Procedure :	
1.	Turn on the ultrasound device and “freeze” the image.
2.	Make a hardcopy of the monitor image (print).Using X-ray film for ultrasound print-outs evaluate this print-out.
3.	Visual evaluation of the grey-level bars:compare the number of displayed bars of the monitor and hard-copy image (Fig. 3-35). Are large differences available? Rating :1 = visual no differences remarkable 2 = slight differences remarkable
4.	In case of large differences : call the maintenance or :Repeat (until visual differences are not seen any longer)
5.	Adjust Hard-copy unit (printer) and make print-outs as long as the monitor and hardcopy have an identical (visual) outlook
Tolerance:	Visual evaluation with ratings 1-2 are tolerable, vis evaluationwith rating> call maintenance if adjustments are
Test	andafter maintenance
Evaluation:	e
Remarks:	dure, tolerance, and test interval are new
Technical Relevance: The Hardcopy-unit can change and drift; if film material is used the substances can have ageing effects depending on storage and climate conditions.	
Clinical Relevance: Large differences between monitor and hard-copy should not be detected , to guarantee an optimal diagnosis if performed by the evaluation of the hard-copy	

CHAPTER FOUR

Results

Table 4.1: Does your Hospital have separate areas for each of the following functions?

Functions	**Yes**	**No**	**N/A**	**Percentage (%)**		
(A) Patient waiting area	35	15	0	70	30	00
(B) Change rooms	10	35	5	20	70	10
(C) Patient washrooms	32	12	6	64	24	12
(D) Procedure rooms	50	0	0	100	00	00
(E) Image storage	8	40	2	16	80	04
(F) Processing areas	12	34	4	24	68	08
(G) Facility storage supply	6	38	6	12	76	12

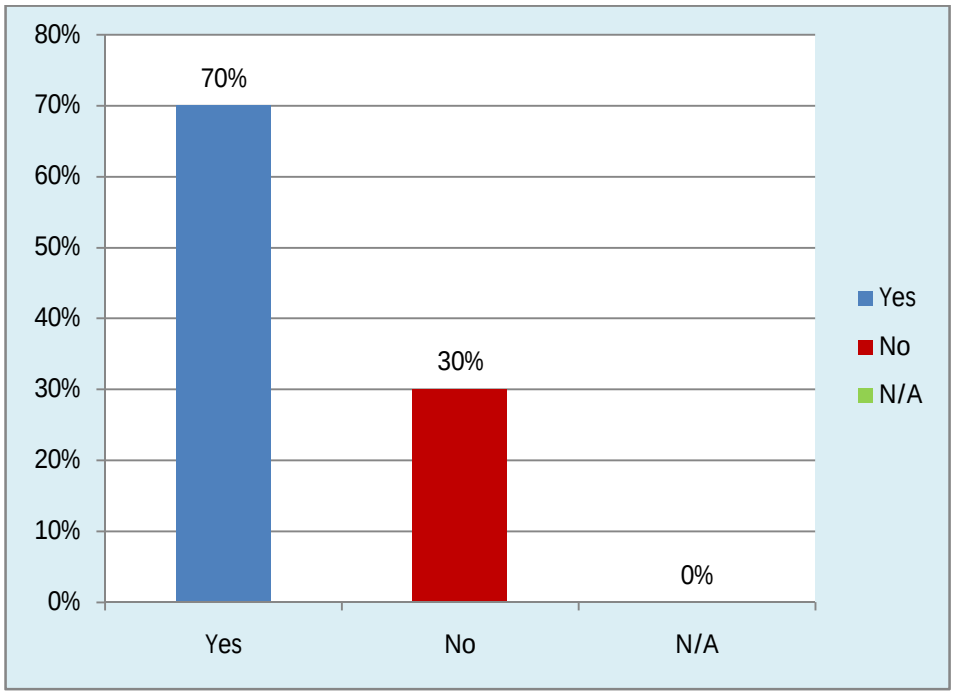

Figure4.1(A) Patient waiting area.

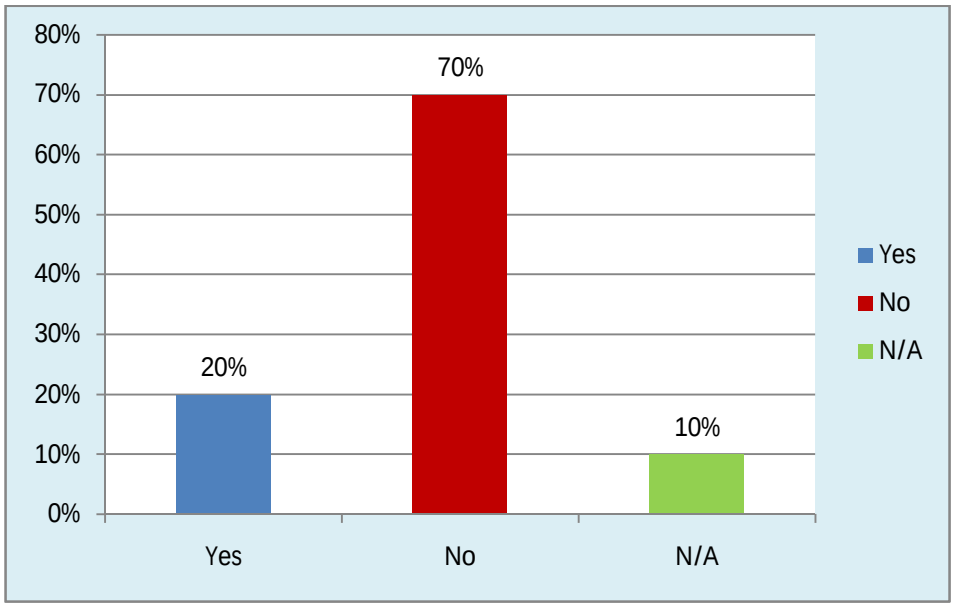

Figure4.1(B) Change rooms.

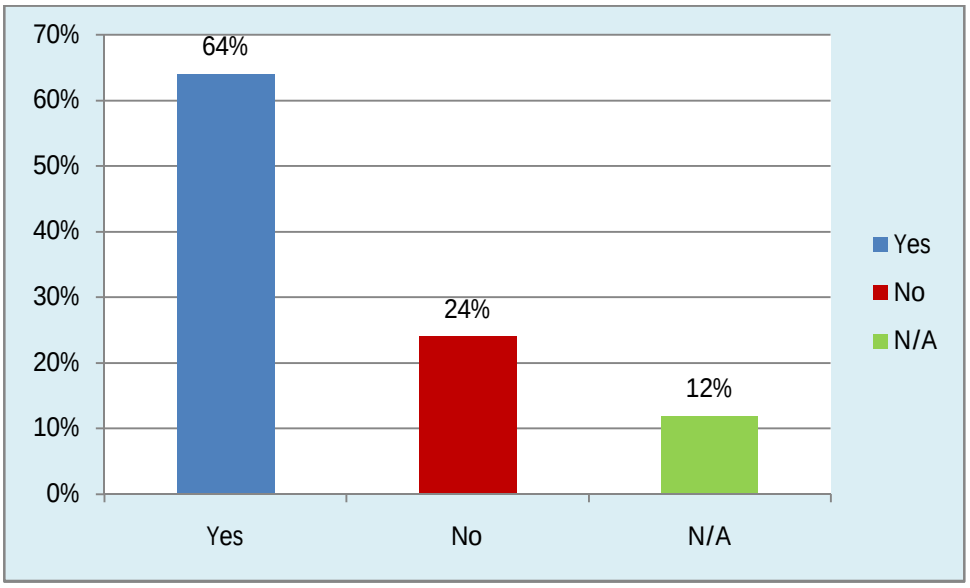

Figure 4.1(C) Patient washrooms.

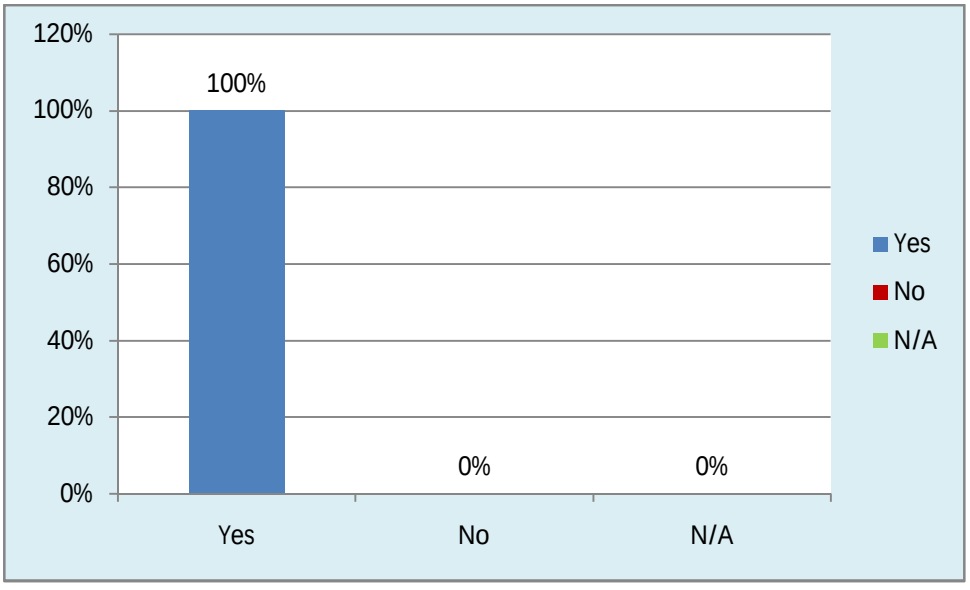

Figure4.1(D) Procedure rooms.

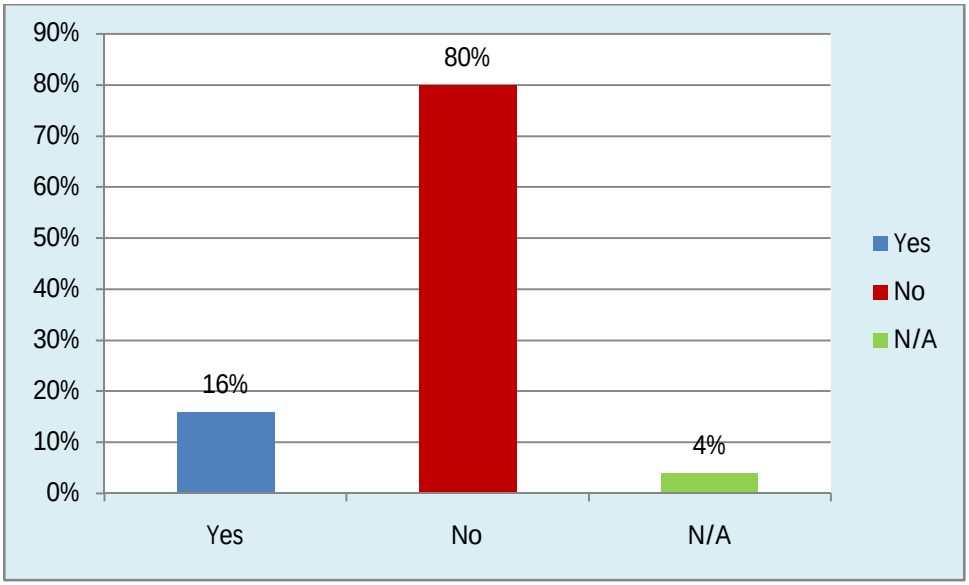

Figure4.1(E) Image storage.

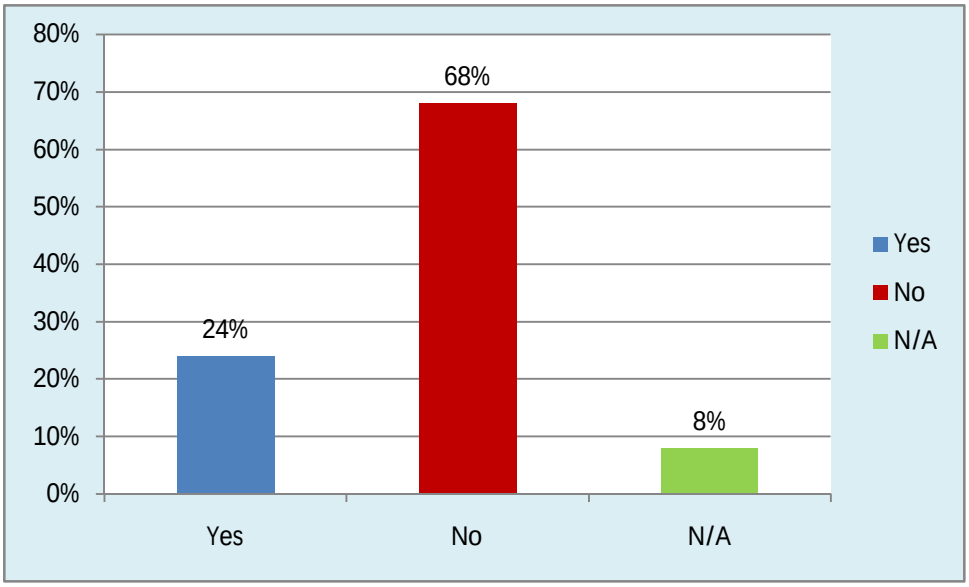

Figure 4.1(F) Processing areas.

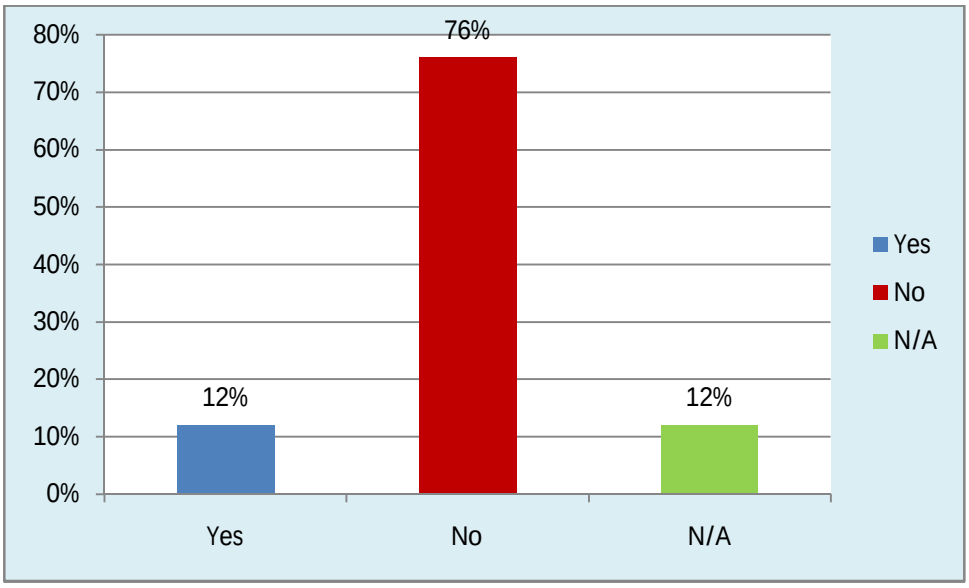

Figure 4.1(G) Facility storage supply.

Key of Table 4.2: Number of ultrasound Rooms:

Group(A)	Four Ultrasound Rooms (2) Hospitals
Group(B)	Three Ultrasound Rooms(3) Hospitals
Group(C)	Two Ultrasound Rooms (7) Hospitals
Group(D)	One Ultrasound Room (23) Hospitals

Table 4.2: Number of ultrasound Rooms:

Hospital Groups	**One Ultrasound Room**	**Two Ultrasound Rooms**	**Three Ultrasound Rooms**	**Four Ultrasound Rooms**	**Percentage (%)**
Group(A)				2x4=8	16
Group(B)			3x3=9		18
Group(C)		7x2=14			28
Group(D)	23x1=23				46

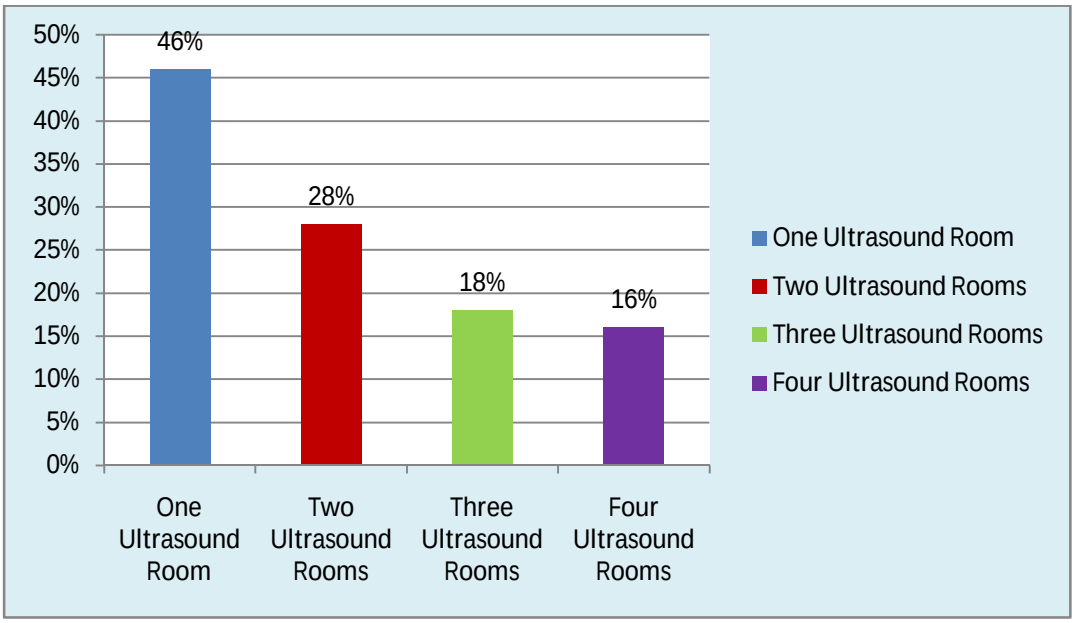

Figure4.2 Number of ultrasound Rooms.

Table 4.3: Is the Facility Wheelchair accessible?

Hospital Groups	YES	NO	N/A
Group(A)	8		0
Group(B)	9		0
Group(C)	8	2	0
Group(D)	3	20	0
Total	**28**	**22**	**0**
Percentage (%)	**56**	**44**	**00**

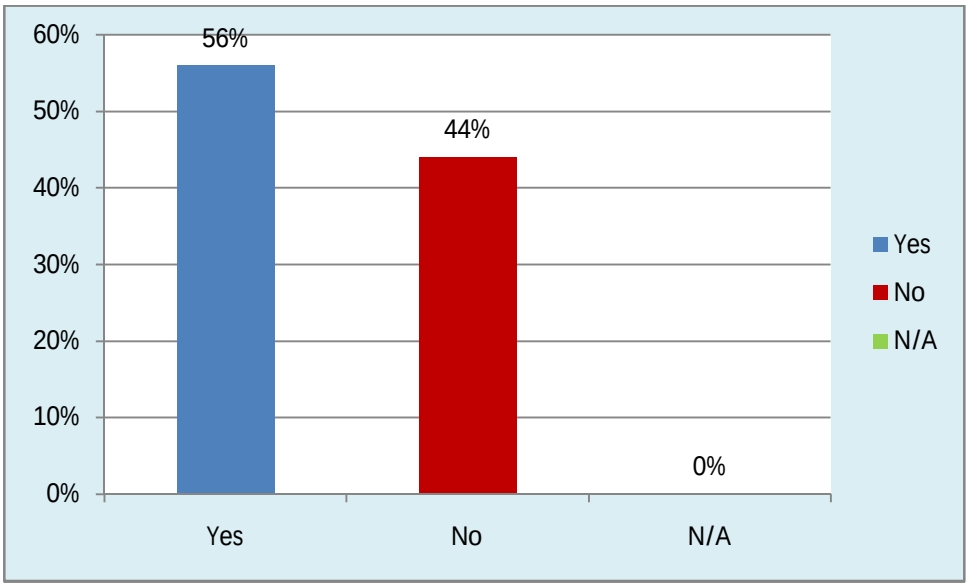

Figure 4.3 Number of Wheelchair accessible.

Key of Table 4.4: Number of transducers (Probes) in each ultrasound machine:

Group(A) Ultrasound Machine	Four Ultrasound Probes (4)
Group(B) Ultrasound Machines	Three Ultrasound Probes (3)
Group(C) Ultrasound Machines	Two Ultrasound Probes (2)
Group(D) Ultrasound Machines	One Ultrasound Probes (1)

Table 4.4: Number of transducers (Probes) in each ultrasound machine:

Ultrasound Machines	**One Probe**	**Two Probes**	**Three Probes**	**Four Probe**	**Percentag (%)**
Group(A)				5	10
Group(B)			10		20
Group(C)		23			46
Group(D)	12				24

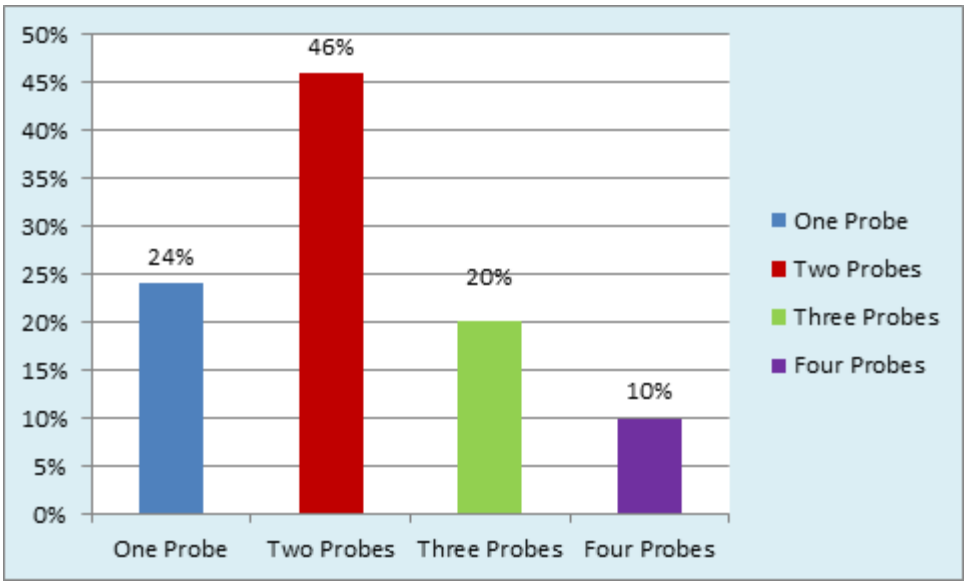

Figure 4.4 Number of transducers (Probes) in each ultrasound machine.

Table 4.5: Is the Standard ultrasound Table available in the ultrasound room?

Value	Yes	No
Standard ultrasound Tables	12	38
Percentage (%)	24	76

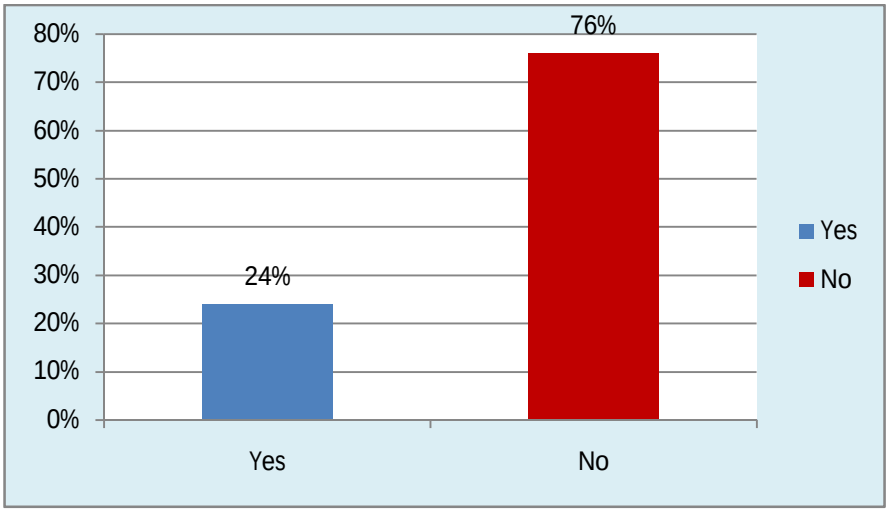

Figure 4.5 Standard ultrasound Table available in the ultrasound room.

Table 4.6: Is the Standard ultrasound Operator adjustable Chair available in the ultrasound room?

Value	Yes	No
Standard ultrasound Operator adjustable Chair	18	32
Percentage (%)	36	64

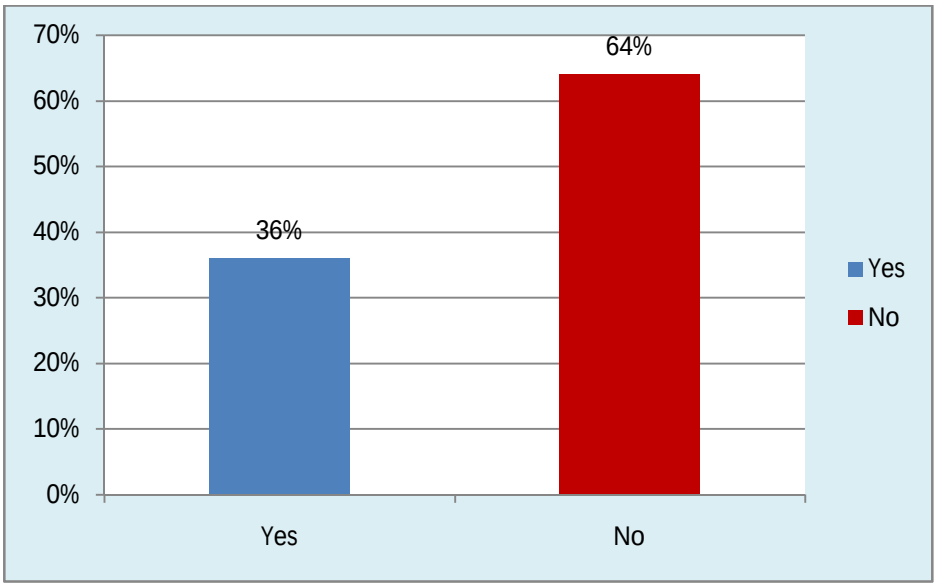

Figure4.6 Standard ultrasound Operator adjustable Chair available in the ultrasound room.

Table 4.7: Are you making a regular maintenance and checkup for the ultrasound machines?

Value	Yes	No
Regular maintenance and checkup for the ultrasound machines	11	39
Percentage (%)	22	78

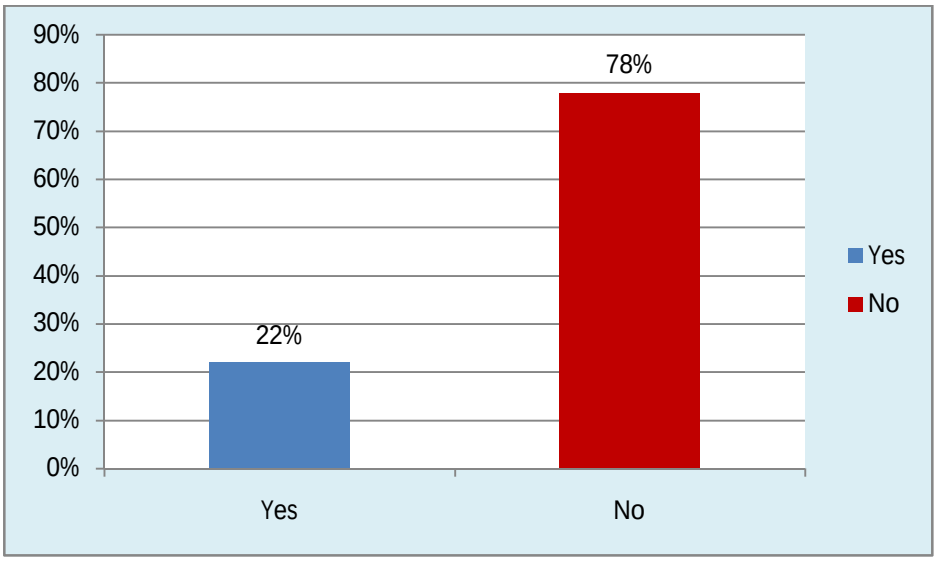

Figure 4.7 Regular maintenance and checkup for the ultrasound machines.

Table 4.8: Are all cords and cables intact (no frays)?

Value	Yes	No
All cords and cables intact (no frays)	43	07
Percentage (%)	86	14

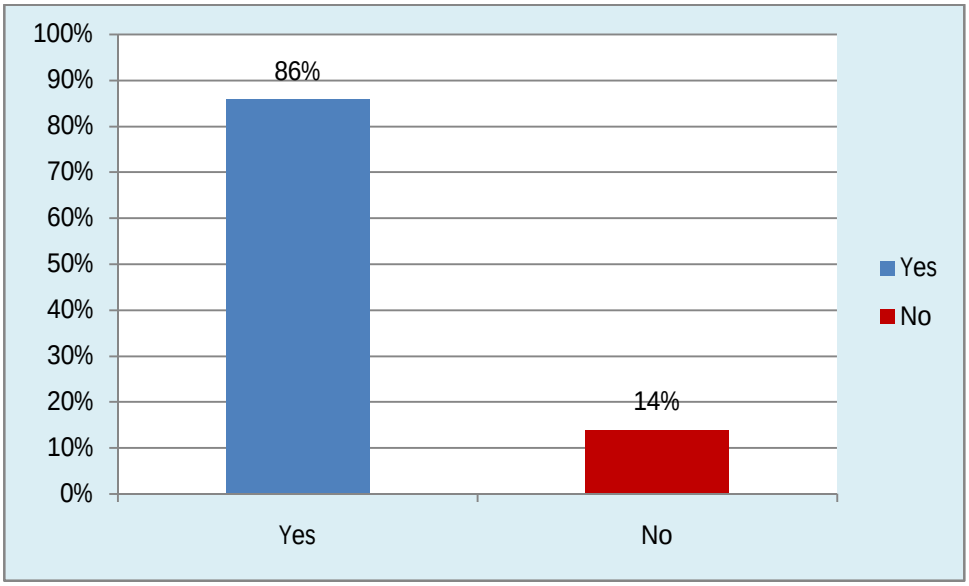

Figure 4.8 All cords and cables intact (no frays).

Table 4.9: Are all transducers handled with care and proper way?

Value	Yes	No
All transducers handled with care and proper way.	33	17
Percentage (%)	66	34

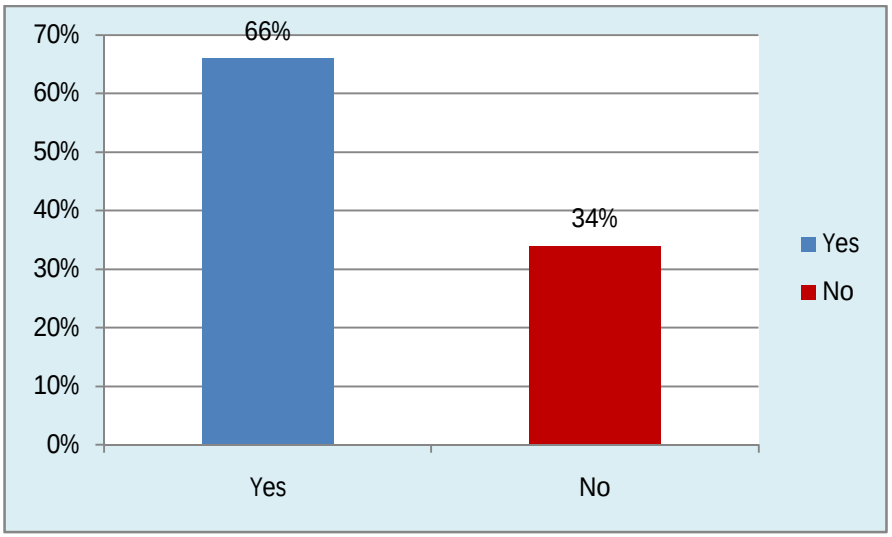

Figure 4.9 All transducers handled with care and proper way.

Table 4.10: Are all transducers intact without crack or delamination?

Value	Yes	No
All transducers intact without crack or delamination.	41	09
Percentage (%)	82	18

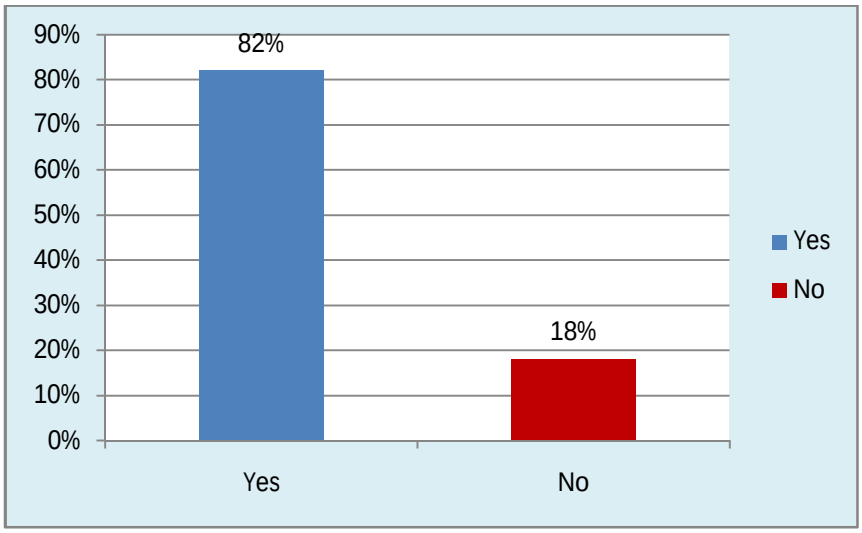

Figure 4.10 All transducers intact without crack or delamination.

Table 4.11: Are the transducers cleaned after each use?

Value	Yes	No
The transducers cleaned after each use	40	10
Percentage (%)	80	20

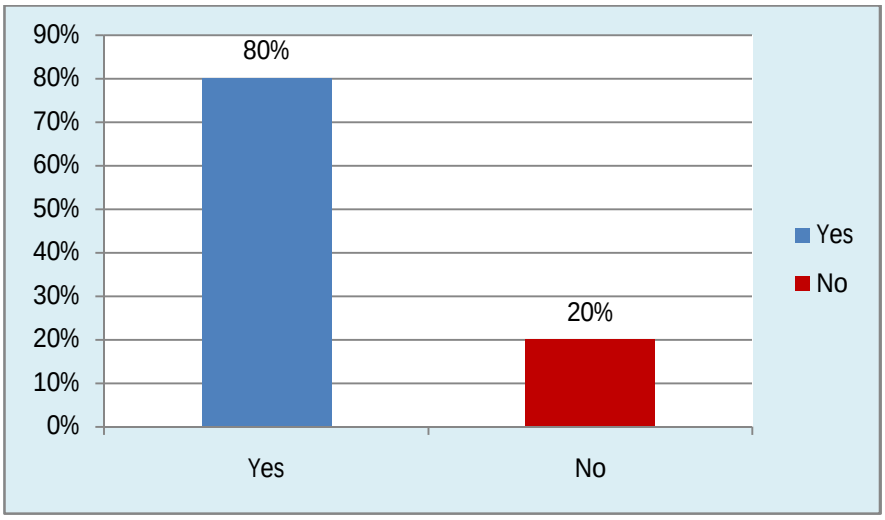

Figure 4.11 The transducers cleaned after each use.

Table 4.12: Are the image monitors clean?

Value	Yes	No
The image monitors clean.	36	14
Percentage (%)	72	28

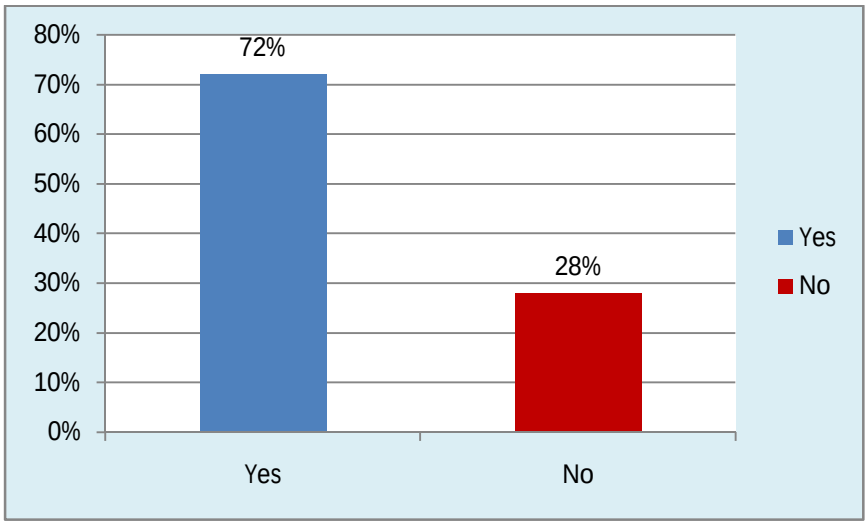

Figure 4.12 The image monitors clean.

Table 4.13: Are the dimmer lights used in the ultrasound room?

Value	Yes	No
The dimmer lights usage.	10	40
Percentage (%)	20	80

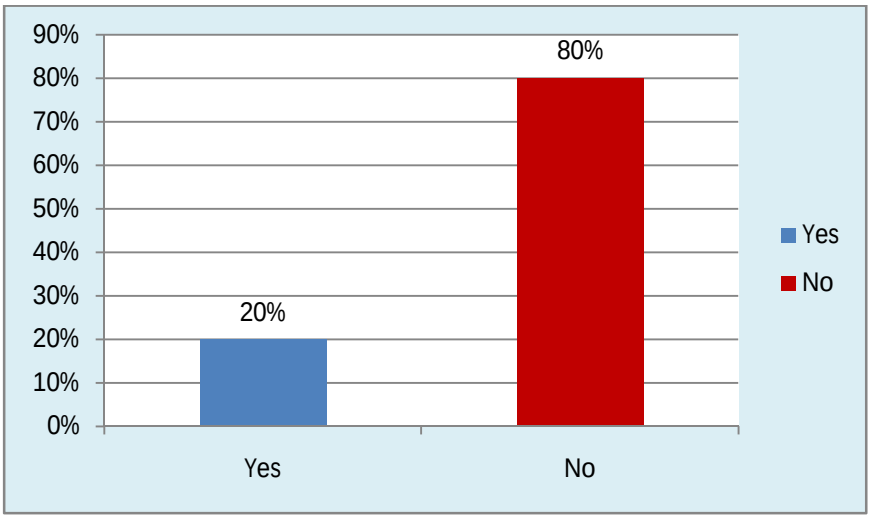

Figure 4.13 Thedimmer lights usage.

Table 4.14: Are the wheel locks in working condition?

Values	Yes	No
The wheel locks in working condition.	35	15
Percentage (%)	70%	30%

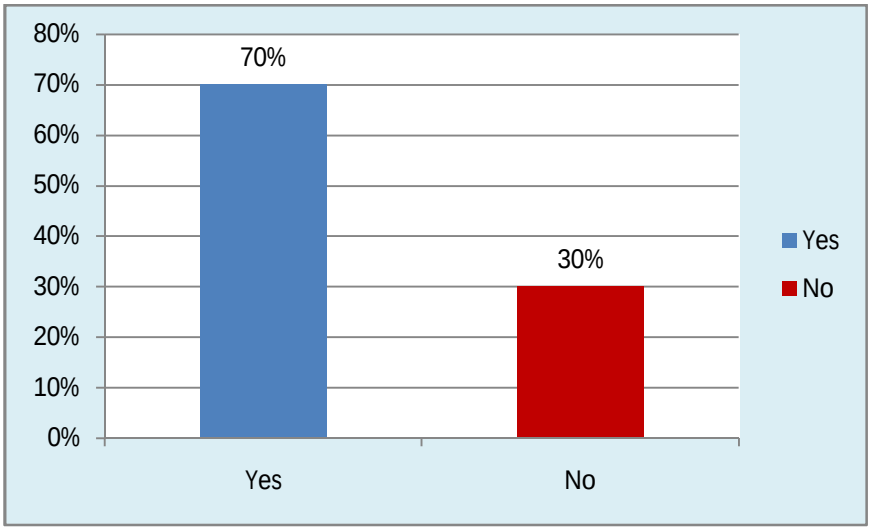

Figure 4.14 The wheel locks in working condition.

Table 4.15: Are the wheels fastened securely to the US unit and do the wheels rotate easily?

Value	Ye	N
The wheels fastened securely to the US unit and do the wheels rotate easily	3	2
Percentage (%)	6	4

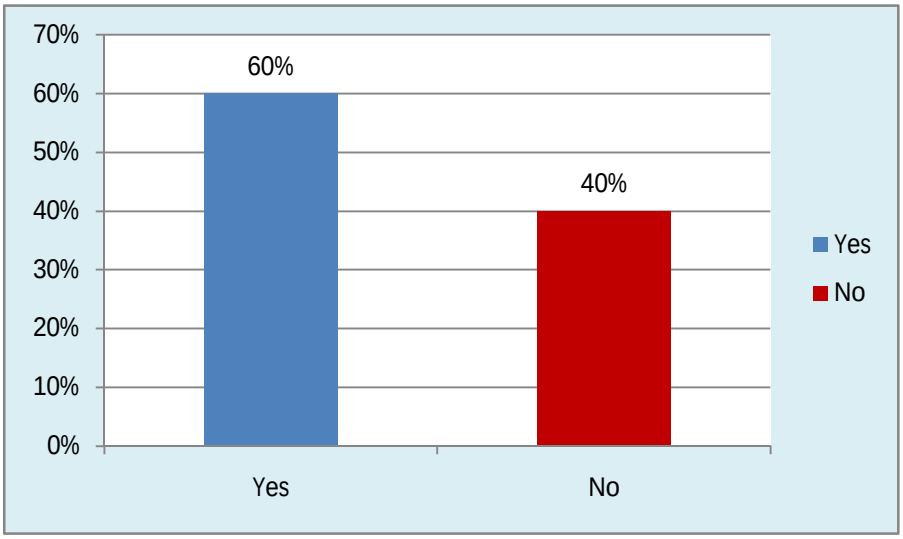

Figure 4.15 The wheels fastened securely to the US unit and do the wheels rotate easily.

Table 4.16:of the total ultrasound units; indicate how many are fixed or mobile.

Ultrasound Units Type	Numbe	Percentag (%)
Fixed Ultrasound Units.	33	66
Fixed Mobile Ultrasound Units.	14	28
Mobile Ultrasound Units. (Vans Change Location)	03	06

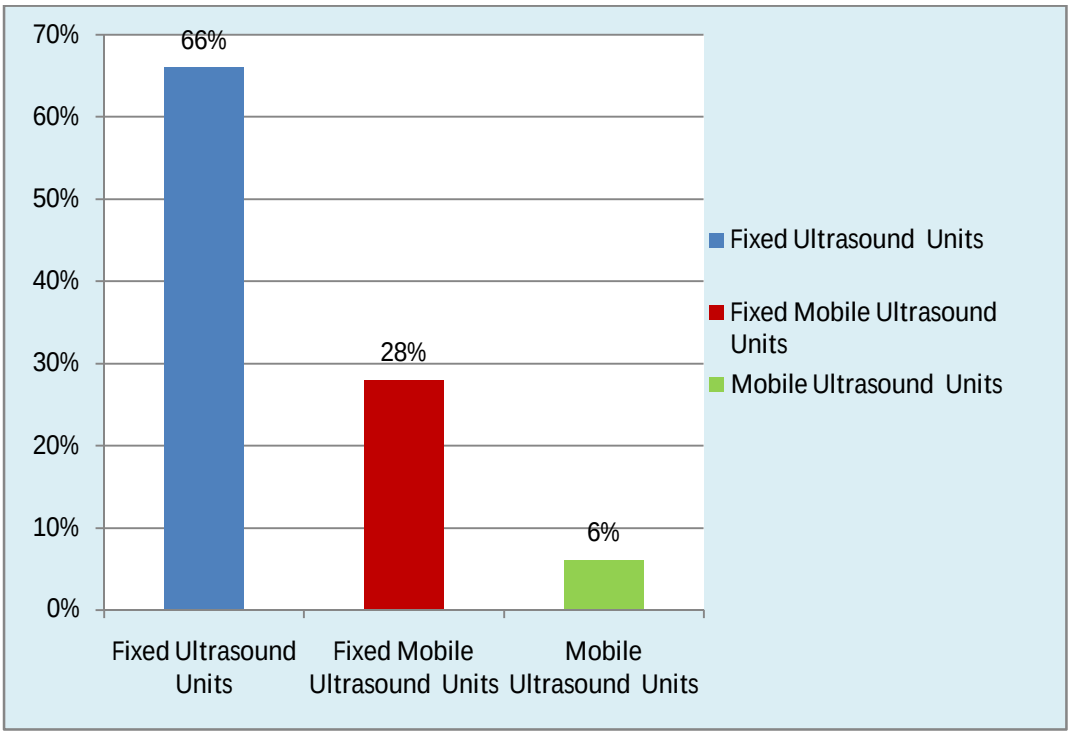

Figure 4.16 Ultrasound Units Type.

Table 4.17: What is the average number of sonograms performed at this facility per month?

Number of Sonograms per Mo	Number of facilitie	Percentage (%
0-10	00	00
11-25	00	00
26-50	00	00
51-75	00	00
76-100	00	00
101-250	02	04
251-500	06	12
501-750	10	20
Over 750	32	64
Total	50	100

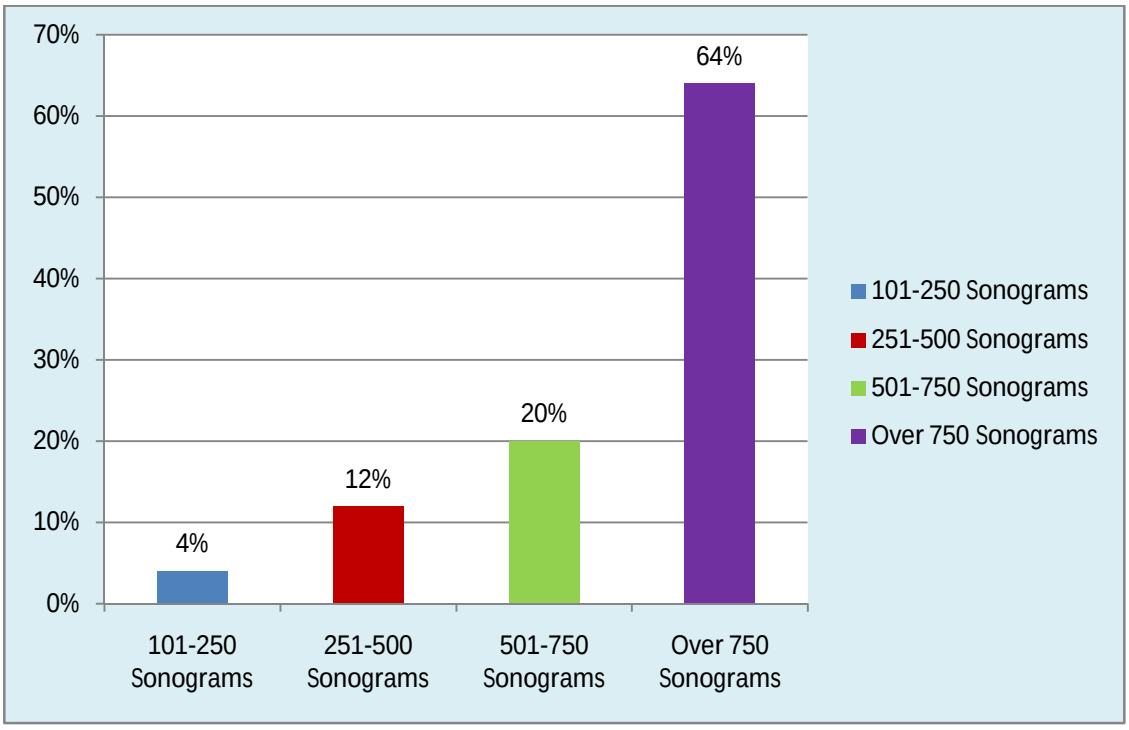

Figure 4.17 The average number of sonograms performed at this facility per month.

Key of Table 4.18: Indicate the number of exams/month for the procedures listed.Enter number in blocks. Enter "0", if the procedure is not performed at your facility.

Group(A) Ultrasound Examinations	1. Antepartum OB US. 2. Female Pelvis US. 3. Upper Abdominal US. 4. Renal/Urinary Tract US.
Group(B) Ultrasound Examinations	1. Extracranial Carotid US. 2. Transcranial Vascular US. 3. Aorta and Branches US. 4. IVC & Draining Veins US.
Group(C) Ultrasound Examinations	1. Liver Vascular US. 2. Renal Vascular US.
Group(D) Ultrasound Examinations	1. Peripheral Arterial US. 2. Peripheral Venous US.
Group(E) Ultrasound Examinations	1. Scrotal US. 2. Thyroid US.
Group(F) Ultrasound Examinations	1. Transrectal Prostate US. 2. Pediatric Neurosonology US.

Table 4.18(A): Group (A) Ultrasound Examinations:

Ultrasound Examinations Type	**YES**	**NO**	**Number of Exams**
Group(A)	50	0	15433
Percentage (%)	100	0	

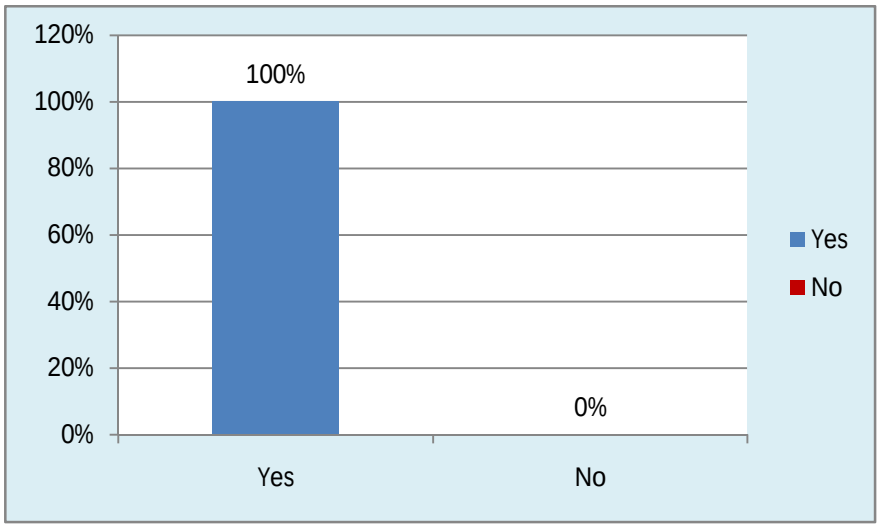

Figure 4.18 (A) The average number of Group (A)Ultrasound Examinations.

Table 4.18(B): Group (B) Ultrasound Examinations:

Ultrasound Examinations Type	**YE**	**N**	**Number of Exams**
Group(B)	08	4	1235
Percentage (%)	16	8	

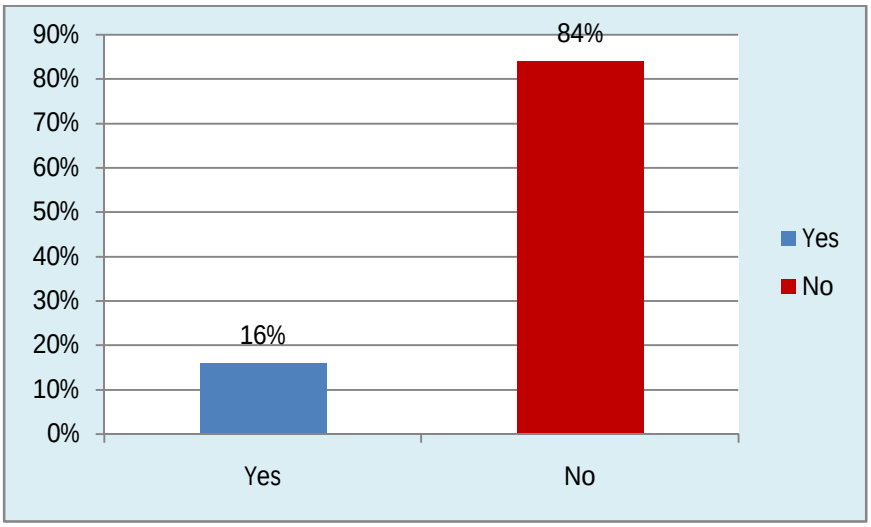

Figure 4.18 (B) The average number of Group (B) Ultrasound Examinations.

Table 4.18 (C): Group (C) Ultrasound Examinations:

Ultrasound Examinations Type	**YE**	**N**	**Number of Exams**
Group(C)	22	28	3396
Percentage (%)	44	56	

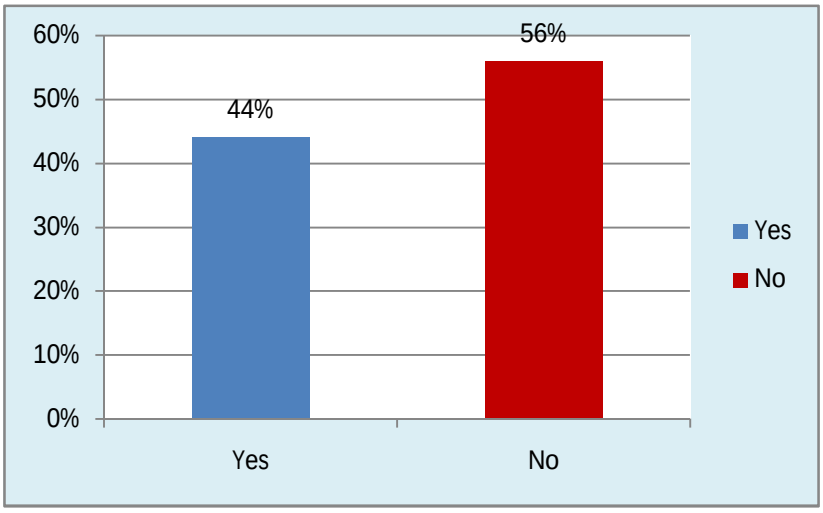

Figure 4.18 (C) The average number of Group(C) Ultrasound Examinations.

Table 4.18(D):Group (D) Ultrasound Examinations:

Ultrasound Examinations Type	YES	NO	Number of Exams
Group(D)	6	44	926
Percentage (%)	12	88	

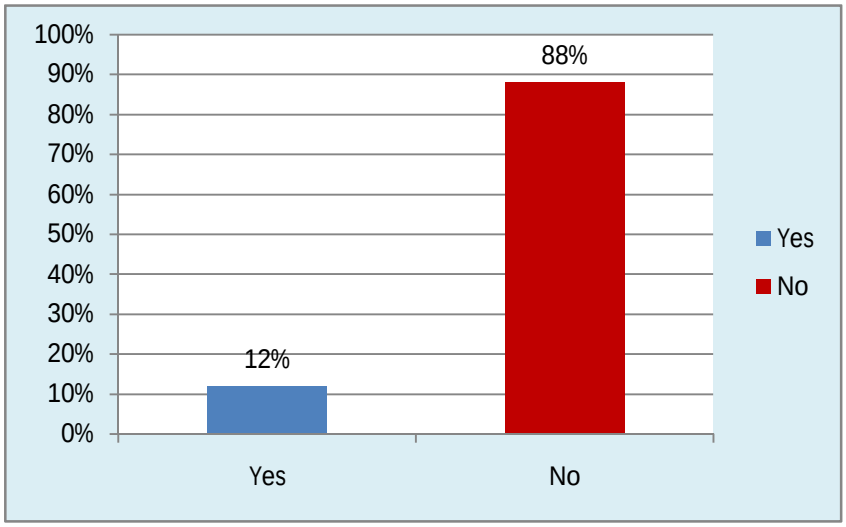

Figure 4.18 (D) The average number of Group (D)Ultrasound Examinations.

Table 4.18(E):Group (E) Ultrasound Examinations:

Ultrasound Examinations Type	YE	NO	Number of Exam
Group(E)	35	15	10803
Percentage (%)	70	30	

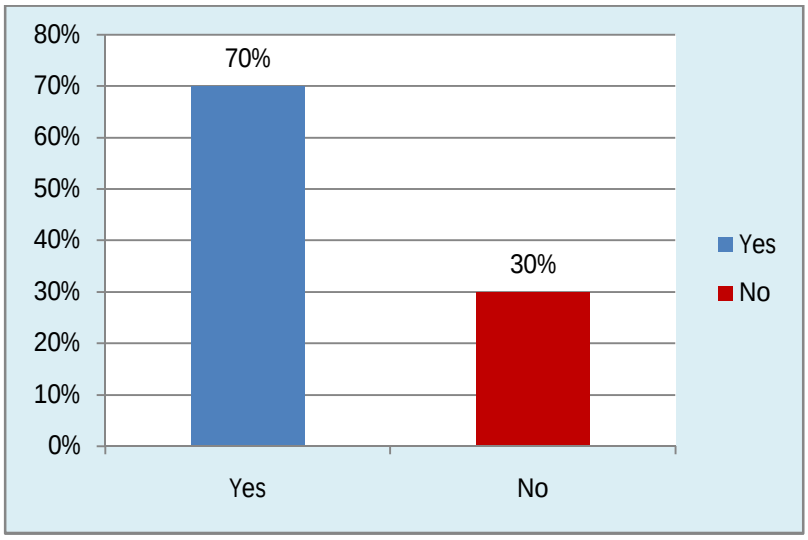

Figure 4.18 (E) The average number of Group (E)Ultrasound Examinations.

Table 4.18(F):Group (F) Ultrasound Examinations:

Ultrasound Examinations Type	YE	NO	Number of Exam
Group(F)	5	45	772
Percentage (%)	10	90	

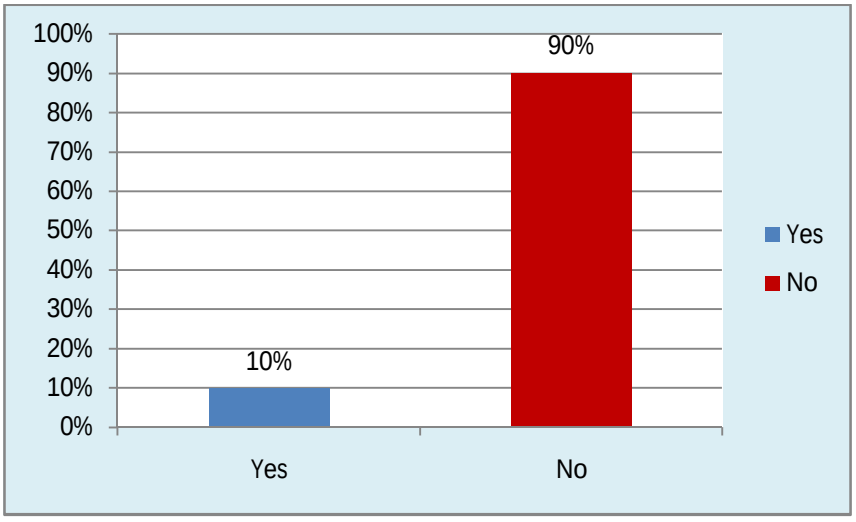

Figure 4.18 (F) The average number of Group (F) Ultrasound Examinations.

Table 4.19: Policy for film/image retention:

Time for film/image retention	Number of Facilities	Percentage (%
Less than 5 years.	27	54
5 years.	09	18
6-10 years.	04	08
11-20 years.	00	00
Over 20 years.	00	00
Indefinitely.	00	00
Lifetime of patient.	00	00
Not applicable.	10	20

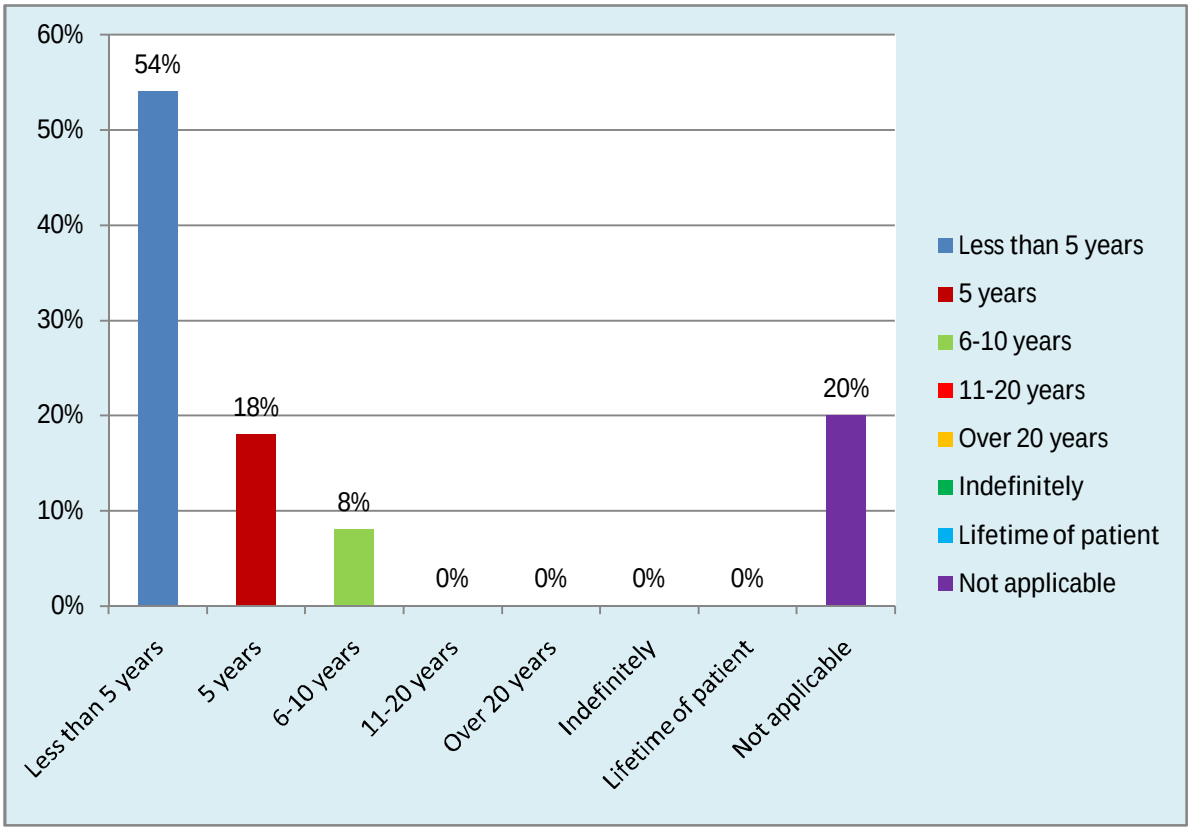

Figure 4.19 Policy for film/image retention.

Table 4.20: Reporting procedures in compliance with the ACR Practice Guideline for Communication:

Value	Ye	N	N/
ACR Practice Guideline for Communication	22	18	10
Percentage (%)	44	36	20

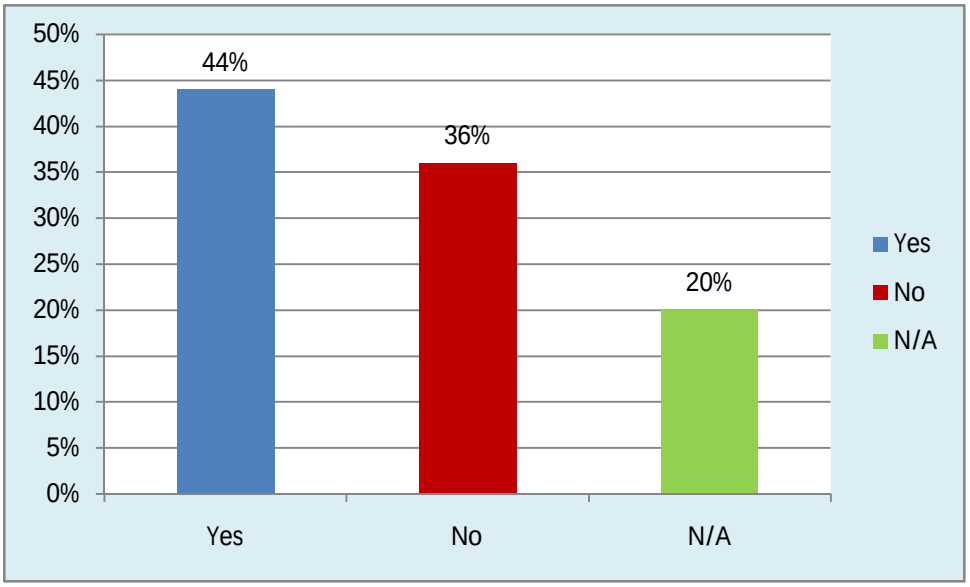

Figure 4.20 Reporting procedures in compliance with the ACR Practice Guideline for Communication.

Table 4.21: Do you have a policy on report turnaround time?

Value	Ye	N	N/
Policy on report turnaround time	10	28	12
Percentage (%)	20	56	24

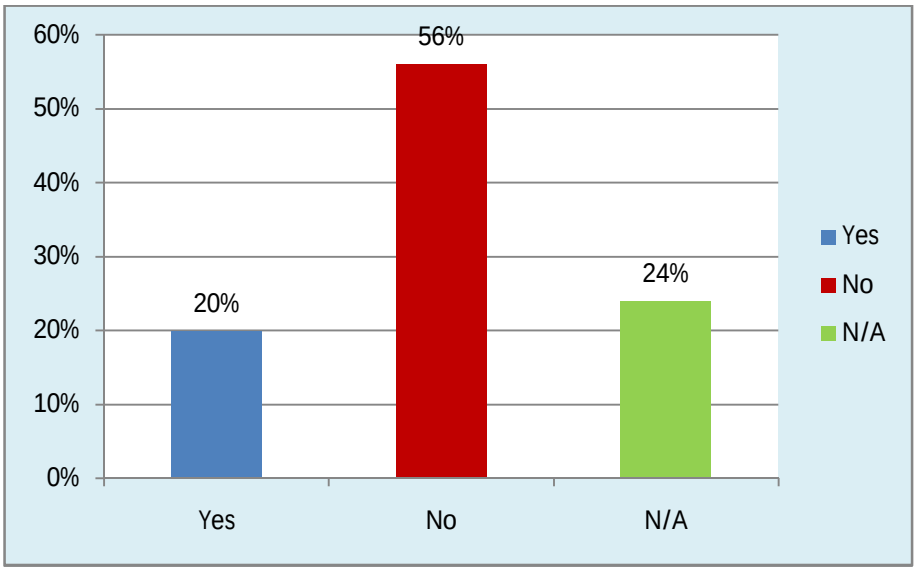

Figure 4.21 Policy on report turnaround time.

Table 4.22: What is the average time from examination to final report being sent to referring physician?

Time	Less than 12 hrs	12-24 hrs	4-72 hrs	Greater than 72 hrs	N/A
Facilities	36	11	03	00	00
Percentage (%)	72	22	06	00	00

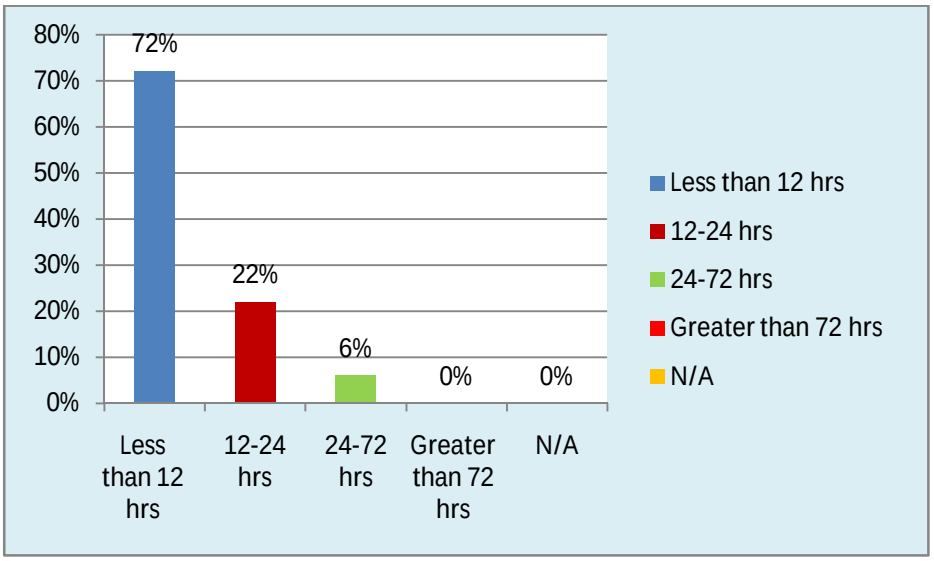

Figure 4.22 The average time from examination to final report being sent to referring physician.

Table 4.23: Policy in place for educating and informing patients about procedures and/or interventions to be performed.

Value	Y	N	N/
Policy in place for educating and informing patients about procedures	1	3	0
Percentage (%)	2	6	1

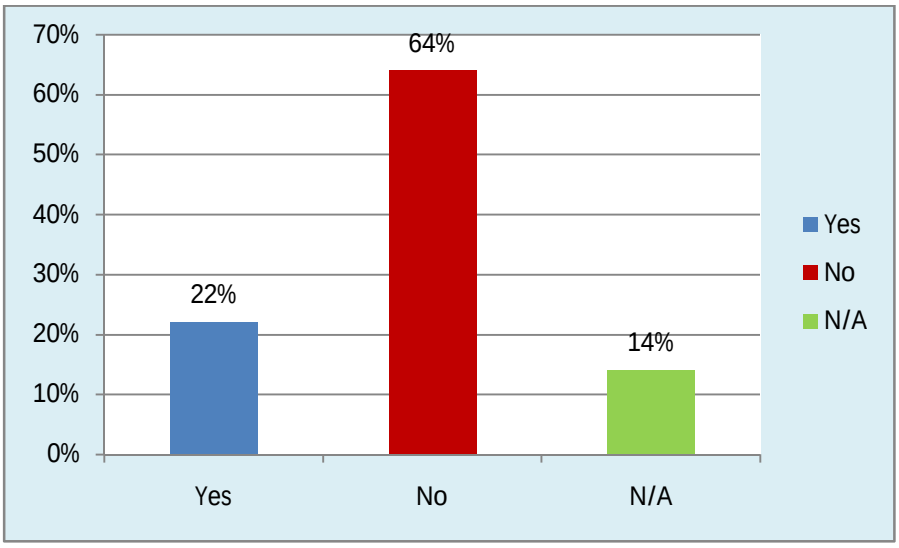

Figure 4.23 Policy in place for educating and informing patients about procedures and/or interventions to be performed.

Table 4.24: Are there policies and procedures to ensure confidentiality of patient-related information?

Value	Ye	No	N/A
Policies and procedures to ensure confidentiality of patient-related information	45	04	01
Percentage (%)	90	08	02

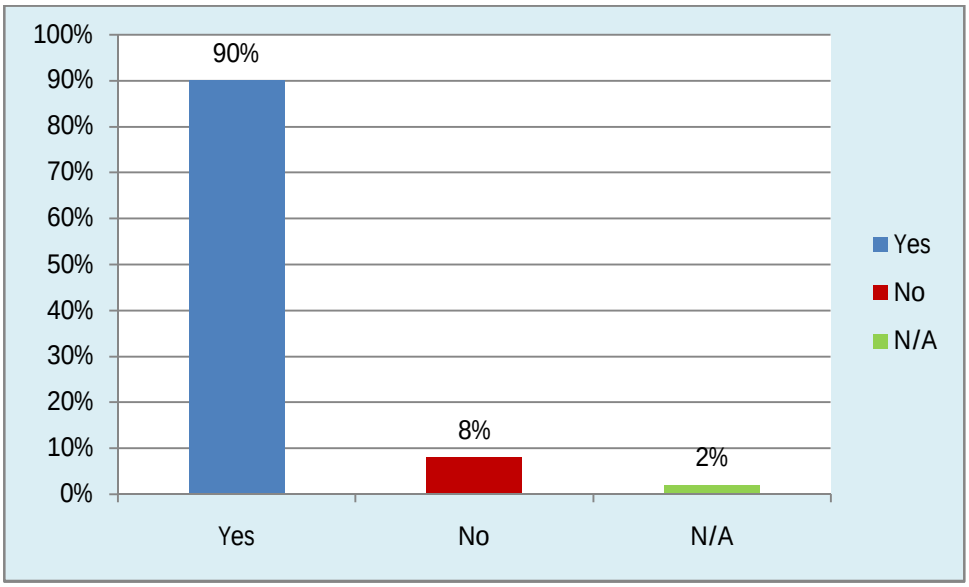

Figure 4.24 Policies and procedures to ensure confidentiality of patient-related information.

Table 4.25: Is there a mechanism for handling patient complaints?

Value	Yes	No	N/A
Policy on report turnaround time	03	44	03
Percentage (%)	06	88	06

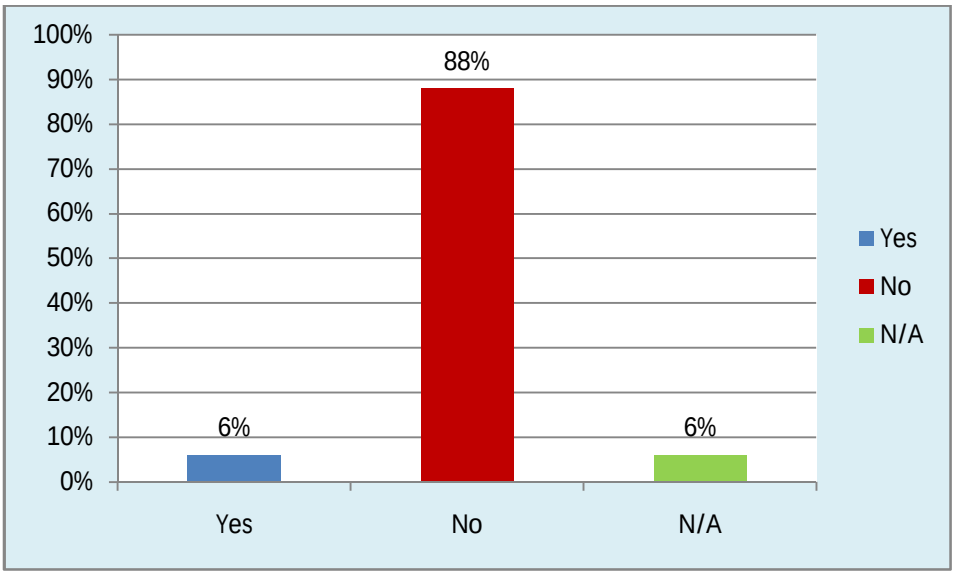

Figure 4.25 Mechanism for handling patient complaints.

Table 4.26: Does your QA program include a mechanism for obtaining follow-up on all operated cases?

Value	Ye	N	N/
QA program include a mechanism for obtaining follow-up on all operated cases	08	42	00
Percentage (%)	16	84	00

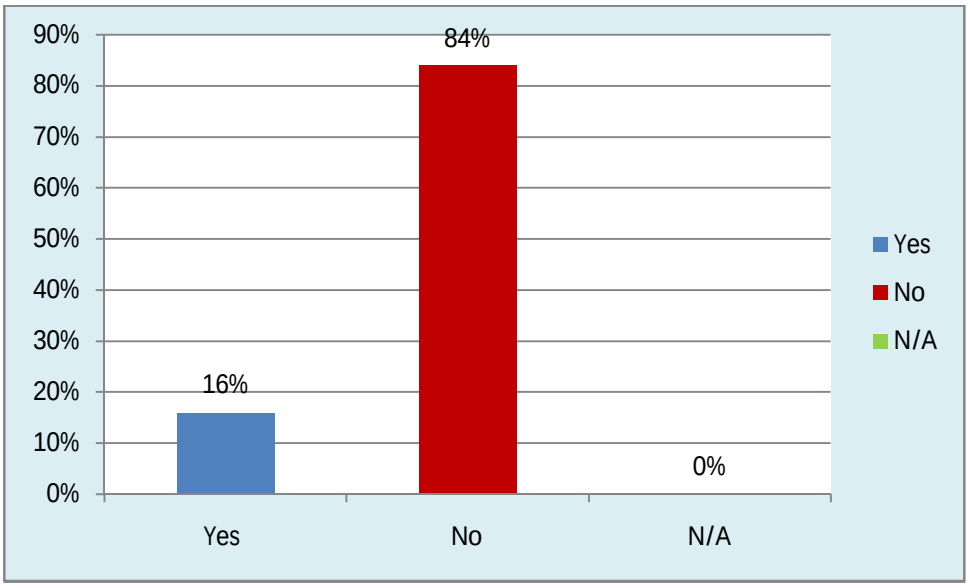

Figure 4.26QA program include a mechanism for obtaining follow-up on all operated cases.

Table 4.27: Does your quality assurance program include a mechanism for obtaining outcome data regarding positive sonograms and pathological correlation?

Value	Y	N	N/
Quality assurance program include a mechanism for obtain outcome data regarding positive sonograms and pathological correlation.	1	3	0
Percentage (%)	2	6	0

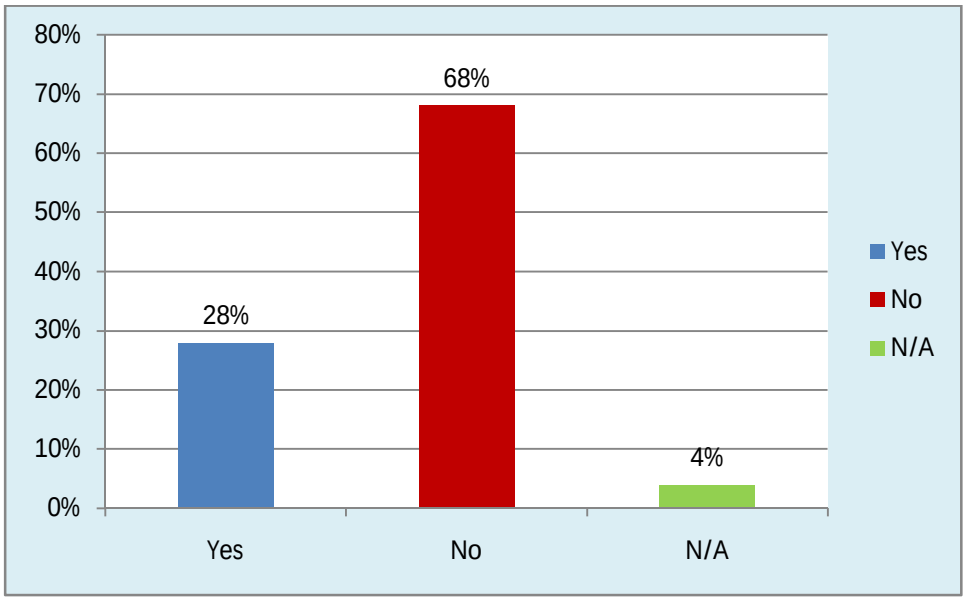

Figure 4.27 Quality assurance program include a mechanism for obtaining outcome data regarding positive sonograms and pathological correlation.

Table 4.28: The Usage of coupling gel in your ultrasound room?

Value	Yes	No	N/A
The Usage of coupling gel in your ultrasound room	50	00	00
Percentage (%)	100	00	00

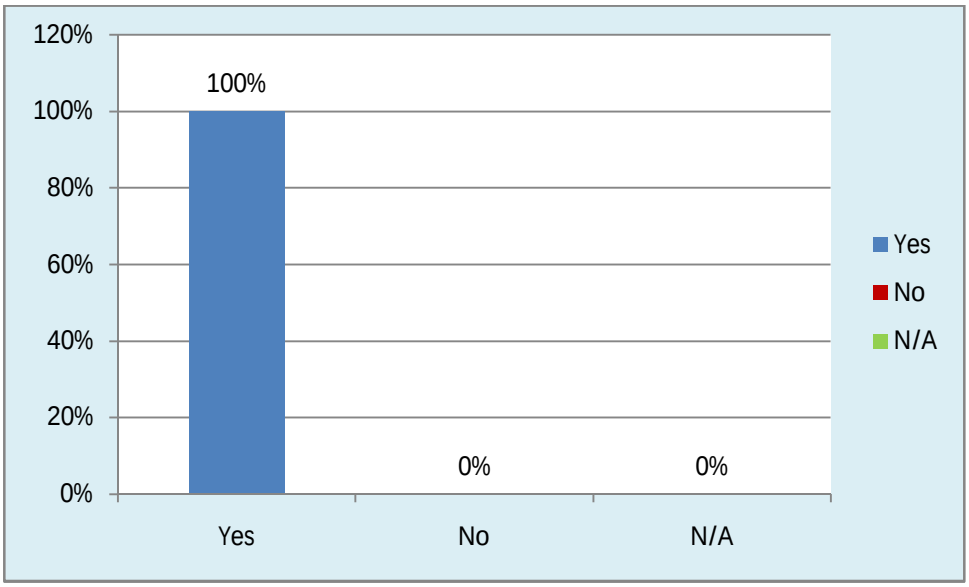

Figure 4.28 The Usage of coupling gel in your ultrasound room.

Table 4.29: The coupling gel Warmer availability in your ultrasound room?

Value	Ye	N	N/
The coupling gel Warmer availability in your ultrasound room	04	4	00
Percentage (%)	08	9	00

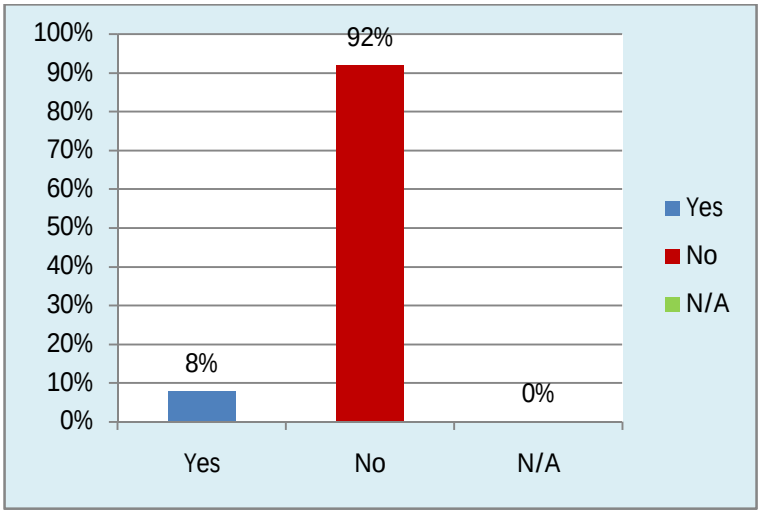

Figure 4.29 The coupling gel Warmer availability in your ultrasound room.

Table 4.30: What type of Thermal Ultrasound Paper is required by Ultrasound Printers?

Value	High-end regular paper	Low-end print paper	Crap Low-end paper	N/A
Type of Thermal Ultrasound Paper	6	16	07	21
Percentage (%)	12	32	14	42

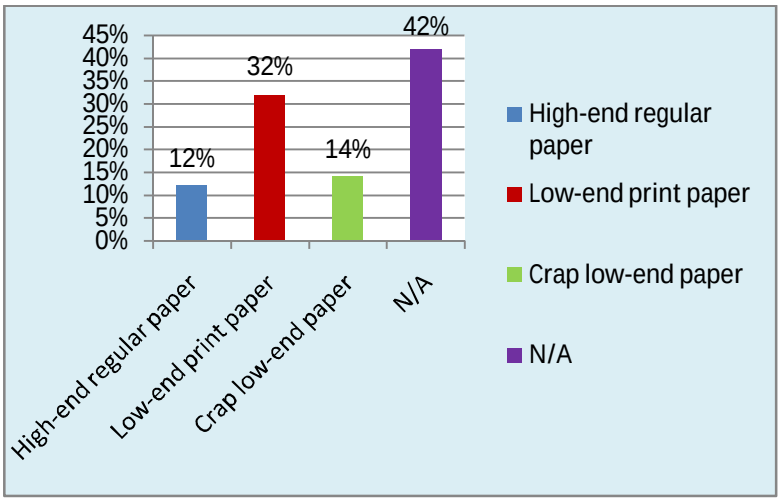

Figure 4.30 Type of Thermal Ultrasound Paper is required by Ultrasound Printers.

Table 4.31: Are the following identifying demographic data displayed on each image?

Values	Yes	Percentage (%)	No	Percentage (%)
(A) First and last name	24	48	26	52
(B) Medical record number	20	40	30	60
(C) Institution name	33	66	17	34
(D) Date and time of examination	45	90	05	10
(E) Date of birth or age	44	88	06	12
(F) Type of examination	26	52	24	48

Table 4.31(A): First and last name:

Value	Yes	Percentage (%)	No	Percentage (%
(A) First and last name	24	48	26	52

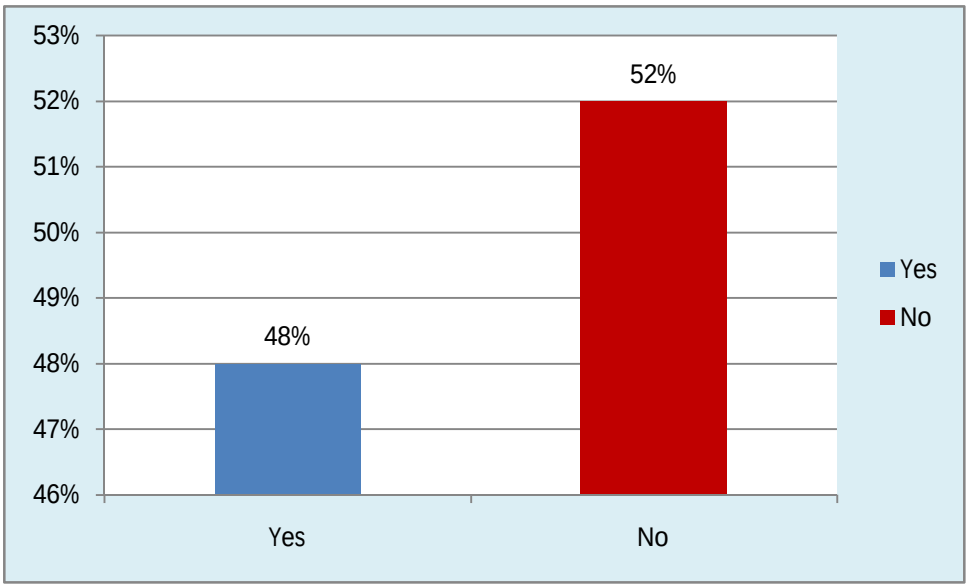

Figure 4.31(A) First and last name.

Table 4.31(B): Medical record number:

Value	Yes	Percentage (%)	No	Percentage (%)
(B) Medical record number	20	40	30	60

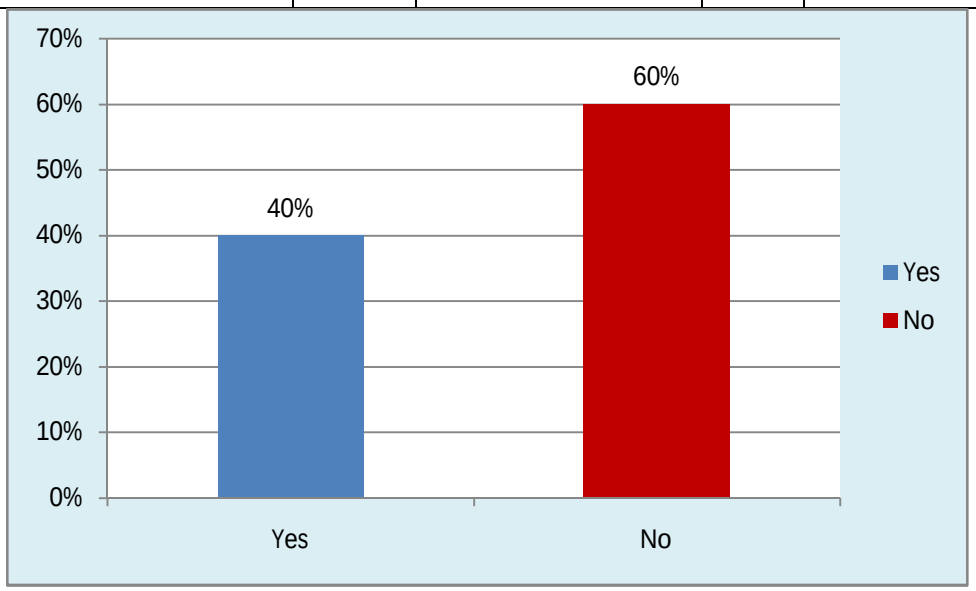

Figure 4.31(B) Medical record number.

Table 4.31(C): Institution name:

Value	Yes	Percentage (%)	No	Percentage (%)
(C) Institution name	33	66	17	34

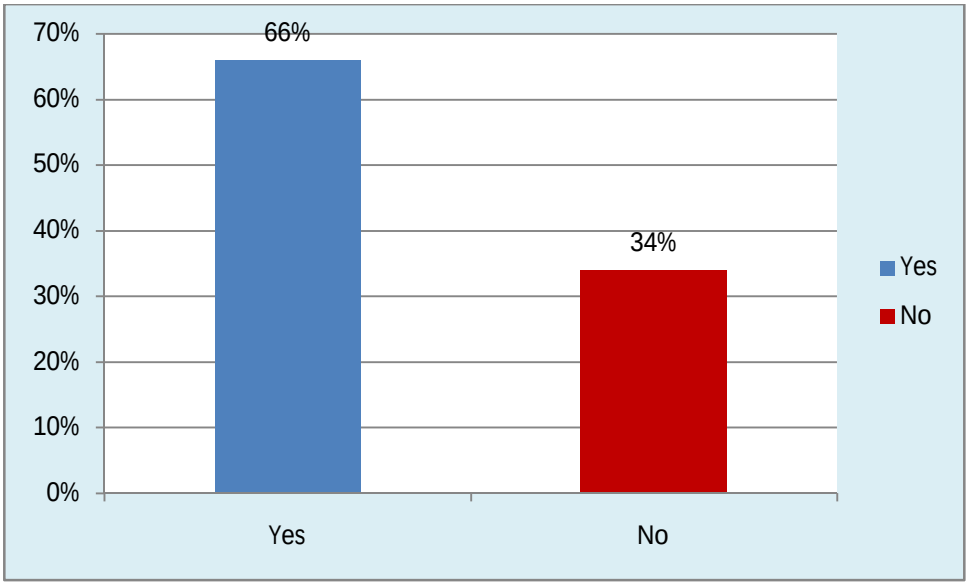

Figure 4.31(C) Institutionname.

Table 4.31(D): Date and time of examination:

Value	Yes	Percentage (%)	No	Percentage (%)
(D) Date and time of examination	45	90	05	10

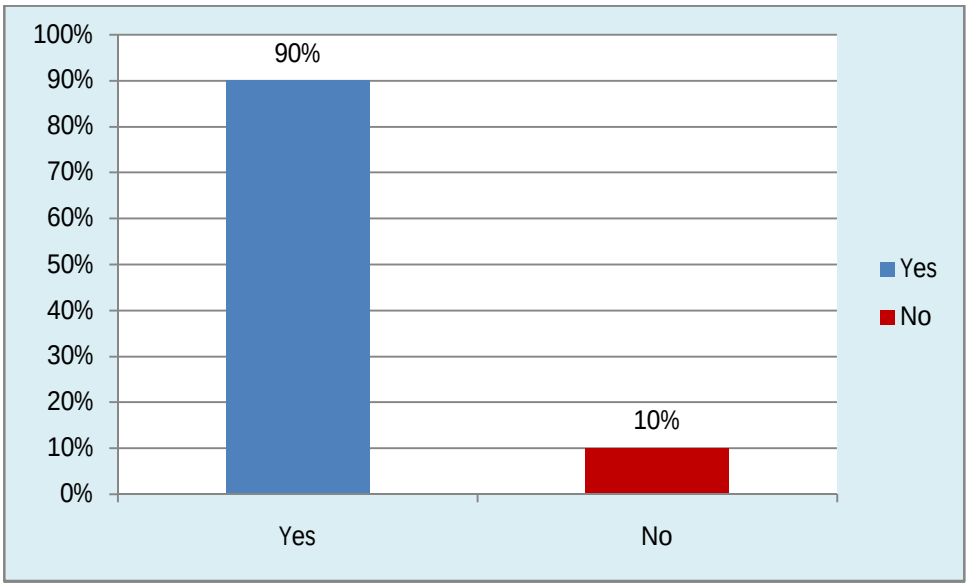

Figure 4.31(D) Date and time of examination.

Table 4.31(E): Date of birth or age:

Value	Yes	Percentage (%)	No	Percentage (%)
(E) Date of birth or age	44	88	06	12

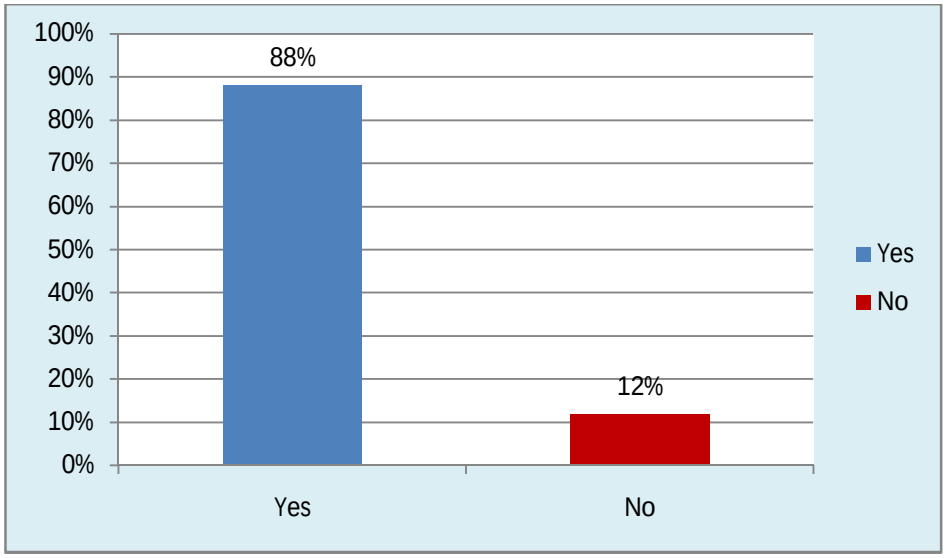

Figure 4.31(E) Date of birth or age.

Table 4.31(F): Type of examination:

Value	Yes	Percentage (%)	No	Percentage (%)

(F) Type of examination	26	52	24	48

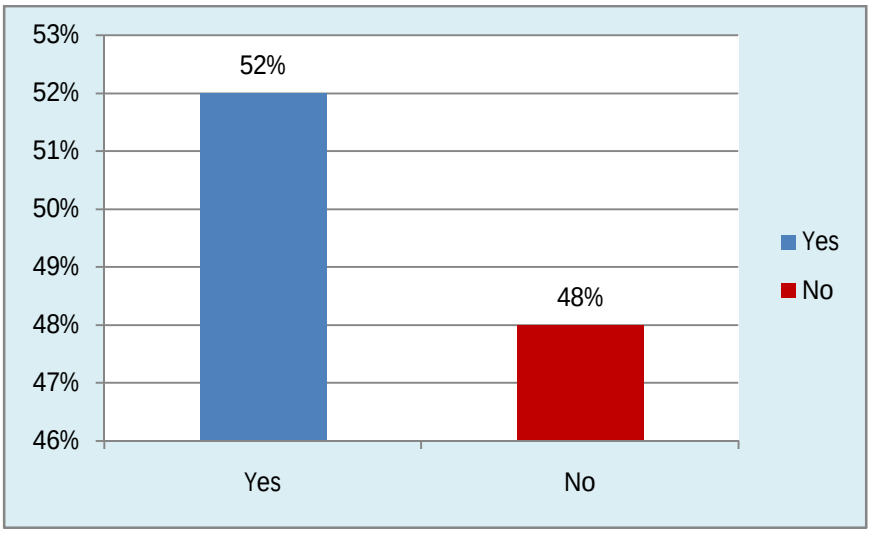

Figure 4.31(F) Type of examination.

Table 4.32: Adding the technologist's identification number, name, or initials to at least one image of the examination is recommended:

Value	**Yes**	**No**
Adding the technologist's identification number, name, or initials	13	37
Percentage (%)	26	74

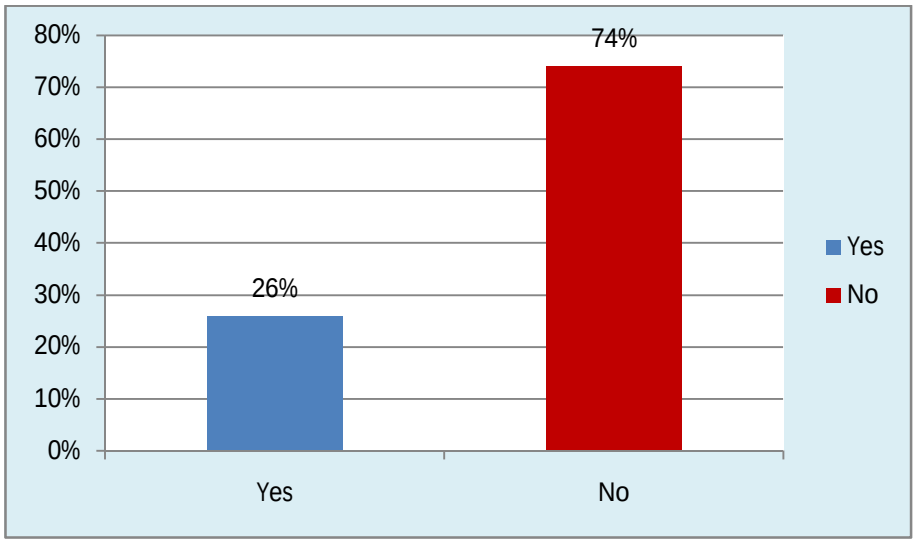

Figure 4.32 Adding the technologist's identification number, name, or initials to at least one image of the examination is recommended.

Key for Table 4.33: Ultrasound Quality Assurance Tasks routinely performed and their frequencies:

Group(A) Ultrasound Rooms	Not Done (1)
Group(B) Ultrasound Rooms	Daily (2)
Group(C) Ultrasound Rooms	Weekly (3)
Group(D) Ultrasound Rooms	Monthly(4)
Group(E) Ultrasound Rooms	Every 3 Months (5)
Group(F) Ultrasound Rooms	Every 6 Months (6)
Group(G) Ultrasound Rooms	Yearly (7)

Table 4.33: Gray Scale Photography routinely performed and its frequency:

US Rooms	**Not Done**	**Daily**	**Weekly**	**Monthly**	**Every3 Months**	**Every6 Months**	**Yearly**	**Percentage (%)**
Group(A)	36							72
Group(B)		00						00
Group(C)			00					00
Group(D)				00				00
Group(E)					04			08
Group(F)						07		14
Group(G)							03	06

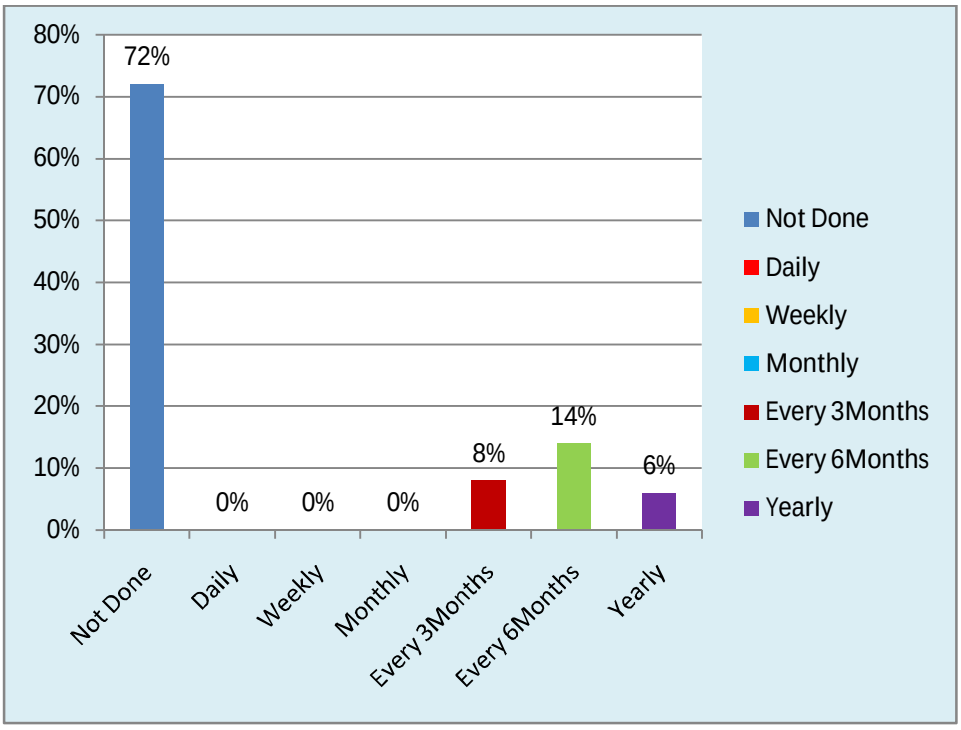

Figure 4.33 Gray Scale Photography routinely performed and its frequency.

Table 4.34: Hard Copy Output Quality Testroutinely performed and its frequency:

US Rooms	Not Done	Daily	Weekly	Monthly	Every3 Months	Every6 Months	Yearly	Percentage (%)
Group(A)	40							80
Group(B)		00						00
Group(C)			00					00
Group(D)				00				00
Group(E)					03			06
Group(F)						05		10
Group(G)							02	04

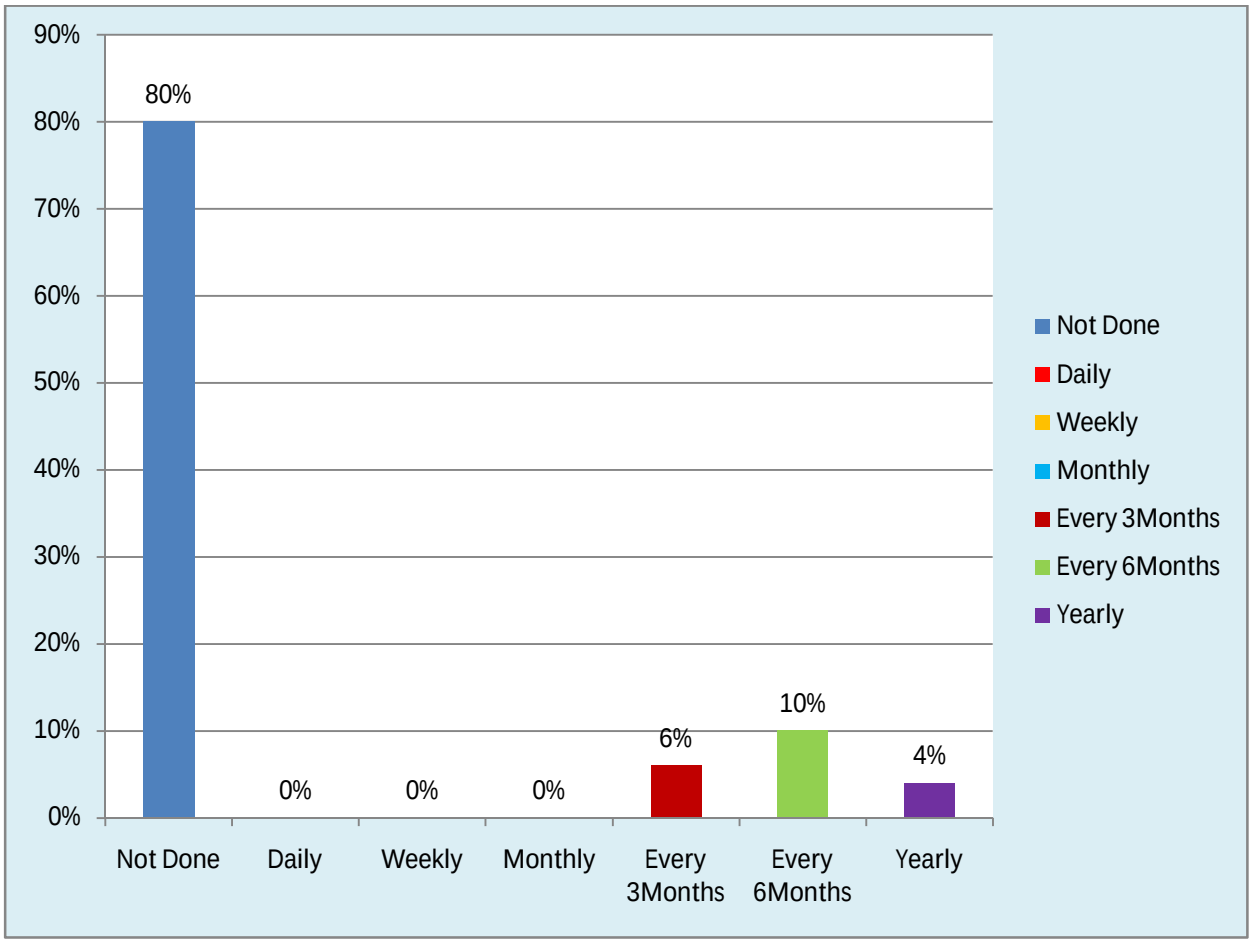

Figure 4.34 Hard Copy Output Quality Test routinely performed and its frequency.

Table 4.35: Electrical Safety Cleanlinessroutinely performed and its frequency:

US Rooms	Not Done	Daily	Weekly	Monthly	Every3 Months	Every6 Months	Yearly	Percentage (%)
Group(A)	07							14
Group(B)		04						08
Group(C)			02					04
Group(D)				16				32
Group(E)					13			26
Group(F)						03		06
Group(G)							05	10

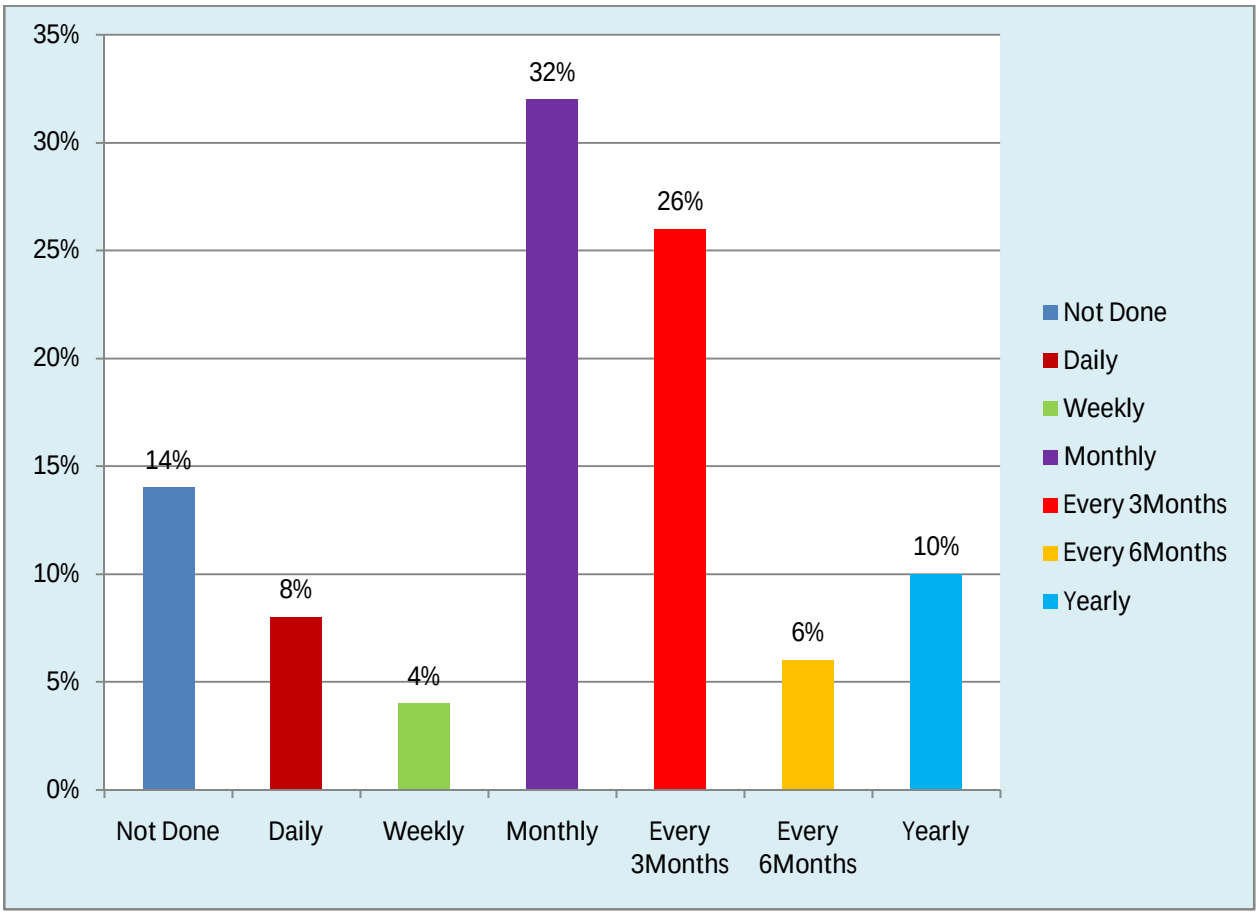

Figure 4.35 Electrical Safety Cleanlinessroutinely performed and its frequency.

Table 4.36: Universal Infection Control Procedure routinely performed and its frequency:

USRooms	Not Done	Daily	Weekly	Monthly	Every3 Months	Every6 Months	Yearly	Percentage (%)
Group(A)	00							00
Group(B)		05						10
Group(C)			22					44
Group(D)				12				24
Group(E)					02			04
Group(F)						03		06
Group(G)							06	12

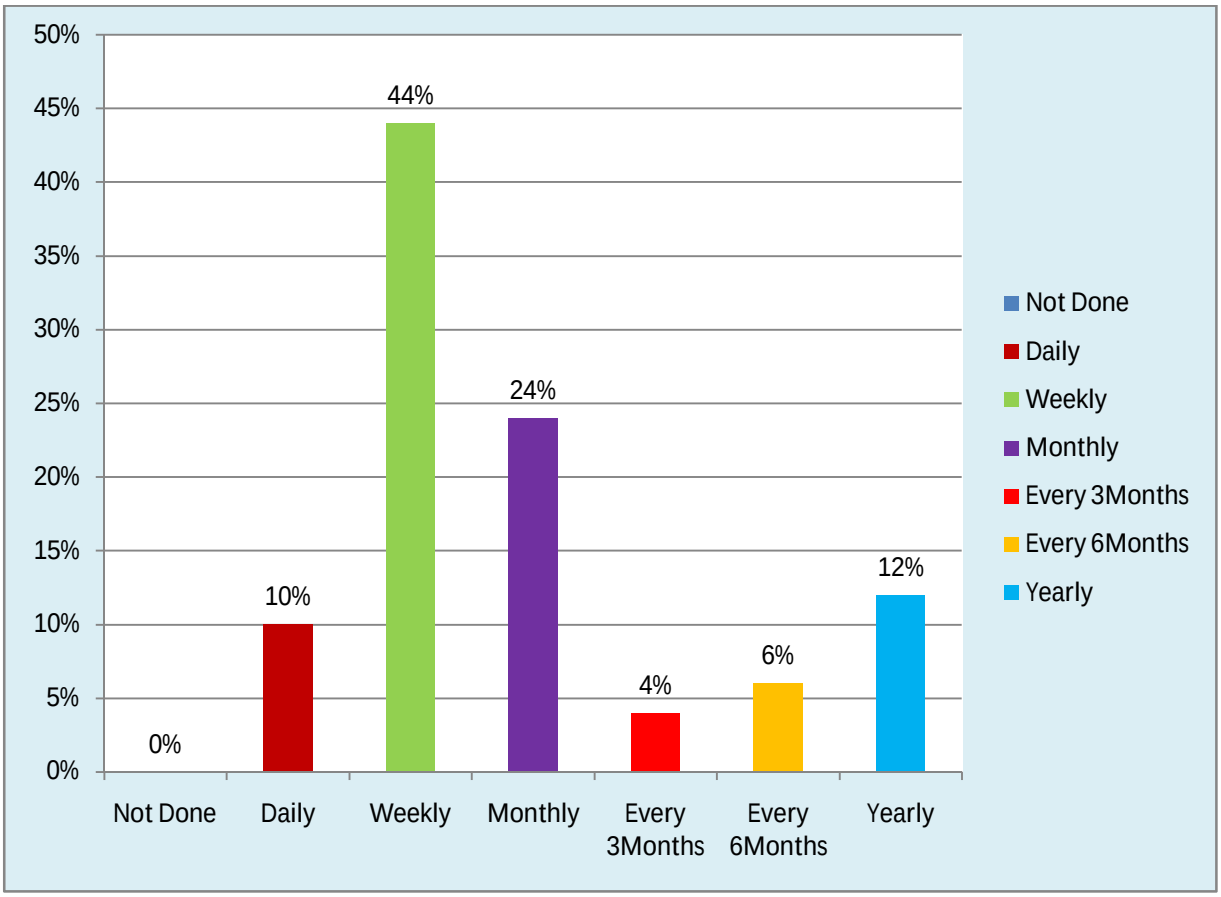

Figure 4.36 Universal Infection Control Procedure routinely performed and its frequency.

Table 4.37: System Sensitivity and /or Penetration capability routinely performed and its frequency:

USRooms	Not Done	Daily	Weekly	Monthly	Every3 Months	Every6 Months	Yearly	Percentage (%)
Group(A)	25							50
Group(B)		00						00
Group(C)			00					00
Group(D)				00				00
Group(E)					08			16
Group(F)						10		20
Group(G)							07	14

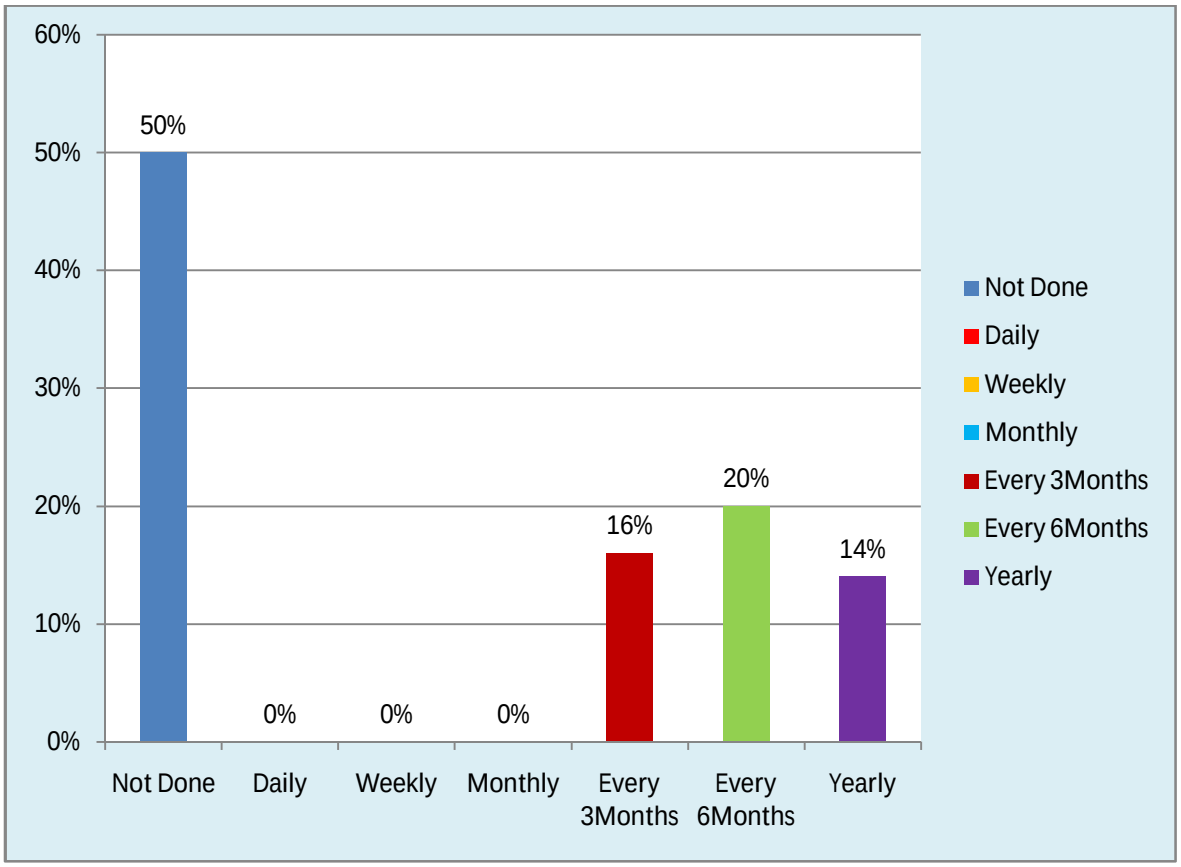

Figure 4.37 System Sensitivity and /or Penetration capability routinely performed and its frequency.

Table 4.38: Uniformityroutinely performed and its frequency:

USRooms	Not Done	Daily	Weekly	Monthly	Every3 Months	Every6 Months	Yearly	Percentage (%)
Group(A)	33							66
Group(B)		00						00
Group(C)			00					00
Group(D)				00				00
Group(E)					06			12
Group(F)						05		10

Group(G)							06	12

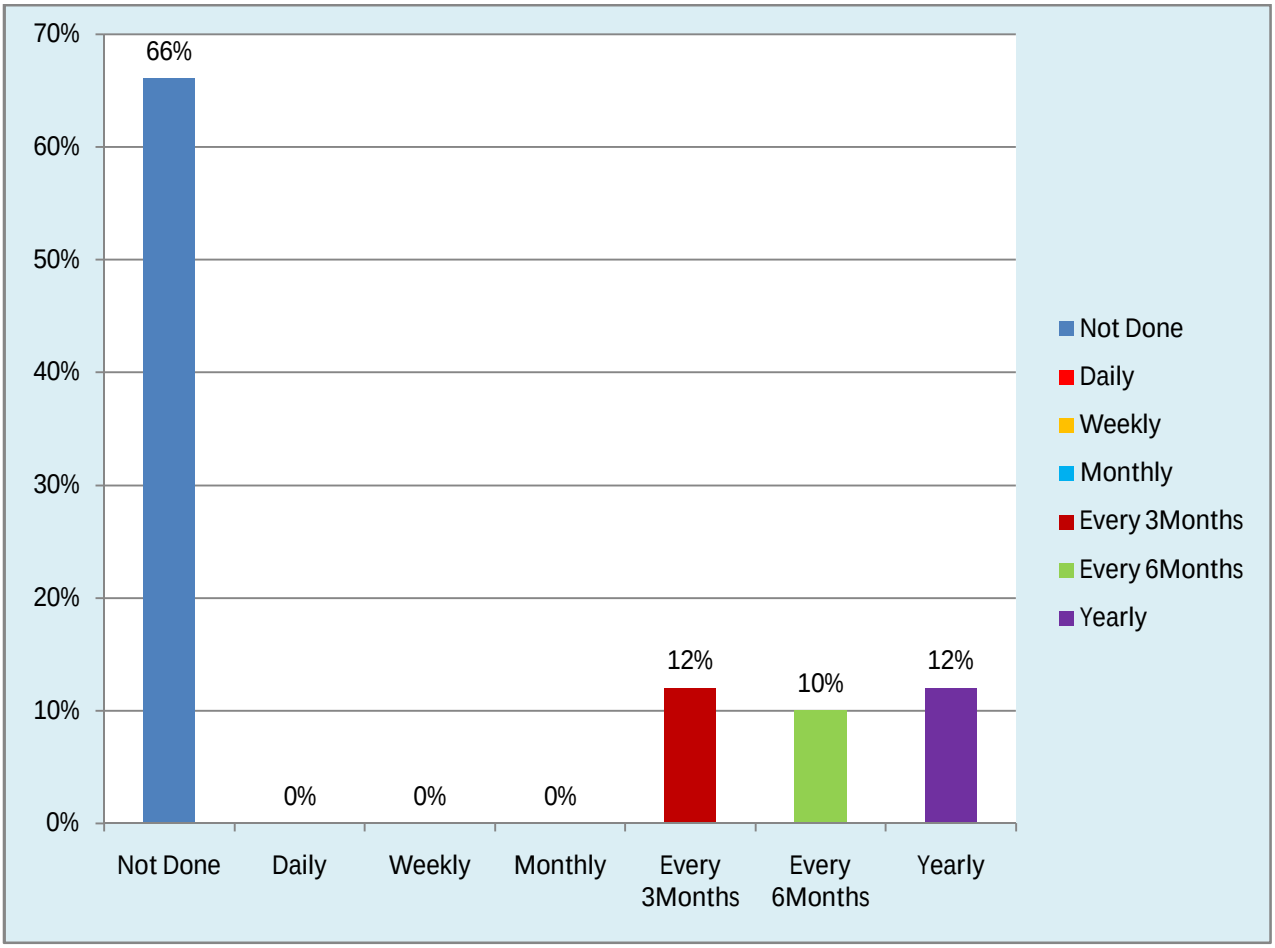

Figure 4.38 Uniformity routinely performed and its frequency.

Table 4.39: Maximal depth of visualization and hard copy recording with Phantom routinely performed and its frequency:

USRooms	Not Done	Daily	Weekly	Monthly	Every3 Months	Every6 Months	Yearly	Percentage (%)
Group(A)	40							80
Group(B)		00						00
Group(C)			00					00
Group(D)				00				00
Group(E)					00			00
Group(F)						06		12
Group(G)							04	08

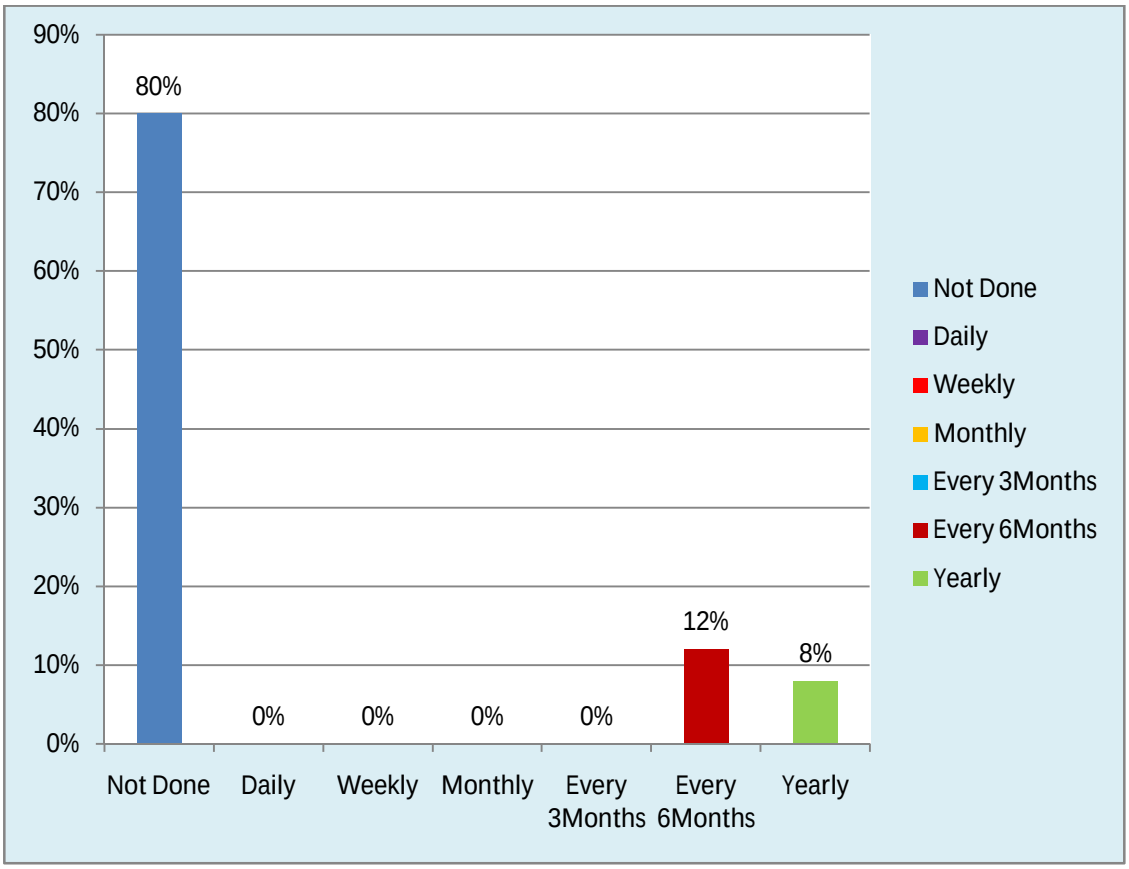

Figure 4.39maximal depthof visualization and hard copy recording with Phantom routinely performed and its frequency.

Table 4.40: Low Contrast Object Detectability routinely performed and its frequency:

US Rooms	Not Done	Daily	Weekly	Monthly	Every3 Months	Every6 Months	Yearly	Percenta (%)
Group(A)	23							46
Group(B)		00						00
Group(C)			00					00
Group(D)				11				22%
Group(E)					08			16
Group(F)						03		06

Group(G)							05	10

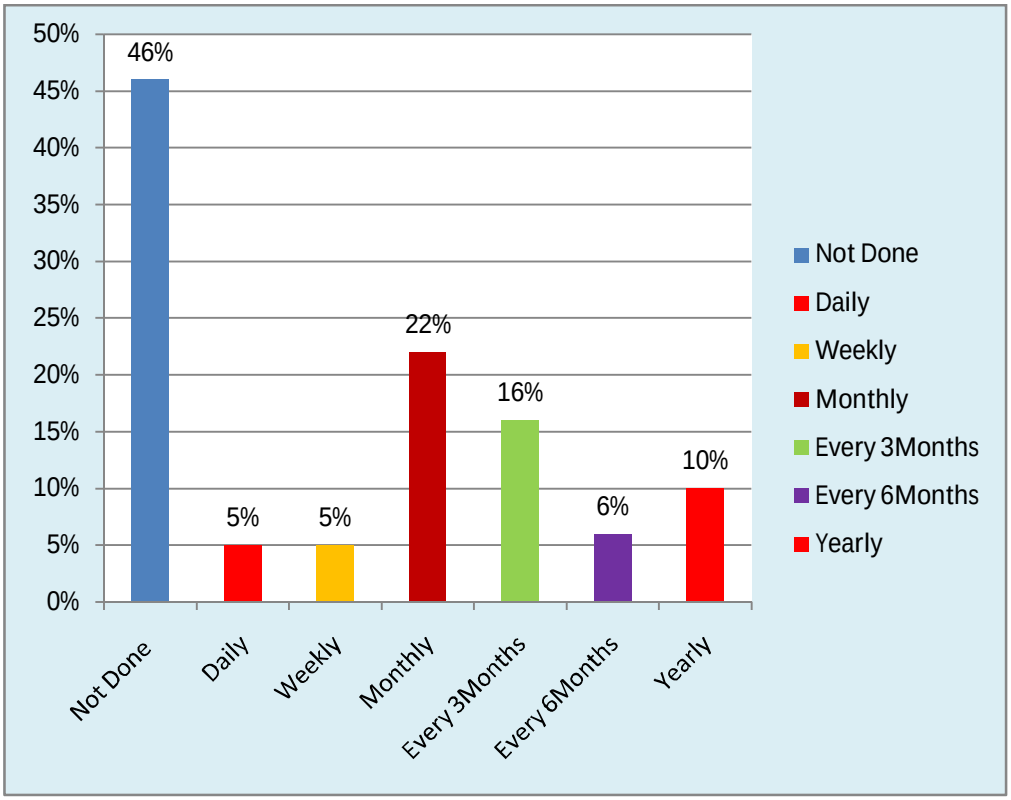

Figure 4.40 Low Contrast Object Detectability routinely performed and its frequency.

Key of Table 4.41 System Sensitivity: The maximum depth can be Visualize**:**

Group(A) Ultrasound Machines	Less Than 3cm ----------5.5cm (1)
Group(B) Ultrasound Machines	6cm----------9cm (2)
Group(C) Ultrasound Machines	9.5cm----------12.5cm (3)
Group(D) Ultrasound Machines	13cm----------16cm(4)

Table 4.41: System Sensitivity (The maximum depthcan be Visualize)**:**

The Values	**The maximum depth/cm**	**Machines**	**Percentage (%)**
Group(A)	Less Than 3 - 5.5	05	10

Group(B)	6 - 9	10	20
Group(C)	9.5 -12.5	22	44
Group(D)	13- 16	13	26

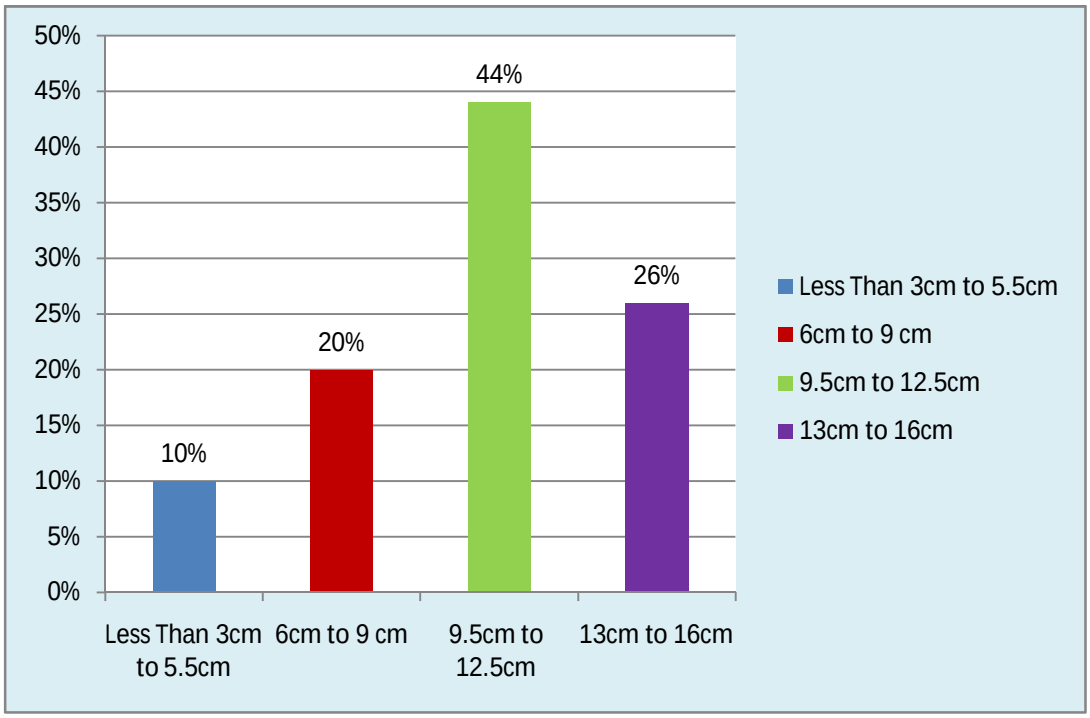

Figure 4.41 System Sensitivity: The maximum depth can be Visualize:

Key of Table 4.42: The average brightness at edge of the scan is the same as the average brightness in the middle:

The Values	**Meanings**
Agree	(1)
Disagree, slight non uniformities present	(2)
Disagree, major non uniformities present	(3)

Table 4.42: The average brightness at edge of the scan is the same as the average brightness in the middle:

The Values	**No. Of**	**Percentage**

	Machines	(%)
Agree (1)	25	50
Disagree, slight non uniformities present (2)	08	16
Disagree, major non uniformities present (3)	17	34

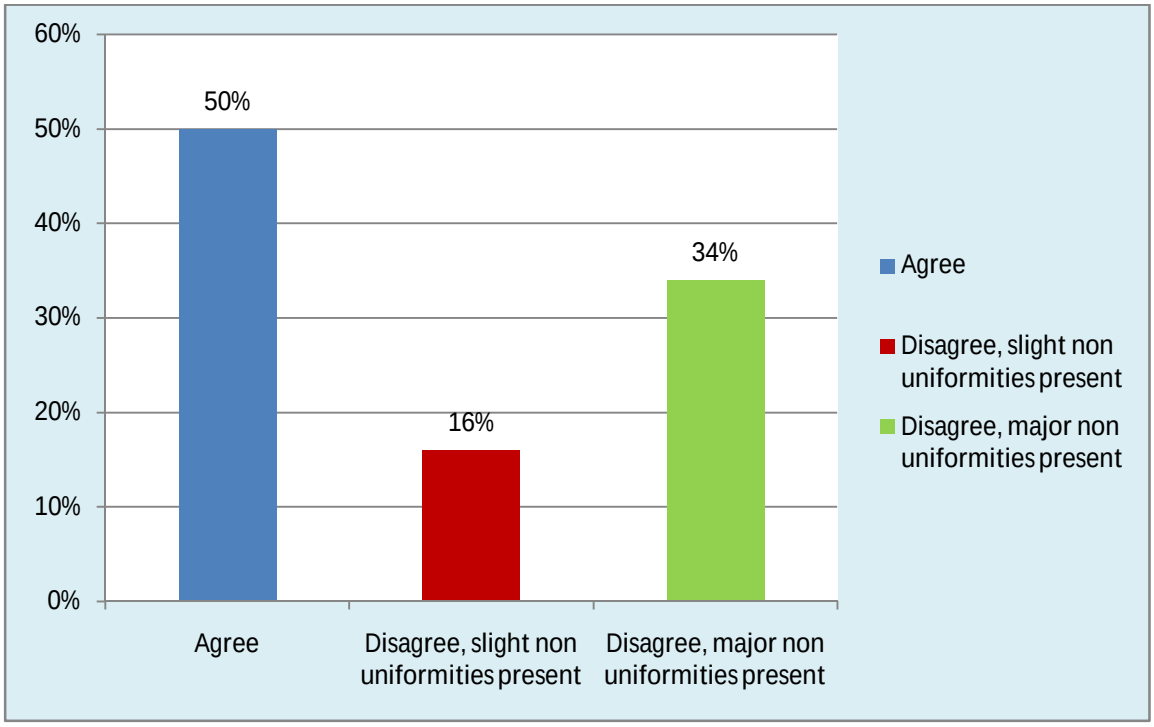

Figure 4.42 The average brightness at edge of the scan is the same as the average brightness in the middle.

Table 4.43: There are no vertically or radially oriented shadows from array element dropout:

The Values	No. Of Machines	Percentage (%)
Agree (1)	18	36
Disagree, slight non uniformities present (2)	23	46
Disagree, major non uniformities present (3)	09	18

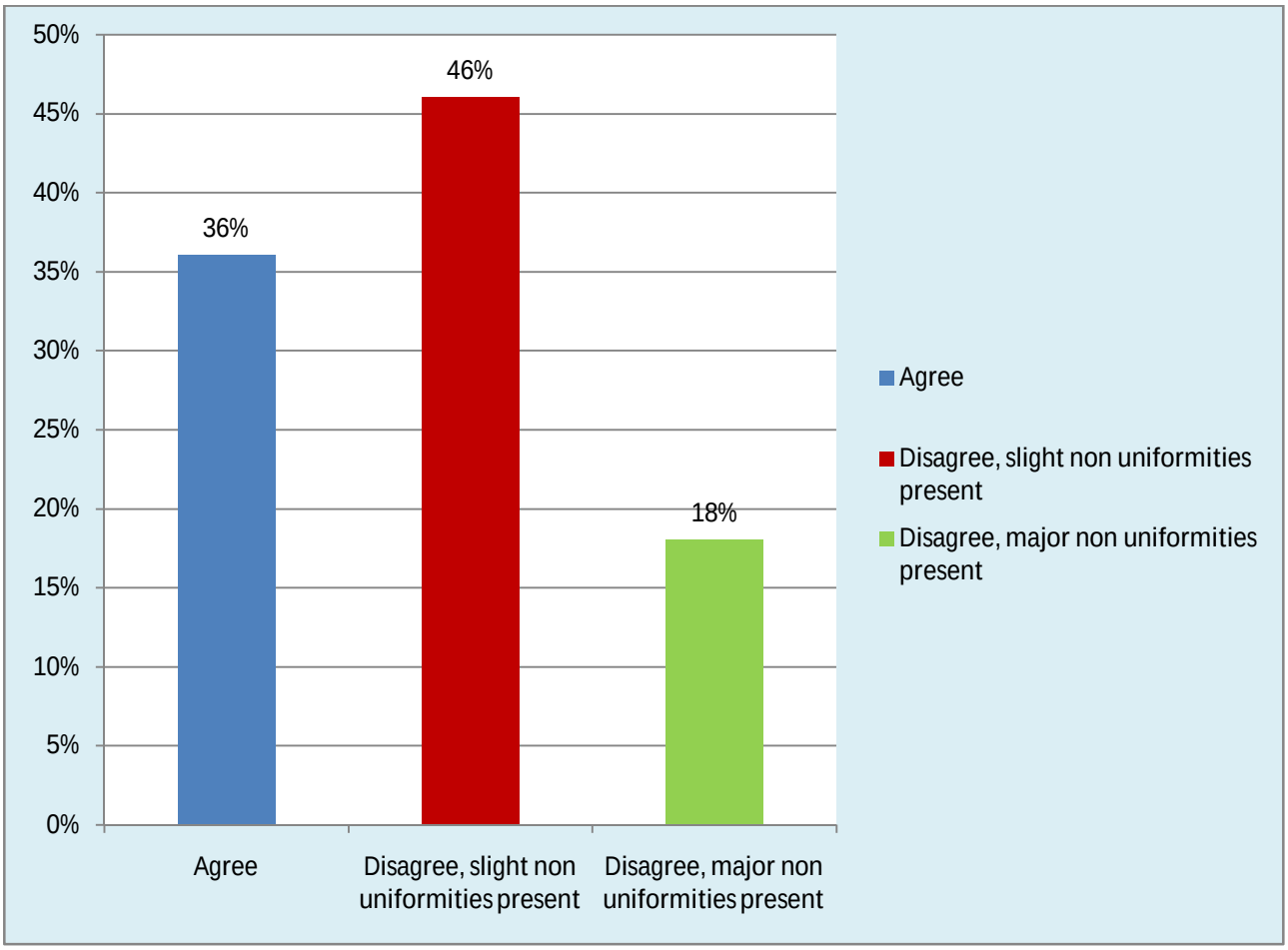

Figure 4.43 There are no vertically or radially oriented shadows from array element dropout.

Table 4.44: There are no brightness transitions between focal zones:

The Values	**No. Of Machines**	**Percentage(%)**
Agree (1)	15	30
Disagree, slight non uniformities present (2)	12	24
Disagree, major non uniformities present (3)	23	46

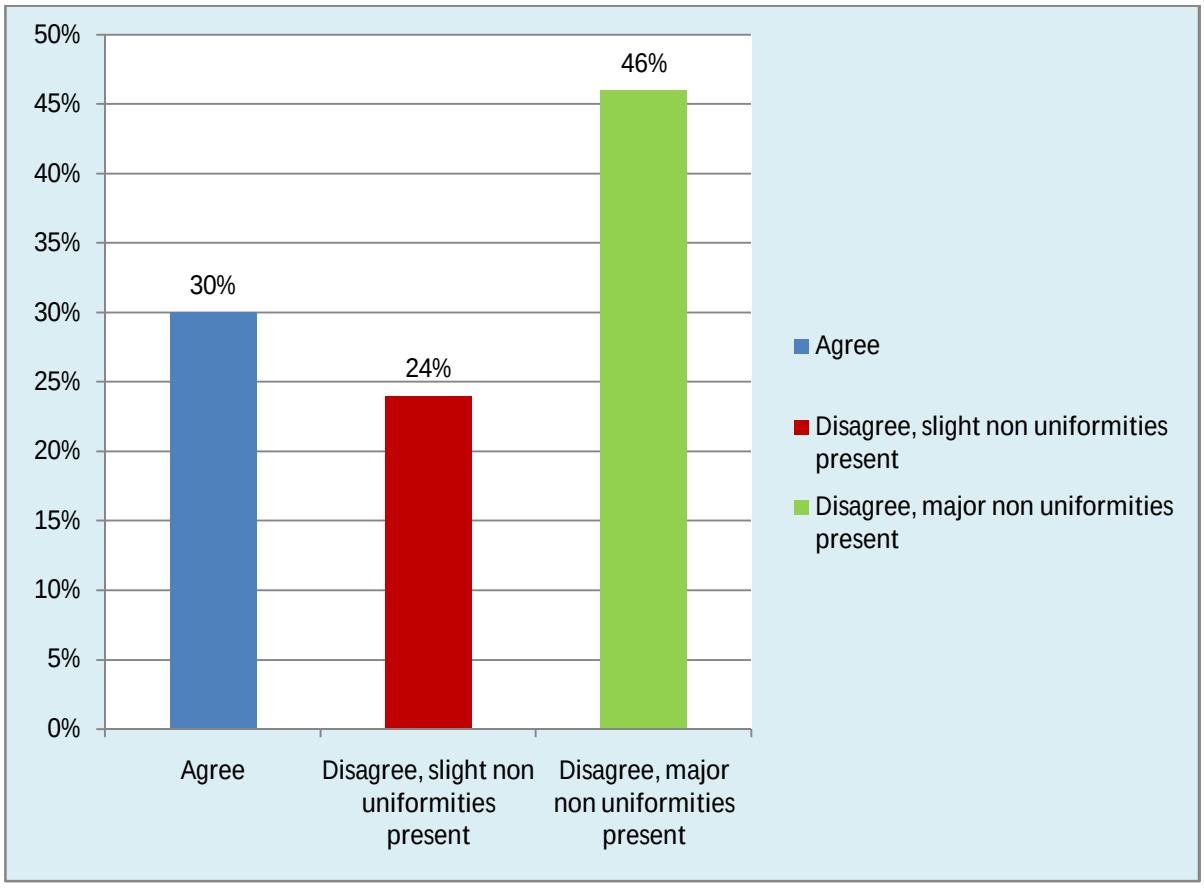

Figure 4.44 There are no brightness transitions between focal zones.

Table 4.45: Scanner Electronic Image Display Performance:

The Values	**No. Of Machines**	**Percentage (%)**
Completed(1)	50	100
Not Completed(2)	00	00

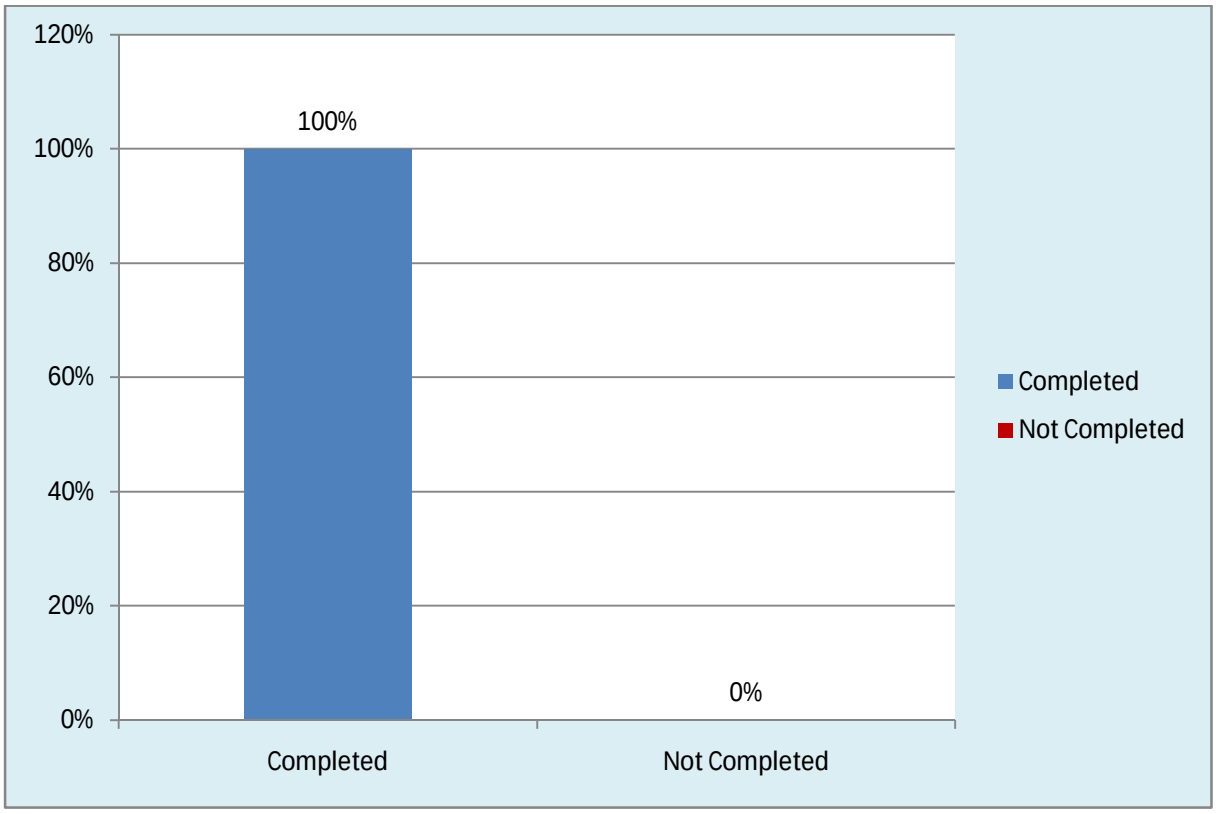

Figure 4.45 Scanner Electronic Image Display Performance.

Table 4.46: Primary Interpretation Display Performance:

The Values	**No. Of Machines**	**Percentage (%)**
Completed	50	100
Not Completed	00	00
N/A (Only required if located at the facility where ultrasound is performed.)	00	00

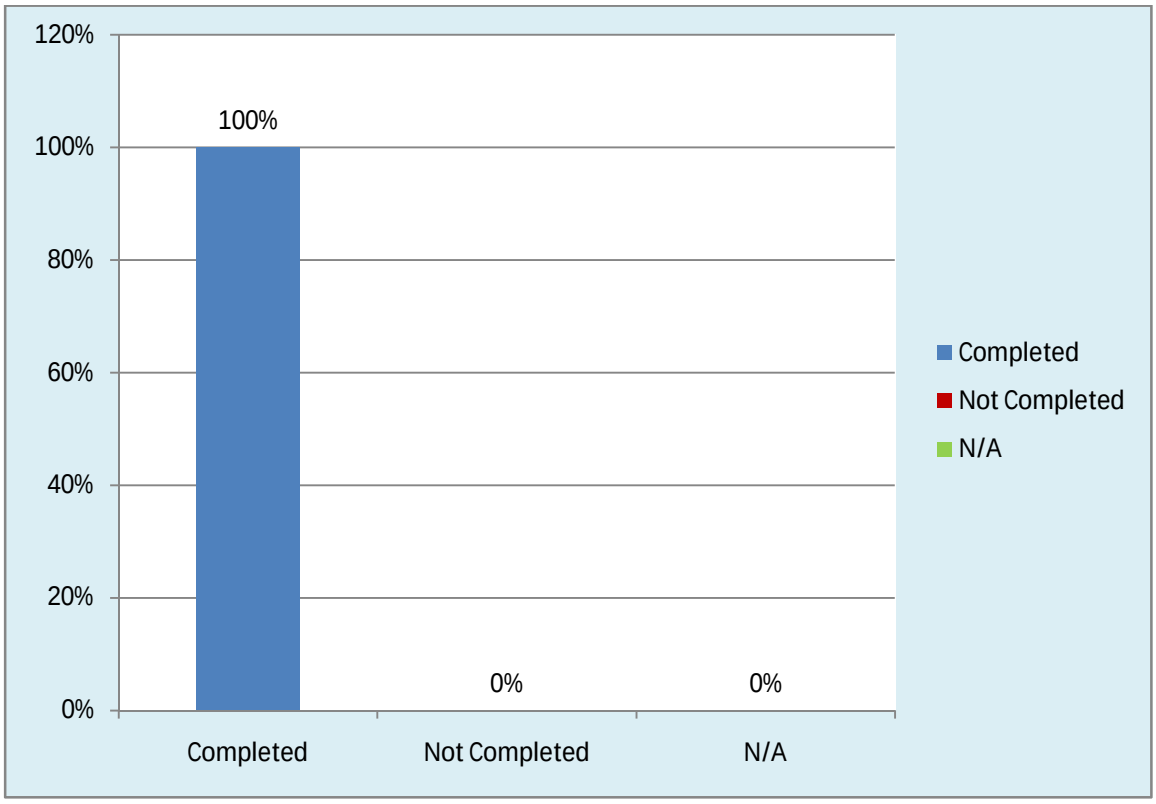

Figure 4.46 Primary Interpretation Display Performance.

Key of Table 4.47: Depth Measurements Accuracy: (Electronic Calipers)

Group(A) Ultrasound Machines	100 mm
Group(B) Ultrasound Machines	90mm----------70mm
Group(C) Ultrasound Machines	70mm----------50mm
Group(D) Ultrasound Machines	50mm----------30mm
Group(E) Ultrasound Machines	30mm----------10mm

Table 4.47: Depth Measurements Accuracy: (Electronic Calipers)

Groups	**Actual Distance/mm**	**Measured Distance/mm**	**Error/mm**	**Machines**	**Percentage (%)**
Group(A)	100	100	00	12	24
Group(B)	100	88	12	23	46
Group(C)	100	67	33	10	20
Group(D)	100	45	55	03	06
Group(E)	100	30	70	02	04

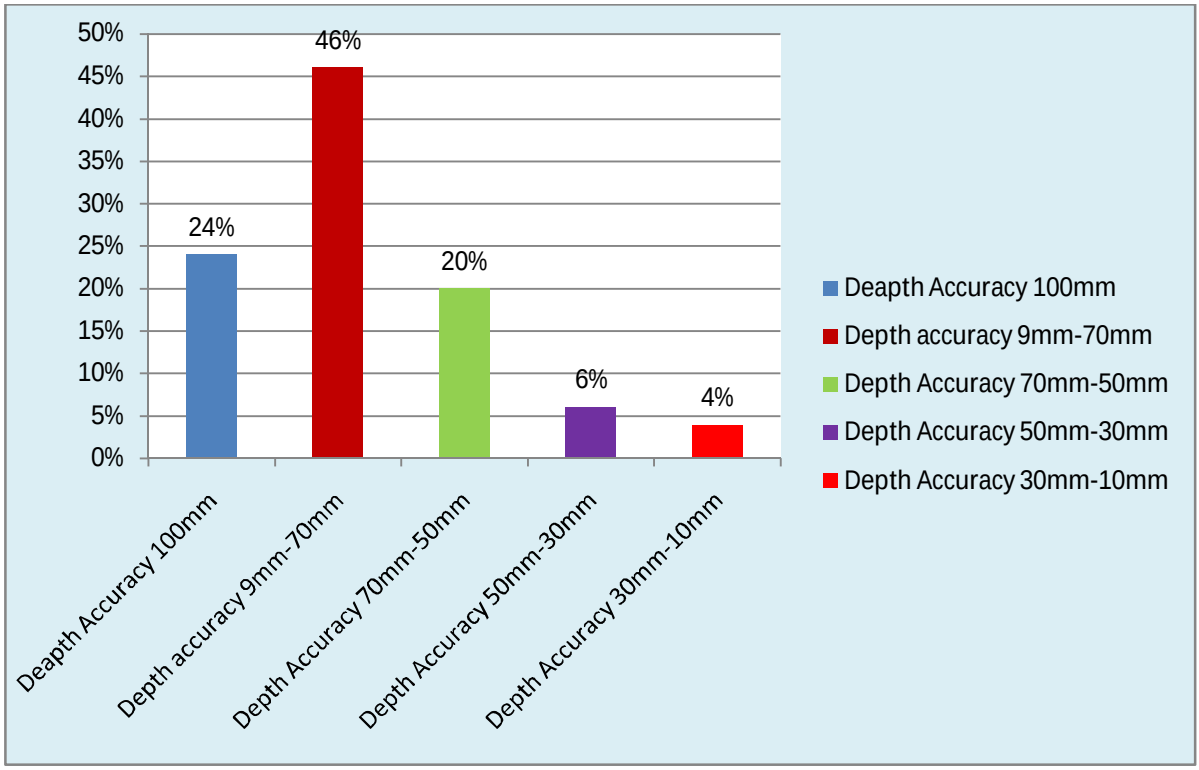

Figure 4.47 Depth Measurements Accuracy.

Key of Table 4.48: Horizontal Measurements Accuracy: (Electronic Calipers)

Group(A) Ultrasound Machines	30 mm
Group(B) Ultrasound Machines	30mm----------20mm
Group(C) Ultrasound Machines	20mm----------10mm
Group(D) Ultrasound Machines	10mm----------00mm

Table 4.48: Horizontal Measurements Accuracy: (Electronic Calipers)

Groups	**Actual Distance/mm**	**Measured Distance/mm**	**Error/mm**	**Machines**	**Percentage (%)**
Group(A)	30	30	00	09	18
Group(B)	30	25	05	14	28
Group(C)	30	15	15	22	44
Group(D)	30	08	22	05	10

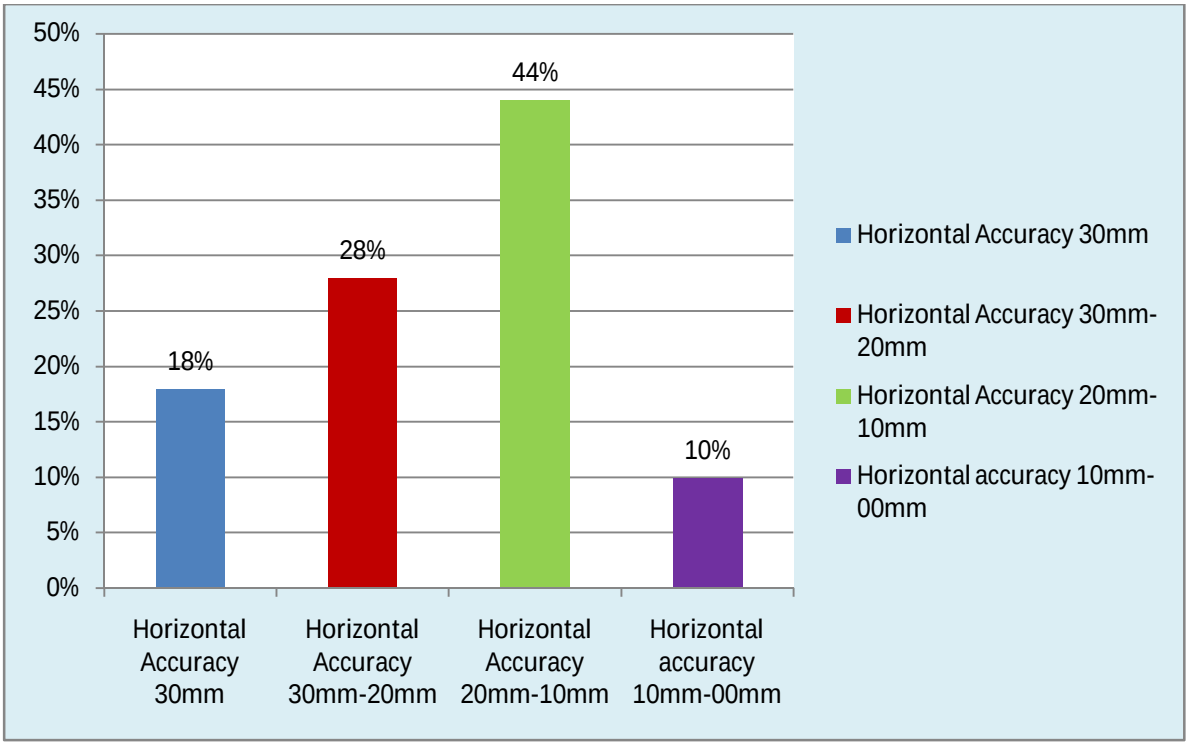

Figure 4.48 Horizontal Measurements Accuracy.

Key of Table 4.49: Depth of penetration: (4MHz) (Electronic Calipers)

Group(A) Ultrasound Machines	150 mm
Group(B) Ultrasound Machines	140mm----------120mm
Group(C) Ultrasound Machines	120mm----------100mm
Group(D) Ultrasound Machines	100mm----------80mm
Group(E) Ultrasound Machines	80mm----------60mm
Group(F) Ultrasound Machines	60mm----------40mm
Group(G) Ultrasound Machines	40mm----------20mm
Group(H) Ultrasound Machines	20mm----------00mm

Table 4.49: Depth of penetration: (4MHz) (Electronic Calipers)

Groups	Baseline Distance/mm	Measured Distance/mm	Variation from baseline/mm	No of machines	Percentage (%)
Group(A)	150	150	00	06	12
Group(B)	150	135	15	11	22
Group(C)	150	117	33	08	16
Group(D)	150	100	50	05	10
Group(E)	150	77	73	09	18
Group(F)	150	58	92	06	12
Group(G)	150	36	114	04	08
Group(H)	150	20	130	01	02

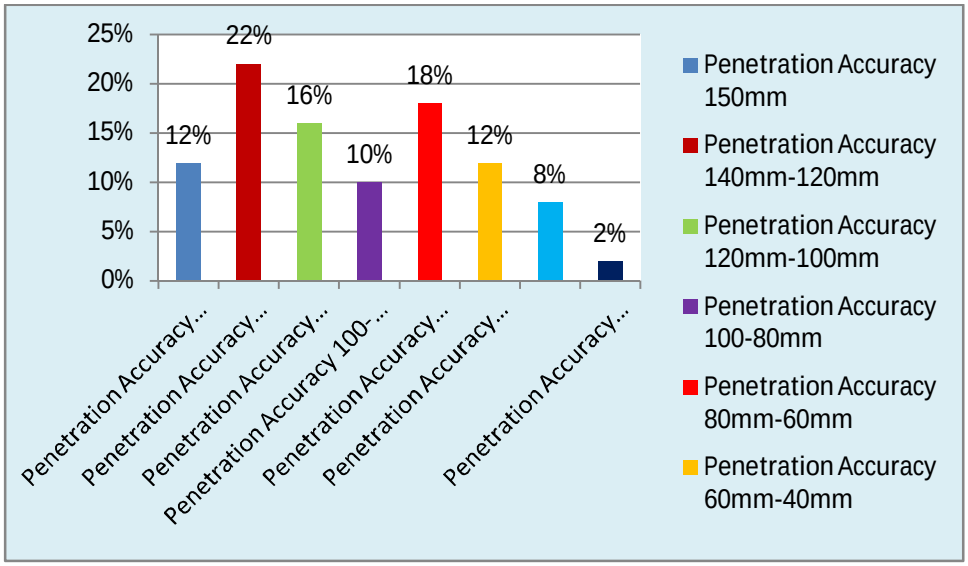

Figure 4.49 Depth of penetration.

Table 4.50: Image Uniformity:

Values	No of machines	Percentage (%)
1 Significant Nonuniformity	06	12
2 Good	05	10
3 Better	18	36
4 Best	13	26
5 Excellent Uniformity	08	16

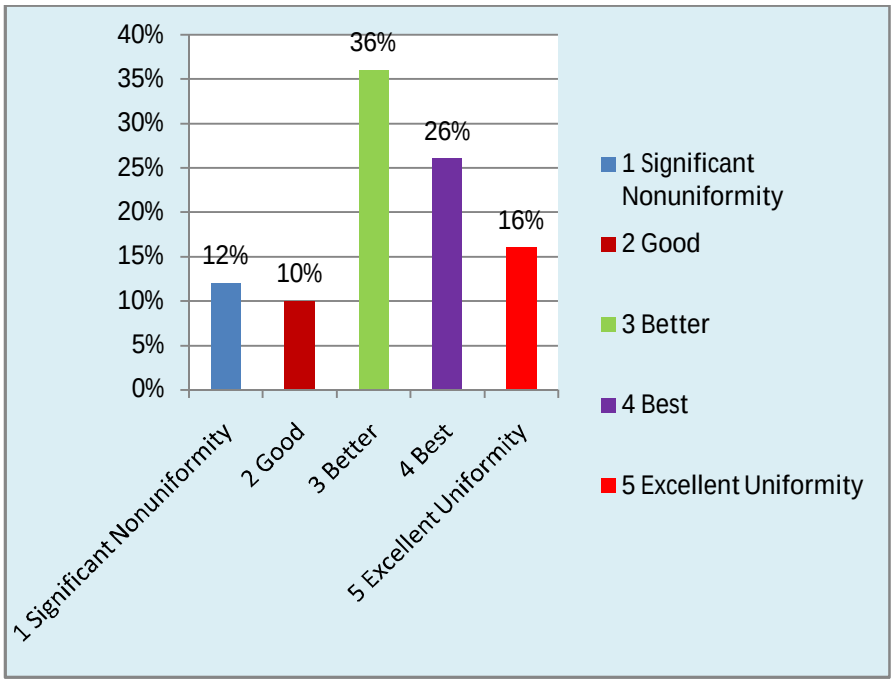

Figure 4.50 Image Uniformity.

Key of Table 4.51: Gray Bars:

Group(A	15mm
Group(B)	14mm----------12mm
Group(C)	11mm----------09mm
Group(D)	08mm----------06mm
Group(E)	05mm----------03mm
Group(F)	02mm----------00mm

Table 4.51: Gray Bars:

Groups	**No. of gray bars visible on baseline/mm**	**No. of gray bars visible/mm**	**Variation from baseline/mm**	**Machines**	**Percentage (%)**
(A)	15	15	00	13	26
(B)	15	13	02	12	24
(C)	15	10	05	14	28
(D)	15	07	08	06	12
(E)	15	03	12	03	06
(F)	15	01	14	02	04

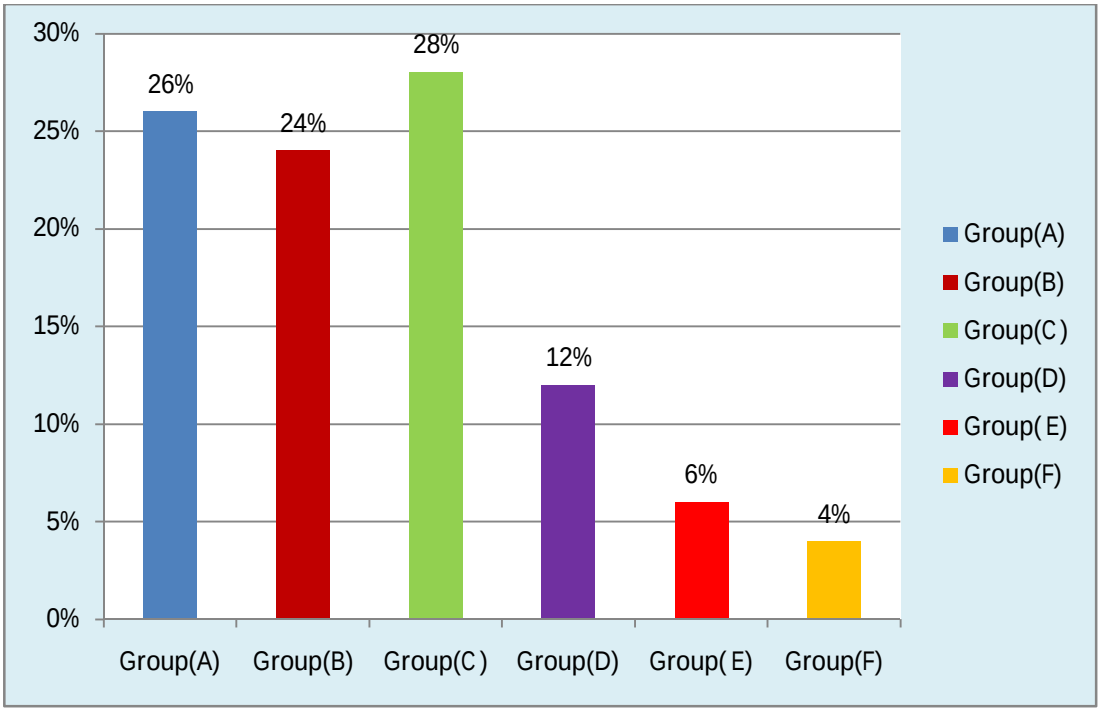

Figure 4.51 Gray Bars.

Table 4.52: Low-Level echoes:(All echoes displayed on viewing monitor also seen on film):

Value	**Yes**	**No**
All echoes displayed on viewing monitor also seen on film	23	27
Percentage (%)	46	54

Table 4.53: Contrast and brightness: (Level of agreement between contrast and brightness on viewing monitor and film):

Values	**No of machines**	**Percentage (%)**
1 Poor	06	12
2 Good	05	10
3 Better	18	36
4 Best	13	26
5 Excellent	08	16

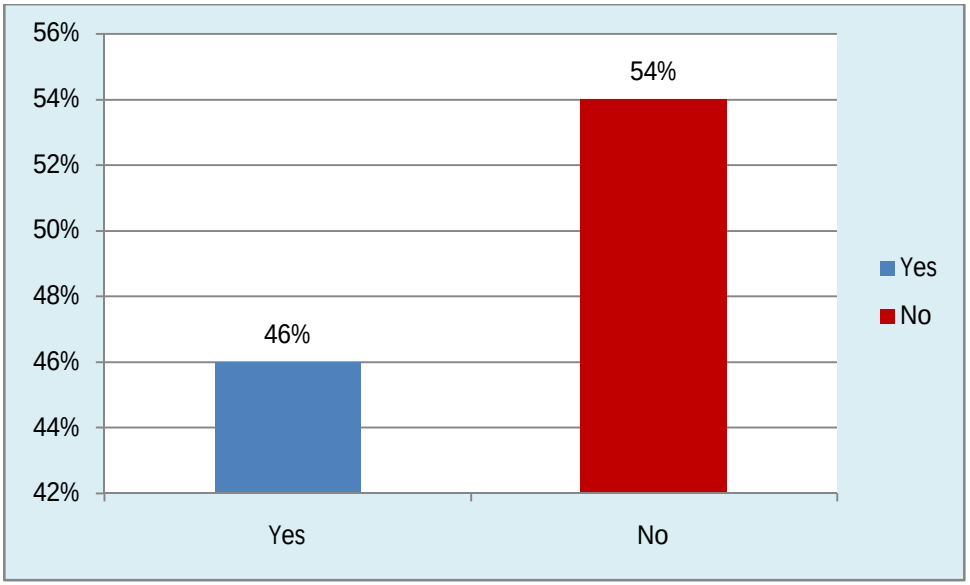

Figure 4.52 Low-Level echoes.

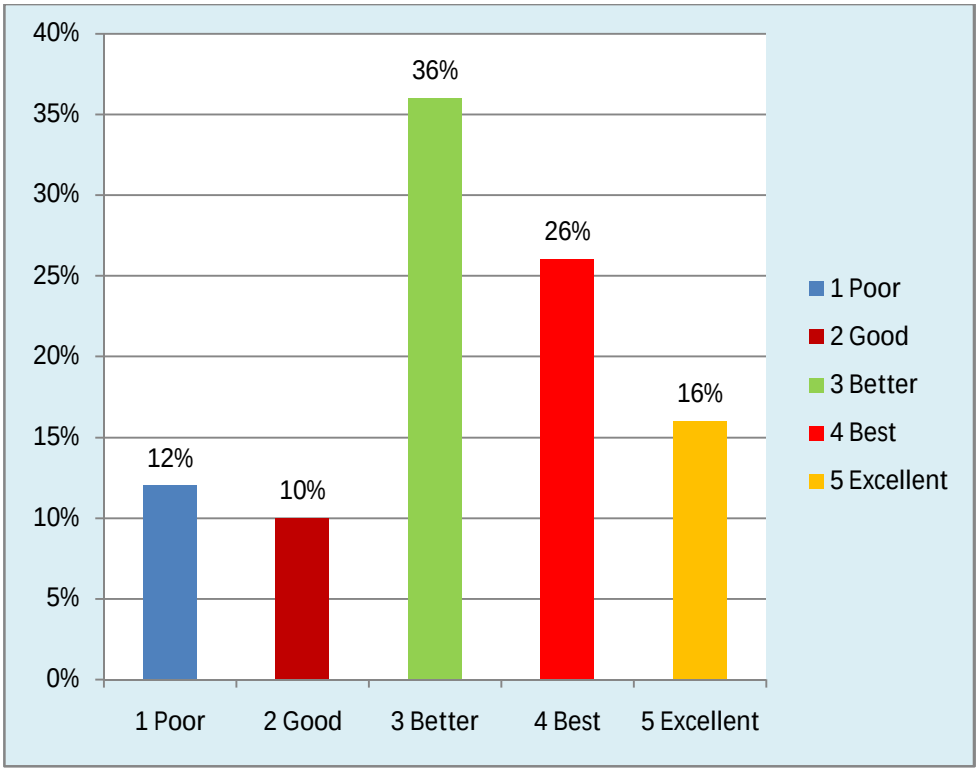

Figure 4.53 Contrast and brightness.

Table 4.54: Filters situation (Clean or Dusty):

Values	No of machines	Percentage (%)
Clean	18	36
Dusty	32	64

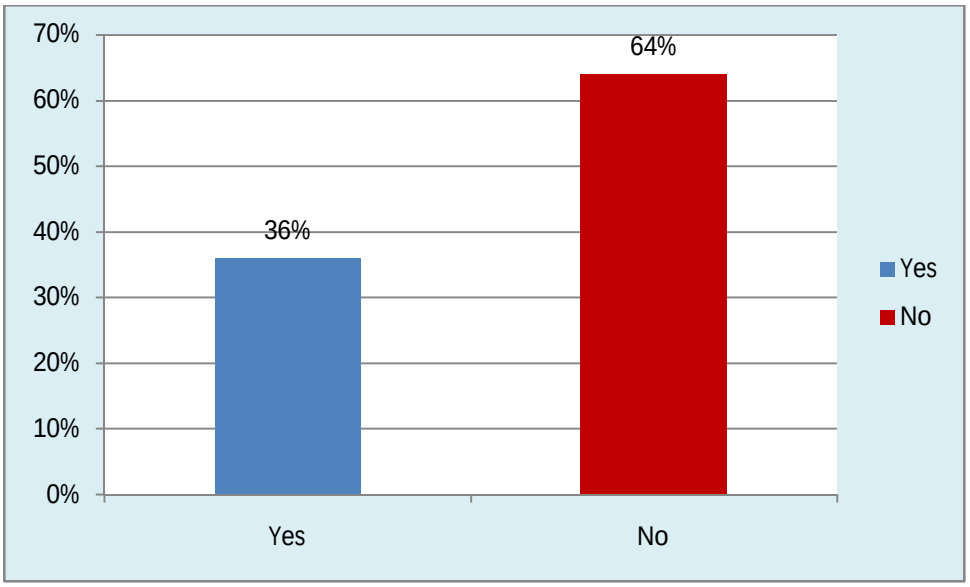

Figure 4.54 Filters situation (Clean or Dusty)

CHAPTER FIVE

5.1 Discussion:

The aim of our prospective study was to assessment and optimize of image Quality in ultrasound departments at Khartoum State to determine whether quality assurance programs and procedures are applied properly.The correct choice of parameters has a great impact on the quality of the output image and, in practice, the default parameters recommended by the manufacturer do not always produce a good quality image, the acquisition of a good quality image is a very challenging task especially for difficult patients who have large body habitus(Hediger et al., 2016). In particular, an abdominal scan involves multiple organs at different depths, is strongly affected by body habitus and requires significant manual tuning (20-45 minutes on average). Previous efforts to produce a good quality image have focused on the hardware aspect of the acquisition by designing probes that have the potential to provide better images (Dudley et al., 2014a).

The sample of this study consisted of 50 ultrasound machines in 35 governmental hospitals. The majority of ultrasound rooms had a waiting areas for patients and the others hadn't, the ratio was (35:15) with percentage of 70% had a waiting area and 30% hadn't a waiting area. Paradoxically, the most of the ultrasound rooms hadn't changing rooms and some of them had changing roomsthe others were not applicable the ratio of (35:10: 5) with percentage of 70%, 20% and 10% receptively. According to the Patient washrooms most of the ultrasound rooms containedwashing rooms about 32 rooms with percentage of 64% and12 rooms hadn’t with percentage of 24% the rest of ultrasound 6 washing rooms with percentage of 12% not applicable. The all hospitals have procedures ultrasound rooms 50 machines with percentage of 100%. According to image storage in the hospitals 8 ultrasound rooms followed the proper way of storage system their

percentage were 16% while 40 ultrasound rooms didn't follow any storage image system (80%) the rest of ultrasound rooms (2 rooms, percentage 4%) storage system not applicable. In these 50 ultrasound rooms there were 12 rooms had a processing areas (24%), no processing areas in (34) room with percentage (68%), while (4 rooms) percentage (8%) processing areas notapplicable. 6 ultrasound rooms had a facility of storage supply (12%), while 38 ultrasound rooms with percentage of (78%) hadn't a facility of storage supply, and also not applicable in 6 ultrasound rooms (12%).

According to the numbers of the ultrasound rooms in the governmental hospitals in our study they were categorized into four groups according tothe ultrasound rooms numbers , group(A) had four ultrasound rooms, group (B) had threeultrasound rooms,group(C)had two ultrasound rooms and group (D) had one ultrasound room.There were two hospitals in group(A) this means that (8 ultrasound rooms) with percentage of (16%), in group(B) there were three ultrasound rooms in three hospitals this means that (9 ultrasound rooms) with percentage of (18%), group (C) had two ultrasound rooms in seven hospitals this means that (14 ultrasound rooms) with percentage of (28%), and group (D) had one ultrasound room in twenty three hospitals this means that (23 ultrasound rooms) with percentage of (46%).

The Wheelchair facility was accessible in 28 ultrasound rooms with percentage of (78%) and not accessible in 22 ultrasound rooms (44%). According to equipment evaluation data there were one ultrasound probe in 12 ultrasound machines with percentage of (24%),two ultrasound probes in 23 ultrasound machines with percentage of (46%), three ultrasound probes in 11 ultrasound machines with percentage of (22%)and four ultrasound probes in 5 ultrasound machines with percentage of (10%). Standard ultrasound tables were available in 12 ultrasound rooms with percentage of (24%) and not available in 38 ultrasound rooms with

percentage of (78%).The exam table should have a height adjustment for sonographer comfort and ease for patient access(Goldstein, 1980).

While standard ultrasound operator adjustable chair were available in 18 ultrasound rooms with percentage of (36%) and not available in 32 ultrasound rooms with percentage of (64%).From aspect of electrical and mechanical safety and cleanliness the regular maintenance and checkup for ultrasound machines were done in 11 ultrasound machines with percentage of (22%) and were not done in 39 ultrasound machines with percentage of (78%).Ultrasound machines and probes cords and cables were intact in 43 ultrasound machines (86%)and were not intact in 7 ultrasound machines (14%). According to probe handle there were 33 ultrasound probes handled with care and proper way with percentage of (66%) and were not handled with care and proper way in 17 ultrasound probes with percentage of (34%). Also according to transducers intact of crack or delamination there were 41 ultrasound transducers were intact without crack or delamination with percentage of (82%) and with crack or delamination in 9 ultrasound transducers with percentage of (18%).Care of transducer cables. For transducers not in use, the cables should be correctly stowed so that they do not trail on the ground. For transducers in use, some of the cables may trail on the ground; in these circumstances care should be taken when moving the scanner or chair to avoid running over the cable as this is a potential cause of damage(Dudley and Gibson, 2017).

Equipment should be routinely inspected and tested for electrical safety. When transporting ultrasound equipment care should be taken to ensure that transducers, transducer cords, and electrical cords are secured to the machine.

According to ultrasound transducers cleaning, 40 ultrasound transducers were cleaned after each use with percentage of (80%) and were not cleaned after each use in 10 ultrasound transducers were cleaned with percentage of (20%). Also

according to ultrasound monitors cleaning, 36 ultrasound monitors were cleaned after each work day with percentage of (72%) and were not cleaned after each work day in 14 ultrasound monitors were cleaned with percentage of (28%).The ultrasound probes, cables and machine should be cleaned immediately following each study. Ultrasound probes have delicate parts which can be damaged by inappropriate handling so equipment manufacturer guidelines should be followed when cleaning probes and equipment. The cleaning method and level of disinfection for probes will depend on the specifics of the procedures and the nature of tissue encountered. Also according to the ultrasound rooms' dimmer lights, were used in10 ultrasound rooms with percentage of (20%) and weren't used in 40 ultrasound rooms with percentage of (80%).The physical environment where ultrasounds are performed should have adequate room for ultrasound equipment with the ability to control lighting and temperature.If there are windows in the exam room, they should have adjustable coverings to reduce the light and glare on the monitor and to preserve patient privacy(Hediger et al., 2016).

In the view of wheel locks in working condition, there were 35 ultrasound machines wheel locks worked properly with percentage of (70%) and were not worked properly in 15 ultrasound machines with percentage of (30%). Also according to the wheels fastened securely to the ultrasound unit and they rotate easily, there were 30 ultrasound machines fastened securely and rotated easily with percentage of (60%) and not fastened securely and not rotated easily in 20 ultrasound machines with percentage of (40%).Also according to the all accessories (VCR, cameras, etc.) fastened securely to the ultrasound unit, there were 43 ultrasound machines fastened securely with percentage of (86%) and not fastened securely in 7 ultrasound machines with percentage of (14%).Brake and wheel function. If the scanner is used in a single location, then check it for stability (namely that the brakes are holding it securely). If the scanner is moved to various

locations then unlock the brakes and check the system for smooth movement ensuring that there is no pull or drag and that one pair of wheels can be locked in position for ease of steering; then re-engage the brakes at the working position and check the system for stability. Damage should be noted and the responsible person informed (Dudley et al., 2014a).

In terms of practice data the total ultrasound units were categorized into 33 fixed ultrasound machines (66%), 14 fixed mobile ultrasound machines (28%) and 3 mobile ultrasound machines (Vans Change Location) with percentage of (6%). The average number of sonograms performed per month in 2 hospitals were in the range between 101-250 sonograms with percentage of (4%), The average number of sonograms performed per month in 6 hospitals were in the range between 251-500 sonograms with percentage of (12%),The average number of sonograms performed per month in 10 hospitals were in the range between 501-750 sonograms with percentage of (20%) and The average number of sonograms performed per month in 32 hospitals were in the range between 101-250 sonograms with percentage of (64%).According to the ultrasound exams procedures were performed ingroup(A) which included Antepartum OB US, Female Pelvis US, Upper Abdominal US and Renal/Urinary Tract US) had fifty ultrasound rooms with percentage of (100%) ,in group (B) which included Extracranial Carotid US, Transcranial Vascular US, Aorta and Branches US and IVC and Draining Veins US) had performed in eight ultrasound rooms with percentage of (16%) and not performed in forty two ultrasound rooms (84%), group(C) which included Liver Vascular US, Renal Vascular US, had performed in twenty two ultrasound rooms with percentage of (44%) and not performed in twenty eight ultrasound rooms (56%), group (D) which included Peripheral Arterial US and Peripheral Venous US, had performed in six ultrasound rooms with percentage of (12%) and not performed in forty four ultrasound rooms

(88%). group (E) which included Scrotal US and Thyroid US, had performed in thirty five ultrasound rooms with percentage of (70%) and not performed in fifteen ultrasound rooms (30%) and in group (F) which included Transrectal Prostate US and Pediatric Neurosonography US, had performed in five ultrasound rooms with percentage of (10%) and not performed in forty five ultrasound rooms (90%).

In our study the policy for film/image retention was less than 5 years in 37 ultrasound rooms with percentage of (74%), 5years in 9 ultrasound rooms with percentage of (18%), between 6-10 years in 4 ultrasound rooms with percentage of (8%).State record retention regulations vary from state to state and are typically based upon the age of the patient. For example, most of the requirements for record retention for adults are in the range of 5 -11 years. One jurisdiction required 2 years for retention, whereas several required up to 30 years, and one even mandated permanent retention. In the case of minors, the majority of the jurisdictions required a retention period of 7 years beyond the age of majority. The retention requirement for the records of minors varied from 20 to 43 years of age. Again in one case, the film retention requirement for minors was permanent. In the view of reporting procedures in compliance with the ACR Practice Guideline for Communication there were 22 ultrasound rooms applied these guidelines with percentage of (44%), 18 ultrasound rooms were not applied with percentage of (36%) and in 10 ultrasound rooms were not applicable with percentage of (20%). One specific cause of this problem is a gap in communication between the radiologist and technologist. Radiologists often will dictate reports without being aware that the exams have not been completed in theradiology information system (RIS) by technologists. Technologists, in turn, may be unaware that reports have been dictated and, under increasing workflow pressure during a full shift, may postpone the completion of an exam. This problem is exacerbated when

radiologists work remotely or in different institutional areas from technologists, making communication difficult.(Nagy PG, et al., 2008).The Policy on report turnaround time were done in 10 ultrasound rooms with percentage of (20%), were not done in 28 ultrasound rooms (56%) and were not applicable in 12 ultrasound rooms (24%). In the radiology department, optimal minimization of turnaround times for ultrasound examinations reduces the complaints that may arise from the patients undergoing ultrasound examinations (Venus, 2012: 41).According to (Frances, 2009:16), the healthcare providers in the radiology department should ensure that proper instructions regarding patient preparations (e.g. intake of fluids for full urinary bladder in pelvic examinations) are prompt and clear. Instructing patients appropriately can reduce errors, inconvenience, and delays in waiting for both patients and the staff.

The average time from examination to final report being sent to referring physician was Less than 12 hours in 36 ultrasound rooms (72%), between 12 to 24 hours in 11 ultrasound rooms (22%) and between 24 to 72 hours in 3 ultrasound rooms (6%).Strife et al. emphasized the importance of quality care and the need to reduce medical errors in the health care system. This group elaborated on ways in which quality and medical error reduction can be improved, citing the utility of practice quality improvement projects focusing on decreasing turnaround time (the time between completion of the exam and availability of the final report to the referring physician).Other authors have discussed approaches to improved turnaround times for medical reports. Branstetterdescribed ways in which the advent of speech recognition in dictation systems significantly reduced turnaround time for medical reports(Branstetter IV, 2007).

According to the Policies and procedures to ensure confidentiality of patient-related information was applied in 45 ultrasound rooms with percentage of (90%), was not applied in 4 ultrasound rooms with percentage of (8%)andwas not

applicable in 1 ultrasound room (2%). The Mechanism for handling patient complaints was applied in 3 ultrasound rooms with percentage of (6%), was not applied in 44 ultrasound rooms with percentage of (88%)andwas not applicable in 3 ultrasound room (6%). According to QA program include a mechanism for obtaining follow-up on all operated cases was applied in 8 ultrasound rooms with percentage of (16%), was not applied in 42 ultrasound rooms with percentage of (84%)andwas not applicable in any ultrasound room (0%). Also according to Quality assurance program include a mechanism for obtaining outcome data regarding positive sonograms and pathological correlation was included in 14 ultrasound rooms with percentage of (28%), was not included in 34 ultrasound rooms with percentage of (68%)andwas not applicable in 2 ultrasound room (4%).In accordance with the usage of coupling gel was applied in all 50 ultrasound rooms with percentage of (100%).Also according to the coupling gel warmer availabilitywas available in 4 ultrasound rooms with percentage of (8%), was not available in 46 ultrasound rooms with percentage of (92%)andwas not applicable in any ultrasound room (00%).The type of thermal Ultrasound Paper is required by Ultrasound Printersin type of high – end regular paper was used in 6 ultrasound rooms with percentage of (12%), the type of low – end paper was used in 16 ultrasound rooms with percentage of (32%), the type of crap low – end paper was used in 7 ultrasound rooms with percentage of (14%)andwas not applicable in 21 ultrasound rooms with percentage of (42%).According to the identifying demographic data displayed on the image, first and last name of the patient was written in 24 ultrasound rooms with percentage of (48%) andwas not written in 26 ultrasound rooms with percentage of (52%).Medical record number was written in 20 ultrasound rooms with percentage of (40%) andwas not written in 30 ultrasound rooms with percentage of (60%).The Institution name was written in 33 ultrasound rooms with percentage of (66%) andwas not written in 17 ultrasound rooms with

percentage of (34%).The Date and time of examination was written in 45 ultrasound rooms with percentage of (90%) andwas not written in 5 ultrasound rooms with percentage of (10%).The Date of birth or age was written in 44 ultrasound rooms with percentage of (88%) andwas not written in 6 ultrasound rooms with percentage of (12%).The Type of examination was written in 26 ultrasound rooms with percentage of (52%) andwas not written in 24 ultrasound rooms with percentage of (48%). The technologist's identification number, name, or initials to at least one image of the examination was added in 13 ultrasound rooms with percentage of (26%) andwas not added in 37 ultrasound rooms with percentage of (74%).Patient identification should be verified prior to performing ultrasound procedures. The ultrasound images should be labeled with patient identification, facility name or name of physician/sonographer performing the study, date of the study, and type of study.A separate report should be generated that includes the same elements as those on the ultrasound image along with an interpretation of the findings and the name of physician interpreting the study. The report and images should be included in the patient's medical record(Gilbert, 2015).

In our study in the view of Ultrasound Quality Assurance Tasks routinely performed and their frequencies, the Gray Scale Photography routinely performed and its frequency was not done in 36 ultrasound rooms (72%), was done every three months in 4 ultrasound rooms (8%), was done every six months in 7 ultrasound rooms (14%) and was done yearly in 3 ultrasound rooms (6%).Ultrasound equipment should be in good operating condition and undergo routine calibration at least once per year.Equipment manufacturer specifications and guidelines for the maintenance of ultrasound equipment should be followed.

Hard Copy Output Quality Test routinely performed and its frequency was not done in 40 ultrasound rooms (80%), was done every three months in 3 ultrasound

rooms (6%), was done every six months in 5 ultrasound rooms (10%) and was done yearly in 2 ultrasound rooms (4%).Greyscale bar. The monitor should be viewed and adjusted in the same lighting conditions as scanning is performed; ideally lighting should be subdued with no bright light sources or reflections (this also applies to all subsequent tests where the monitor is viewed). The greyscale bar should show peak white at one end and the darkest grey scale at the other (the latter can be checked by increasing brightness to see if further grey steps appear). The monitor background should be black (only just). There should be a continuous gradient from white to black. If this is not the case, adjust the contrast and brightness to achieve this and record the new values as baseline for future reference (Dudley et al., 2014a).

Electrical Safety Cleanlinessroutinely performed and its frequency was not done in 7 ultrasound rooms (14%), was done daily in 4 ultrasound rooms (8%), was done weekly in 2 ultrasound rooms (4%), was done monthly in 16 ultrasound rooms (32%), was done every three months in 13 ultrasound rooms (26%), was done every six months in 3 ultrasound rooms (6%) and was done yearly in 5 ultrasound rooms (10%).Check the date that electrical safety testing is next due (there should be a sticker on the scanner body, or an entry in the service record). If this is due within the next month, or overdue, inform the responsible person who should arrange for testing (Dudley et al., 2014a).

Universal Infection Control Procedure routinely performed and its frequencywas done daily in 5 ultrasound rooms (10%), was done weekly in 22 ultrasound rooms (44%), was done monthly in 12 ultrasound rooms (24%), was done every three months in 2 ultrasound rooms (4%), was done every six months in 3 ultrasound rooms (6%) and was done yearly in 6 ultrasound rooms (12%).

System Sensitivity and /or Penetration capability routinely performed and its frequency was not done in 25 ultrasound rooms (50%), was done every three

months in 8 ultrasound rooms (16%), was done every six months in 10 ultrasound rooms (20%) and was done yearly in 7 ultrasound rooms (14%). Uniformity routinely performed and its frequency was not done in 33 ultrasound rooms (66%), was done every three months in 6 ultrasound rooms (12%), was done every six months in 5 ultrasound rooms (10%) and was done yearly in 6 ultrasound rooms (12%).

Maximal depth of visualization And hard copy recording with Phantom routinely performed and its frequency was not done in 40 ultrasound rooms (80%), was done every six months in 6 ultrasound rooms (12%) and was done yearly in 4 ultrasound rooms (8%). Low Contrast Object Detectability routinely performed and its frequency was not done in 23 ultrasound rooms (46%), was done monthly in 11 ultrasound rooms (22%),was done every three months in 8 ultrasound rooms (16%), was done every six months in 3 ultrasound rooms (6%) and was done yearly in 5 ultrasound rooms (10%).

According to the System Sensitivity ,the maximum depth can be visualize less Than 3cm to 5.5cm in 5ultrasound machines with percentage of (10%),from 6cm to 9cm in 10ultrasound machines with percentage of (20%),between 9.5cm to 12.5cm in 22ultrasound machines with percentage of (44%), from 13cm to16cm in 13ultrasound machines with percentage of (26%).In the view of system uniformity, the average brightness at edge of the scan is the same as the average brightness in the middle was agreed in 25ultrasound machines with percentage of (50%), was disagree, slight non uniformitiespresent in8 ultrasound machines with percentage of (16%) and was disagree, major non uniformities present in 17 ultrasound machines with percentage of (34%).Ultrasound systems can produce various image artifacts and nonuniformities. Image nonuniformities are a problem because they can mask subtle variations in tissue texture and increase the risk of false negatives. Major nonuniformities should be corrected immediately. Even though one can

often ‘‘work around’’ minor nonuniformities, these defects should be seen as a potentially large problem and should also be corrected if consistently present(Hediger et al., 2016).

There were no vertically or radially oriented shadowed from array element dropout wasagreed in 18ultrasound machines with percentage of (36%),was disagree, slight non uniformities present in 23 ultrasound machines with percentage of (46%) and was disagree, major non uniformities present in 9 ultrasound machines with percentage of (18%).There were no brightness transitions between focal zones was agreed in 15ultrasound machines with percentage of (30%), was disagree, slight non uniformities present in 12 ultrasound machines with percentage of (24%) and was disagree, major non uniformities present in 23 ultrasound machines with percentage of (46%). According to Scanner Electronic Image Display Performance was completed in 50 ultrasound machines with percentage of (100%).Also the Primary Interpretation Display Performance was completed in 50 ultrasound machines with percentage of (100%).

Accoring to the Ultrasound Quality Controls Results, Depth Measurements Accuracy (Electronic Calipers), the actual distance 100mm, the measured distance in group(A) was 100mm with error of 00mm in 12 ultrasound machines with percentage of (24%), the measured distance in group(B) was 88mm with error of 12mm in 23 ultrasound machines with percentage of (46%), the measured distance in group(C) was 67mm with error of 33mm in 10 ultrasound machines with percentage of (20%), the measured distance in group(D) was 45mm with error of 55mm in 3 ultrasound machines with percentage of (6%) and the measured distance in group(E) was 30mm with error of 70mm in 2 ultrasound machines with percentage of (4%).

Horizontal Measurements Accuracy(Electronic Calipers), the actual distance 30mm, the measured distance in group(A) was 30mm with error of 00mm in 9

ultrasound machines with percentage of (18%), the measured distance in group (B) was 25mm with error of 5mm in 14 ultrasound machines with percentage of (28%), the measured distance in group (C) was 15mm with error of 15mm in 22 ultrasound machines with percentage of (44%), the measured distance in group (D) was 8mm with error of 22mm in 5 ultrasound machines with percentage of (10%).

Depth of penetration (4MHz)(Electronic Calipers), the Baseline Distance150mm, the measured distance in group(A) was 150mm with error of 00mm in 6 ultrasound machines with percentage of (12%), the measured distance in group (B) was 135mm with error of 15mm in 11 ultrasound machines with percentage of (22%), the measured distance in group (C) was 117mm with error of 33mm in 8 ultrasound machines with percentage of (16), the measured distance in group (D) was 100mm with error of 50mm in 5 ultrasound machines with percentage of (10%) and the measured distance in group (E) was 77mm with error of 73mm in 9 ultrasound machines with percentage of (18%), the measured distance in group(F) was 58mm with error of 92mm in 6 ultrasound machines with percentage of (12%), the measured distance in group(G) was 36mm with error of 114mm in 4 ultrasound machines with percentage of (8%), the measured distance in group(H) was 20mm with error of 130mm in 1 ultrasound machine with percentage of (2%).

In accordance to Image Uniformity, there were 6 ultrasound machines Significant Nonuniformity with percentage of (12%), 5 ultrasound machines were gooduniformity

with percentage of (10%),18 ultrasound machines were better uniformity with percentage of (36%), 13 ultrasound machines were best uniformity with percentage of (26%), and 8 ultrasound machines were Excellent Uniformity with percentage of (16%).

In Gray Bars, the number of gray bars visible on baseline 15mm, the number of gray bars visible in group(A) was 15mm with error of 00mm in 13 ultrasound

machines with percentage of (26%), the number of gray bars visible in group (B) was 13mm with error of 2mm in 12 ultrasound machines with percentage of (24%), the number of gray bars visible in group (C) was 10mm with error of 5mm in 14 ultrasound machines with percentage of (28), the number of gray bars visible in group (D) was 7mm with error of 8mm in 6 ultrasound machines with percentage of (12%) ,the number of gray bars visible in group (E) was 3mm with error of 12mm in 3 ultrasound machines with percentage of (6%) and the number of gray bars visible in group (F) was 1mm with error of 14mm in 2 ultrasound machines with percentage of (4%). According to Low-Level echoes displayed,All echoes displayed on viewing monitor also seen on film in 23 ultrasound machines with percentage of (46%) and was not displayed in 27 ultrasound machines with percentage of (54%). Also according to Level of agreement between contrast and brightness on viewing monitor and film, Contrast and brightness was poor in 6 ultrasound machines with percentage of (12%), was good in 5 ultrasound machines with percentage of (10%), was better in 18 ultrasound machines with percentage of (36%), was better in 13 ultrasound machines with percentage of (26%) and was Excellent in 8 ultrasound machines with percentage of (16%).Finally, according to Filters situation (Clean or Dusty). They were clean in 18 ultrasound machines with percentage of (36%) and they were dusty in 32 ultrasound machines with percentage of (64%). Inspect the dust filters. They should be clean and free of lint and clumps of dirt. Dirty filters cause over- heating which shortens the life of electronic components. Whoever is responsible should clean or replace the filters at regular intervals (Hediger et al., 2016).

5.2 Conclusion:

Ultrasound imaging is a powerful non-invasive diagnostic tool which is often preferred in imaging modality because of its ability to provide continuous, real

time images without the risk of ionizating radiation and at lower cost. The final image of the Ultrasound image scanner is the basis for diagnostic decision. Hence the quality of the scanner should be of the highest quality. However like all other imaging modalities ultrasound imaging is subjected to a number of artifacts that degrade the image quality.

In a busy hospital environment so many clinical decisions are based on B-mode parameter measurements that it is important to undertake regular and accurate QA testing appropriate to the clinical application.

Ultrasound scanners are extremely complex imaging devices and developing clinically relevant performance tests is a challenge. Consequently, ultrasound quality assurance has been in a state of evolution for many years. Today, a convergence of philosophies, combined with gained experience, is beginning to be noted. It remains our responsibility as sonologists to promote and improve the practice of ultrasound quality assurance testing. As interest and enthusiasm increases in the physics community, refinement and proliferation of quality assurance tests will continue. With proliferation of testing, the benefits of performance testing will become more widespread and will eventually lead to a standard practice of quality assurance in ultrasound departments. As professionals in the healthcare environment, our ultimate goal is to improve patient care, and assuring that adequate and appropriate diagnostic ultrasound image quality is achieved and maintained directly serves that purpose.

We recommend that match data be obtained where it is practical to do so for US QA purposes, but if this is not feasible, measurements from mixed scanner-transducer combinations may be obtained, especially if QA program efficiencies may be obtained.

It is recommended that equipment operators implement quality assurance measures to maintain the capability of obtaining reliable diagnostic information at acoustic

exposures which are **As Low As Reasonably Achievable**. Guidance on quality assurance methods can be found in several documents, including Guidelines of the Canadian Society of Diagnostic Medical (CSDMS 1998), as well as publications of the American Institute for Ultrasound in Medicine (AIUM 1991, AIUM 1995a, AIUM 1995b).

As the quality of diagnostic information depends, in part, on operator training, it is also recommended that sonographers (ultrasound technologists) be appropriately qualified and registered with either the Canadian Association of Registered Diagnostic Ultrasound Professionals (CARDUP) or the American Registry of Diagnostic Medical Sonographers (ARDMS).

The tested methods produced partly complementary results and seemed all to be necessary. Thus a quality assurance protocol is forced to be rather labored, and therefore the benefits and costs must be closely followed.

Ultrasound QA offered benefits in optimizing the quality of US scanners for patient studies and managing the diverging equipment. The methods studied in this work – transducer tests, phantom measurements and visual checks for physical faults – produced partly complementary results and seemed all be necessary for the QA of US scanners. This means that a QA protocol is forced to be rather labored, including several professional groups. Therefore, the impact of the QA protocol must be closely followed and, if necessary, the protocol revised.

The American College of Radiology (ACR) strongly recommends that the training for “appropriately trained sonographers or service engineers” conducting routine QC be provided by a qualified medical physicist.

If unable to acquire training by a qualified medical physicist, training can be achieved through the ultrasound equipment manufacturer or through an appropriate course.

It has been increasingly recognized that quality assurance programs directed at equipment and operator performance can be of great value in improving the diagnostic information content, reducing radiation exposure, reducing medical costs, and improving departmental management. Quality assurance programs thus contribute to the provision of high quality health care.

In conclusion, we have defined standards for US scanner phantom images that will be used in performing screening examinations for ultrasound equipment in Khartoum State. This is the first step toward establishing a standardized US QA test, and validation of these standards should be performed in an upcoming nationwide survey of all US scanners in Sudan.

5.3 Recommendations:

- Establishing the quality assurance units in each ultrasound department in the hospitals at Khartoum State.
- Work with someone who users the ultrasound equipment on a regular basis - better still, coordinate with an applications person from the vendor.
- Use identical settings each time the unit is evaluated - failure to do this will produce little confidence in your results.
- Learning how to do Quality assurance tests and doing it develops experience and expertise for the physicist and sonologists.
- Greater communication with technical staff in the Radiology department as well as other departments.
- Increased interaction with biomedical/clinical engineers.
- Accreditation push is on! General scrutiny of imaging QC from radiation "incidents" and US is getting swept in with other modalities.
- Check the scanner for any visible damage such as cracks to the casing or damage to control buttons and the keyboard or screen.
- Check the integrity of the mains cable and, if present, power transformer. Make sure there are no breaks in the cable outer insulation and in particular that there is no kinking or breaks in the cable at the point where it joins the mains plug, transformer or back of the ultrasound machine. If any damage is identified the machine must be removed from service and the fault reported.
- Check the integrity of the transducer cable and transducer head. This includes breaks in the cable or damage, cracks or splits in the latex lens surface of the transducer face. If damage is identified, the scanner must be taken out of service or the transducer swapped.
- When the scanner is switched on look for any error messages or obvious abnormalities such as a flickering screen or excessive noise in the image that might indicate a problem.
- A log of faults, actions and outcomes should be recorded and retained by the local screening program.
- It is important that equipment checking and testing monthly, every three months, every six months and annually.
- We recommend that match data be obtained where it is practical to do so for US QA purposes, but if this is not feasible, measurements from mixed scanner-transducer combinations may be obtained, especially if QA program efficiencies may be obtained.

- It is important that equipment checking and testing logs are kept up to date and maintained as local programmes may be called upon to provide these as evidence that appropriate checking processes have been undertaken and acted upon, as part of the ongoing quality assurance programme.
- We recommended that annual assessment of the systems is performed by the regional medical physics department by a trained specialist or by the equipment manufacturer as part of preventative maintenance using an appropriate test object.
- It is recommended that all ultrasound machines have maintenance contracts in place that ideally provide preventative maintenance visits on an annual basis.
- We recommended further and continuous studies in US QA Programs.

References:

BRANSTETTER IV, B. F. 2007. Basics of imaging informatics: part 2. *Radiology,* 244**,** 78-84.

BRENDEL, K., FILIPCZYNSKI, L., GERSTNER, R., HILL, C., KOSSOFF, G., QUENTIN, G., REID, J., SANEYOSHI, J., SOMER, J. & TCHEVNENKO, A. 1977. Methods of measuring the performance of ultrasonic pulse-echo diagnostic equipment. *Ultrasound Med Biol,* 2**,** 343-350.

CHOI, J. I., KIM, P. N., JEONG, W. K., KIM, H. C., YANG, D. M., CHA, S. H. & CHUNG, J. J. 2011. Establishing cutoff values for a quality assurance test using an ultrasound phantom in screening ultrasound examinations for hepatocellular carcinoma: an initial report of a nationwide survey in Korea. *J Ultrasound Med,* 30**,** 1221-9.

CIVALE, J., RIVENS, I. & TER HAAR, G. 2015. Quality assurance for clinical high intensity focused ultrasound fields. *Int J Hyperthermia,* 31**,** 193-202.

DUDLEY, N., GRIFFITH, K., HOULDSWORTH, G., HOLLOWAY, M. & DUNN, M. 2001. A review of two alternative ultrasound quality assurance programmes. *European journal of ultrasound,* 12**,** 233-245.

DUDLEY, N., RUSSELL, S., WARD, B. & HOSKINS, P. 2014a. BMUS guidelines for the regular quality assurance testing of ultrasound scanners by sonographers. *Ultrasound,* 22**,** 8-14.

DUDLEY, N., RUSSELL, S., WARD, B., HOSKINS, P. & PARTY, B. Q. W. 2014b. BMUS guidelines for the regular quality assurance testing of ultrasound scanners by sonographers. *Ultrasound,* 22**,** 8-14.

DUDLEY, N. J. & GIBSON, N. M. 2017. Is Grey Level a Suitable Alternative to Low-Contrast Penetration as a Serial Measure of Sensitivity in Computerised Ultrasound Quality Assurance? *Ultrasound Med Biol,* 43**,** 541-545.

GILBERT, B. R. 2015. *Ultrasound of the male genitalia*, Springer.

GOLDSTEIN, A. 1980. *Quality assurance in diagnostic ultrasound: a manual for the clinical user*, US Dept. of Health and Human Services, Public Health Service, Food and Drug Administration, Bureau of Radiological Health.

GOODSITT, M. M., CARSON, P. L., WITT, S., HYKES, D. L. & KOFLER, J. M. 1998. Real-time B-mode ultrasound quality control test procedures. Report of AAPM Ultrasound Task Group No. 1. *Med Phys,* 25**,** 1385-1406.

HEDIGER, M. L., FUCHS, K. M., GRANTZ, K. L., GREWAL, J., KIM, S., GORE-LANGTON, R. E., BUCK LOUIS, G. M., D'ALTON, M. E. & ALBERT, P. S. 2016. Ultrasound Quality Assurance for Singletons in the National Institute of Child Health and Human Development Fetal Growth Studies. *J Ultrasound Med,* 35**,** 1725-33.

HEDRICK, W. R., HYKES, D. L. & STARCHMAN, D. E. 2005. Ultrasound physics and instrumentation.

HOSKINS, P. R., MARTIN, K. & THRUSH, A. 2010. *Diagnostic ultrasound: physics and equipment*, Cambridge University Press.

KOFLER, J. M. & MADSEN, E. L. 2001. Improved method for determining resolution zones in ultrasound phantoms with spherical simulated lesions. *Ultrasound Med Biol,* 27**,** 1667-1676.

LEE, D., KIM, Y. S. & RA, J. B. Automatic time gain compensation and dynamic range control in ultrasound imaging systems. Proc. SPIE Med. Imag, 2006. 614708-614708.

MERZ, E. & BATZEL, A. 2009. Quality assurance in ultrasound diagnostics--where are we at the end of 2009? *Ultraschall Med,* 30**,** 525-7.

NAGY, P. G., PIERCE, B., OTTO, M. & SAFDAR, N. M. 2008. Quality control management and communication between radiologists and technologists. *Journal of the American College of Radiology,* 5**,** 759-765.

PAPP, J. 2014. *Quality Management in the Imaging Sciences-E-Book*, Elsevier Health Sciences.

SIMPSON, C. Ø. 2009. *Objective image quality metrics for ultrasound imaging.* Institutt for elektronikk og telekommunikasjon.

SIPILÄ, O., MANNILA, V. & VARTIAINEN, E. 2011. Quality assurance in diagnostic ultrasound. *Eur J Radiol,* 80**,** 519-525.

SLADE, M. G. & SLADE, G. C. 2011. Quality assurance in endobronchial ultrasound. *Thorax,* 66**,** 354; author reply 354.

THIJSSEN, J., VAN WIJK, M. & CUYPERS, M. 2002. Performance testing of medical echo/Doppler equipment. *European journal of ultrasound,* 15**,** 151-164.

THIJSSEN, J. M., WEIJERS, G. & DE KORTE, C. L. 2007a. Objective performance testing and quality assurance of medical ultrasound equipment. *Ultrasound Med Biol,* 33**,** 460-471.

THIJSSEN, J. M., WEIJERS, G. & DE KORTE, C. L. 2007b. Objective performance testing and quality assurance of medical ultrasound equipment. *Ultrasound Med Biol,* 33**,** 460-71.

TOME, W. A. & ORTON, N. P. 2008. Quality assurance of ultrasound imaging systems for target localization and online setup corrections. *Int J Radiat Oncol Biol Phys,* 71**,** S53-6.

TRADUP, D. J., HANGIANDREOU, N. J. & TAUBEL, J. P. 2003. Comparison of ultrasound quality assurance phantom measurements from matched and mixed scanner-transducer combinations. *J Appl Clin Med Phys*, 4**,** 239-47.

ÜSTÜNER, K. F. & HOLLEY, G. L. Ultrasound imaging system performance assessment. AAPM Annual Meeting, 2003.

VITIKAINEN, A. M., PELTONEN, J. I. & VARTIAINEN, E. 2017. Routine Ultrasound Quality Assurance in a Multi-Unit Radiology Department: A

Retrospective Evaluation of Transducer Failures. *Ultrasound Med Biol,* 43**,** 1930-1937.