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Study of the effects of posture on the volume of abdominal and pelvic organs using Ultrasonography

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Dedication

To

My Teachers and My Family

Declaration:

I Certify that this thesis submitted for the degree of Master is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any other university institution.

Signed

Jessica Salim Jeries Badawi

Date: 1 6 /05 /2024

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Abstract

Study of the human body organs sizes and their clinical positions is of particular importance in different clinical applications including diagnostics and therapeutical. This kind of studies is important in the investigation of anthropometrical characteristics of populations as well. This thesis deals with the determination of dimensions and volumes of organs of healthy adult people in the abdominal and pelvic regions using Ultrasonography (USG) in supine and sitting postures and investigate the change in organ volume between the two postures.

Twenty healthy participants (subjects) were investigated in the study 11 females and 9 males. The age of all subjects ranged from 30 and 70 years with different body mass indexes. The average body mass index of females was 25.56 ± 1.49 kg/m^2 and of males was 26.32 ± 1.55 kg/m^2.

Prior to the measurement of organs sizes by USG, a pilot study was conducted on two subjects; female and male to check the consistency of USG modality with Magnetic resonance imaging technique (MRI) which is considered the golden standard for evaluation of body organ dimensions. Both the organs span and volume of the two subjects involved in the pilot study were determined by the MRI and USG techniques in supine and sitting positions according to standard protocols. The organs investigated were; liver, spleen, right and left kidneys, ovaries, prostate, urinary bladder, gall bladder and testicles all in supine position.

Statistical analysis of results of all organs measurements of the two subjects including graphical presentations, normal probability plots of the difference between the two techniques, Bland-Altman analysis confirmed a strong correlation between MRI and USG in the determination of organs dimensions (spans and volumes). As example correlation coefficient between MRI and USG in measuring female abdominal and pelvic organs spans in supine was 0.99. Mean difference (bias) was about 0.0012, the lower CI at 95% confidence level was – 0.33, upper CI at 95% confidence level was 0.33. compatible results were also obtained for the male in pilot study.

Volumes of organs were calculated from the measured dimensions (AP, Length and Transverse) assuming ellipsoidal shape of the organs. Calculated volumes for the pilot study subjects were compatible with the values published in literature. Comparison between liver volume calculated in the pilot study and by using Child's equation considered the most accurate for estimating liver volume using 2D Ultrasound was in very good agreement (difference of about 0.6%). All measurements in sitting position were conducted by USG only on a folding chair specially constructed for the purpose of this study. Mean splenic span for all females in supine position was 10.18 ±0.95 cm, in sitting position 10 ± 0.7 cm; for males 12.34 ± 1.71 cm in supine position and 11.72 ± 1.69 cm in sitting position. The average decrease in organs span varies between organs from about 7% for spleen to about 16% for left ovary. There was statistically significant difference between the span of organs measured in supine and sitting positions. Two tailed t-tests were used to analyze the difference in the spans of organs between supine and sitting positions at 95% confidence level.

For all organs, in no case, the volume of any organ in sitting position was equal or greater than that in supine position and the average decrease in volume between supine and sitting positions for all investigated organs was about 28%. To analyze the differences in organ volume between supine and sitting positions, paired t-tests (two-tailed) as well as Wilcoxon Signed rank were used for different organs separately for males and females and also for main organs together for both genders (for liver, spleen, right kidney and left kidney). For individual organs as well as for the main four organs also Wilcoxon Signed rank (the non-parametric version of the paired t-test) tests were used. The two tests gave similar results. For female right kidney volume difference, the two tailed p-value was 0.00001, for males liver volume the p-value was 0.0008. For female spleen volume differences analysis between supine and sitting positions p-value was $1.3x10^{-5}$. For differences analysis in volumes including four main organs mentioned above (n=80 all the 4 organ volumes of all participants) a paired two tailed t-test and Wilcoxon signed rank test both gave a p-value < 0.00001. Both tests indicate a strong statistically significant difference in volumes 95% confidence level. The differences in organ spans and volumes between supine and sitting positions are statistically significant and therefore can be detected by Ultrasonography.

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Abbreviations:

AQU: Al-Quds University

BMI: Body Mass index

CT: Computed Tomography

CPU: Central Processing Unit

DR: Digital radiography

DNA: Deoxyribonucleic acid

EIT: Electrical impedance tomography

GB: Gallbladder

LT: Left

MRI: Magnetic resonance imaging

MSCT: Multi-slice computed tomography

MDCT: Multidetector computed tomography (MDCT)

MHz: Mega Hertz

OCT: Optical coherence tomography

PET: Positron emission tomography

POP: Pelvic organ prolapse

R: Pearson product-moment correlation coefficient

RT: Radiation Therapy

RT: Right

UB: Urinary Bladder

USG: Ultrasonography

Z: Acoustic impedance

2D: Two Dimensions

3D: Three Dimensions

Definition

Computed Tomography: A computerized x-ray imaging procedure in which a narrow beam of x-rays is aimed at a patient and quickly rotated around the body, producing signals that are processed by the machine's computer to generate cross-sectional images, or "slices.

Contrast Resolution: The ability to distinguish between different echo amplitudes of adjacent structures

Claustrophobia: The irrational fear of confined or close spaces

Dyspnea: Shortness of breath

Dose: The radiation delivered to the whole human body or to a specified area or organ of the body. This term is used frequently in whole body counting applications.

Diabetes: Elevated levels of blood glucose

Electrical impedance tomography: Imaging technique that reconstructs images of a specific region in the human body based on the electrical conductivity of biological tissue.

Hypertension: The pressure in your blood vessels is too high

Ionization: The process by which an electrically neutral atom acquires a charge (either positive or negative).

Magnetic Resonance Imaging: is a medical imaging technique that uses a magnetic field and computer-generated radio waves to create detailed images of the organs and tissues in your body.

Nuclear Medicine: Medical specialty that uses radioactive tracers (radiopharmaceuticals) to assess bodily functions and to diagnose and treat disease

Nephrectomy: Surgical removal of one or both of the kidneys.

Positron emission tomography: Type of nuclear medicine procedure that measures metabolic activity of the cells of body tissues

Proton Therapy: Radiation treatment that precisely delivers a beam of protons to disrupt and destroy tumor cells

Radiation Therapy: Type of cancer treatment. This treatment uses beams of intense energy to kill cancer cells and shrinks tumors.

Spatial Resolution: The ability of the ultrasound system to detect and display structures that are close together

X-Ray: A penetrating form of electromagnetic radiation emitted during electron transitions in an atom to a lower energy state; usually when outer orbital electrons give up some energy to replace missing inner orbital electrons

Chapter I

1.1 Introduction

Over the past 50 years, medical imaging has made significant progress in medicine with the development of various modalities such as Radionuclide imaging, Ultrasonography, Computed tomography (CT), Magnetic resonance imaging (MRI), and Digital radiography (DR). This has established medical imaging as an important tool in patient management, particularly in radiologic diagnosis. (Doi, 2006). Indeed, diagnostic imaging plays a critical role in healthcare, serving as a fundamental asset for timely diagnosis, disease staging, and management, as well as for treatment choice, planning, guidance, and follow-up.(Van Sloun et al., 2020) .

Ultrasonography is a medical imaging modality which its very popular and widely used in medicine. Primarily it was mainly used to visualize organs and looking for visible pathology such as tumours, but recent advances have opened a whole range of new possibilities due to numerous and extensive advantages; it is safe, non-invasive, does not involve radiation, cheap, widely available in almost all the centres and hospitals and it has high spatial and contrast resolution(Wilson et al., 2009). Nevertheless, the disadvantages in the ultrasonography that it may be subject to image impairment due to excessive abdominal fat and gas bubbles, the technique is relatively user dependent and the high-density tissue such as bone reflects ultrasound waves to such a degree that underlying tissues are impossible to visualize (Steinsvik et al., 2021)

Ultrasound physics refers to acoustic energy with a frequency above human hearing, Diagnostic sonographic scanners use a frequency range of 2 to 18 megahertz, much higher than human hearing. The higher frequencies create smaller wavelength for detailed sonograms. Ultrasound is a diagnostic imaging technique that visualizes body structures like tendons, muscles, organs and it is effective for imaging soft tissues, then the sonographers use a hand-held probe called a transducer with water-based gel to couple the ultrasound between the transducer and patient. This transmission technology is based on distinguishing the tissues with different absorbance of ultrasound. Due to different absorption of ultrasound images provides internal structure that consists of a mosaic of lighter and darker places. (Steinsvik et al., 2021)

In medicine, the determination of volume measurement of an organ or a tumour in the diagnostic radiotherapy is crucial important, particularly in following the evolution of a disease. In most cases, examination of a patient's abdomen includes an estimation of liver and spleen size, assessment of possible urinary bladder distension, and prostatic size in males. However, it is well known that clinical estimates of organ volumes based solely on physical examination are grossly inaccurate. Accordingly, there is a need for methods of examination which permit calculation of organ volume with sufficient more accuracy and precision, and at the same time be rapid, inexpensive and cause little discomfort to the patient. The simplest method of calculating the volume of an organ is based on the multiplication of three diameters perpendicular to each other, often adjusted by a suitable constant (Carovac et al., 2011). Every part of the human body of interests has physical characteristic depending on organ or soft tissue composition (Gilja et al., 1999) and the human body can determine based on weight height shapes and dimeters of the body part of interest.

Many studies in medicine are related to the examination of the geometrical properties of an organ. In these studies, statistical analysis consists of the quantitative or qualitative measurement of given values; for example, recently a given organ appearance or shape has been used as the input data for the development of imaging techniques (Slice, 2005) Volume, size and density measurements of human body organs or tumors present in the body are of particular importance mainly in following the evolution of disease. A multitude of medical conditions are associated with changes in volume and size of these organs. For instance, infectious, hematologic, or metabolic conditions may result in an increase in the size of the spleen. Kidney dimensions may change in correlation with the severity of the renal pathology involved (Caglar et al., 2014; Heuck et al., 1987).

Treatments in radiotherapy in the seated position are a cost-effective solution for proton therapy centres. The treatment positions are limited to prone or supine patient orientations. Planners can modify beam direction through a combination of gantry angle or couch rotation. The existing features are supplemented with an option to have patient support to be on a chair, or an additional patient treatment option of sitting. These additional features could be configured to have a seamless workflow for seated position radiotherapy. Along with other advanced capabilities offered such as Monte Carlo dose calculations for proton therapy. Chair-based treatments may also be needed for some patients who cannot tolerate lying flat either due to cancer or other underlying condition(Gani et al., 2018)

In radiotherapy as image guided therapy mainly, in proton therapy the positioning and immobilization system must maintain well defined postures of the patient and counteract the tendency of patients to slouch due to the gravitational pull and the onset of relaxation using these current clinical devices for immobilization in sitting. Non -traditional proton therapy suggests irradiating patients in sitting position instead of supine to minimize the cost and the use of gantries. A patient chair with a soft immobilization device attached to it, while providing accuracy positioning of the patient, to provide access to the breast region while preventing slouching motion of the patient in sitting position.(Buchner et al., 2020)

To examine abdominal organ location, morphology, and rib coverage variations between supine and seated postures. It is typical to use medical image data from one image modality, often in the supine position, to develop full body finite element models, despite the fact that the models themselves are often designed to represent seated or standing occupants. Studies have been conducted to examine the effects of posture on organ morphology and the relative position of surrounding vertebral bodies. Studies showed that postural changes do affect the location and morphology of organ. The results from this study provide evidence that organ location, exposure displacement, and morphology are affected by postural changes, which is important in prediction injury or treatments mechanisms. Via computational models that accurately reflect organ position and morphology changes with posture, this will lead to increased knowledge of how blunt injury and the treatment influenced by location and morphology variations.(Maes et al., 2020)

Radiation therapy is a form of treatment using radiation directly or indirectly (through oxygen radicals) that hit the DNA and thereby destroy the tumour cells. Proton radiation therapy is generally considered as the most advanced and precise form of radiation therapy. Proton therapy has a substantial physical advantage over conventional cancer radiation treatment with X-rays. It reduces the radiation dose to healthy tissues and therefore the toxicity and side effects to the patients. The suggestion is to change the model by precisely moving a patient relative to a fixed proton beam rather than moving the beam relative to the patient. This requires a strong immobilization device to ensure that the patient's body position remains accurate during movement.(Buchner et al., 2020)

Cancer treatment using ionizing radiation (radiation therapy) has been witnessing a very rapid development in recent years providing curative and palliative intent management for a wide range of tumours. Medical imaging modalities are playing critical role in helping to achieve this development. Currently, Ultrasonography imaging is used for target localization and verification of prostate, gynecological, breast and other treatment sites (Kim et al., n.d.; Thariat et al., 2013)

Establishing a suitable treatment position to enable the delivery of a therapeutic radiation dose while respecting tolerances of healthy surrounding organs is a fundamental step in the planning process of radiation therapy (RT). Patient positioning and stabilization has significantly evolved since the early use of this modality, facilitating tighter margins, and higher doses (Verhey, n.d.). In conventional Radiotherapy, most patients are positioned on a treatment couch, treated by gantry-mounted photon/electron linear accelerators. An alternative is to have patients sit in an upright treatment position in a treatment chair. Treating patients in a sitting position offers potential benefits in terms of patient comfort especially for patients experiencing dyspnea and saliva accumulation when lying down as well as dosemetric benefits from changing the volume and location of some body organs. Moreover, gravitational changes afforded with sitting positioning may prove beneficial for the irradiation of certain tumour volumes and critical organs at risk (Rahim et al., 2020)

Radiotherapy is an imaging guided treatment modality; the dose distribution is well known for supine position based on the use of existing imaging modalities which are exclusively used in this position. In traditional proton therapy, patients are typically treated in a supine position. However, recent advancements suggest treating patients in a sitting position for reasons that are more optimistic, reducing costs, reducing machine weight by eliminating the gantries and for the comfort of patients during treatments especially for patients who cannot lying on their back due to different diseases. These studies support this huge development to know how changing the patient position from supine to seated position, will cause a translation in organ volume and dimensions under the influence of gravity.

1.2 Application and role of medical imaging modalities in the study of human body morphology

Medical imaging modalities defined as a various techniques and technologies used to create visual representations of the human body for disease diagnosis and treatment purposes. In the last few years, we have seen a good deal of research to further improve the efficacy and image quality of many existing medical imaging modalities including X-ray, CT, MRI, Ultrasound, Nuclear medicine, Cardiovascular imaging, Electrical impedance tomography (EIT), and Positron emission tomography (PET). Therefore, Medical imaging is a very essential tool in the diagnosis and treatment of various diseases.(S. K. M. S. Islam et al., 2023)

Imaging techniques have revolutionized the study of morphology and anatomy, enabling scientists and researchers to explore the intricate details of living organisms in ways never before possible. From traditional X-rays to advanced imaging modalities like MRI and Optical coherence tomography (OCT), these techniques have opened new frontiers in our understanding of the human body, as well as the anatomy. The continuous development of imaging technology promises even greater advancements in the future, leading to more accurate diagnoses, improved treatments and deeper insights into the world of morphology. These imaging tools have significantly contributed to our understanding of the complicated forms and structures that shape the natural world, encourage new discoveries and insights into the field of morphology.(Gordon, 2023)

To determine the volume and morphology of various organs, it is crucial to select a suitable technique. Thus, knowledge of the four common modalities is required in order to compare them and identify the suitable modality for the patient that carries minimal amount of risk with high comfort.

X-ray imaging uses radiation to create detailed images of internal structures, such as bones and organs. Digital systems make the process more efficient, aiding in diagnosing fractures. CT scanning, or Computed Tomography, uses X-rays and computer processing to create detailed body images. It offers 3D views for precise analysis and is commonly used in medical diagnostics. MRI uses magnets and radio waves to create detailed images of soft tissues and organs. It measures hydrogen atom response in cells to produce high-quality images for studying the brain, spinal cord, and musculoskeletal system. Sonography, or ultrasound imaging, uses high-frequency sound waves to create real-time images of internal structures by emitting sound waves and analyzing echoes. Widely used in various medical fields.(Gordon, 2023)

In general, these modalities should primarily consider ionizing radiation, availability, cost, and comfort as key factors. The Ultrasound modality is safe does not cause any adverse health effects to the participants or patients recruited, it is widely utilized and accessible in almost all facilities, have a small machine size comparable to other modalities, and it is eliminating the concerns for claustrophobia in contrast to other modalities like MRI or CT.

In this study, liver volume estimation is considered as an integral part in preoperative evaluation in patients undergoing liver transplantation; computed tomography and magnetic resonance imaging are considered the gold standard methods for liver volume estimation, and both are reliable and valid in determination of liver volume via manual and semi-automated methods. Reliable and accurate set of three simple measurement planes using two-dimensional ultrasound for volumetric assessment of liver was determined, and predictive equation using these three simple measurements were performed, which is simple to perform and easy to calculate, in order to evaluate liver volume and validate these measurements against CT images. This study aimed to evaluate the efficacy and validity of two-dimensional ultrasound in liver volume estimation compared to CT. Computed tomography (CT) has been widely used for volumetric assessment of the liver, magnetic resonance imaging (MRI) and ultrasound also, and has shown trustable organ volume measurements in light of appropriate scanning protocols.

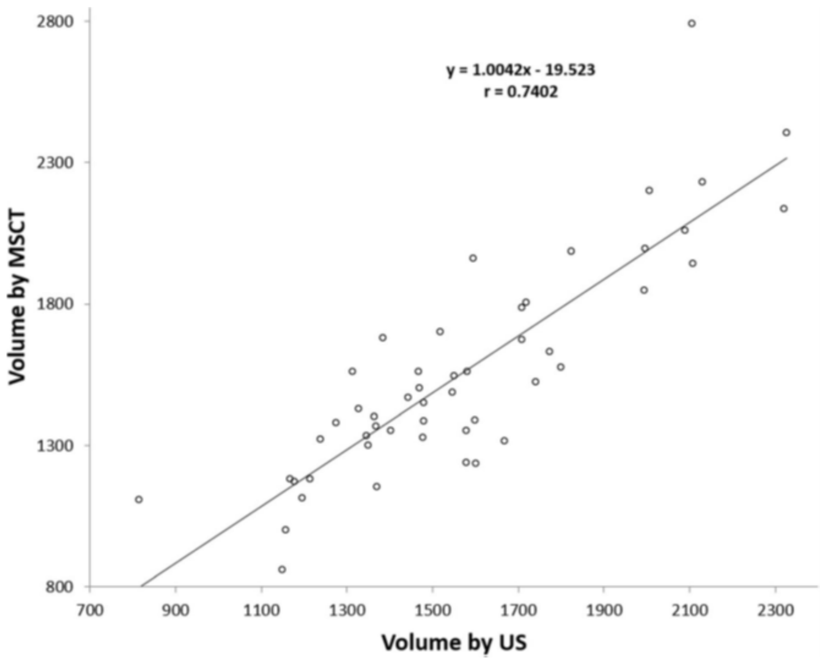

Figure 1.1: Scatter plot diagram is showing correlation coefficient between US and semi-automated CT volumetry with strong positive correlation(Farghaly et al., 2019)

In this study they found that simple linear 2D U/S could be an efficient, accurate, and trustable method for liver volume measurement in clinical practice in the evaluation of linear association with the Pearson product-moment correlation coefficient (r) (which measures the strength and direction of the linear relationship between two variables on a scatter plot) by comparing the results obtained by U/S volumetry with semiautomated multi-slice computed tomography (MSCT) volumetry as gold standard, found that the value of r was 0.7402 as showed in fig 1.1 which means strong linear positive correlation between them.(Farghaly et al., 2019)

Kidney volume measurements are generally preferred as the basis for decisions concerning renal disease and are regarded as surrogates for renal function. Measurement of kidney volume with US is a simple and non-invasive method (Bakker et al., n.d.). Kidney volume is more of an approximation of size than length because the shape of the kidney varies considerably. It is also an excellent indicator of renal function and correlates very well with body indexes (Widjaja et al., 2004).

Shin et al. measured volume in the Korean population using multidetector computed tomography (MDCT) (Shin et al., 2009). The advantage of using MDCT is that the shape of the kidney is irrelevant. However, it is ionizing, potentially nephrotoxic because of the use of contrast media and is not particularly practical. Cheong et al. measured kidney volume and kidney length using magnetic resonance imaging (MRI) (Cheong et al., 2007a). However, MRI is expensive and time consuming and is not widely available for daily clinical practice in most countries. US is the most widely used imaging method for kidney measurements(Jones et al., 1983). It is cheap, fast, and easily available. US is useful in renal disease assessment because of its low cost and the short examination time involved. Measurement of kidney dimensions using US was investigated by Dixit et al (Rath, 1994). In this study they used US to measure kidney volume in a Turkish population.

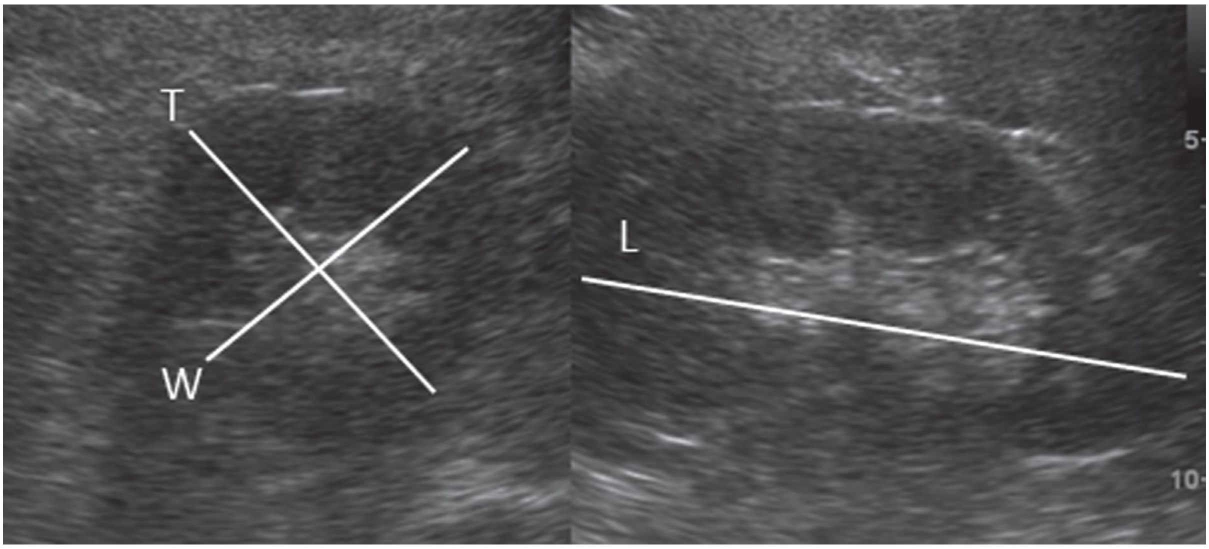

Figure 1.2: Measurement of total kidney volume on the US image. T indicates thickness, W, width; L, length.(Okur et al., 2014)

Measuring ovarian volume has been suggested as a possible screening test to assess a woman's ovarian reserve. For such a screening tool to be clinically useful, knowledge of its precision and reproducibility is essential. Recent advances in ultrasound scanning techniques allow the measurement of volumes in three dimensions. This study adds to the understanding of the role of ovarian volume measurement in reproductive medicine. It has confirmed that the measurement of ovarian volumes leads to high inter- and intra-class correlation. This has important implications for clinical practice, and may explain inconsistencies in the literature for studies in which the measurement of ovarian volume is an important factor.(Brett et al., 2009)

1.3 Motivation of study

This research is interested in the study of some anthropometrical characteristics of Palestinian population and volume measurements for the internal organs in different positions which it's the first of kind in our country where researches and students will be exposed to a new filed of research and it could be a starting point for a large-scale investigation**.**

1.4 Aims and goals of the study

This study has several goals:

1. Evaluation the volume of the internal body organs for abdomen and pelvis organs.
2. Estimate how the posture affects on body organs morphology, volume between supine and sitting.
3. Check the validity of ultrasound comparable with MRI which is the gold standard technique modality to calculate the volume for abdomen and pelvis organs.
4. Evaluate the compatibility of ultrasound for the study of some anthropometrical characterization of Palestinian population.

1.5 Thesis Outline

The next chapter will discuss the ultrasound as alternative method that used in this study with its use and limitations. chapter 3 will be described in details which associated sample population, the experimental work, instrumentation and methodology. Chapter 4 will perform all the results in details associated with the discussion and recommendations.

Chapter II

Ultrasonography as alternative modality for internal organs studies

2.1 Ultrasonography

Ultrasound also called Ultrasonography, is probably the most widely employed imaging tool in medicine today. The technology uses high-frequency (2 −18) MHz sound waves inaudible to humans to produce images from inside the body (Subedi, 2019). A device called a transducer that is placed on the skin sends the soundwaves into the body and records the echoes as they bounce back, thus defining the size, shape and mass of soft tissues and organs. It is a useful and flexible modality in medical imaging, and often provides an additional or unique characterization of tissues and measuring the volume for different organs, compared with other modalities such as conventional radiography, CT and MRI. In addition, an ultrasound exam offers the benefit of producing images quickly and in real time, so movement can easily be observed on ultrasound but MRI and CT images are time consuming to capture and it takes time longer than US , Due to pain, physical limitations, or psychological limitations such as claustrophobia and anxiety, some patients find MRI exams challenging to endure. The procedure requires patients to lie still for extended periods of time, and the machine itself can feel confining, Also, MRI and CT have high cost for patients comparable with USG.

Production of Ultrasound:

Ultrasound waves are produced by a transducer, which can both emit ultrasound waves, as well as detect the ultrasound echoes reflected back. In most cases, the active elements in ultrasound transducers are made of special ceramic crystal materials called piezoelectric. These materials are able to produce sound waves when an electric field is applied to them, but can also work in reverse, producing an electric field when a sound wave hits them. When used in an ultrasound scanner, the transducer sends out a beam of sound waves into the body. The sound waves are reflected back to the transducer by boundaries between tissues in the path of the beam. When these echoes hit the transducer, they generate electrical signals that are sent to the ultrasound scanner. Using the speed of sound and the time of each echo's return, the scanner calculates the distance from the transducer to the tissue boundary. These distances are then used to generate two-dimensional images of tissues and organs. During an ultrasound exam, the technician will apply a gel to the skin. This keeps air pockets from forming between the transducer and the skin, which can block ultrasound waves from passing into the body.

Ultrasound system consist of:

- The transducer sends and receives the sound waves. The transducer is the small handheld probe that the technician uses.

There are most common types of transducers as shown in table 2.1:

1. Linear Transducer
2. Convex Transducers (Curved Transducer)
3. Phase Array Transducer
4. Micro-convex Transducers
5. Sector Array
6. Small Linear

- Screen: The screen or monitor shows the image of what the transducer is scanning. This allows the doctor to analyse the image before creating their diagnosis. It also enables the technician to navigate to the exact area that requires ultrasound imaging.

- Central Processing Unit (CPU): The CPU is the brain behind an ultrasound machine. It coordinates the different signals emitted and received by the transducer, interpreting the electrical signals in the form of a visual image on the monitor.

- Control: Enable the technician to adjust the settings for ultrasound scans to get a clear picture on the display. Other functions include zooming the picture in and out

- Keyboards are used during ultrasound scans to enter patient data. Entering patient data allows every image to be saved correctly in the patient file. Storing patients' ultrasounds with their data helps maintain accurate patient records on any digital medium.

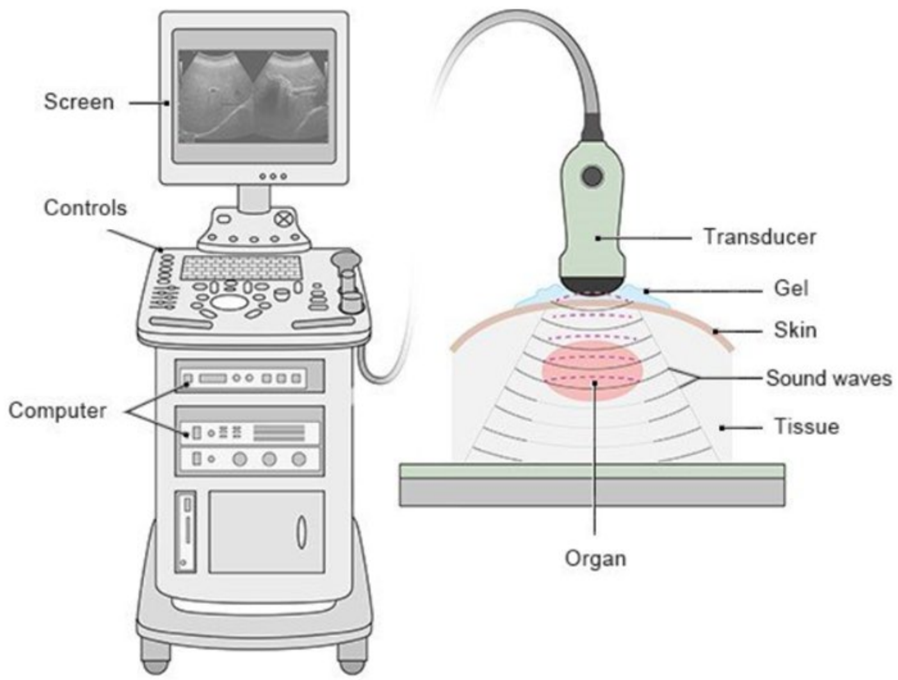

Figure 2.1: Ultrasound machine parts

Table 2.1: Summary table of different types of ultrasound probes and potential use cases(Dixon et al., 2022)

Appearance	Type	Depth (cm)	Description and use cases
	Linear array 7-15 MHz	2-7	Very high spatial resolution but limited penetration. Creates a rectangular field of view with less artifact compared to convex arrays. Typically large foot-print so limited to large craniotomies.
	Convex array 2-10 MHz	10-30	High spatial resolution with good penetration. Fan shaped large field of view. Large foot-print so limited to large craniotomies.
	Micro-convex 4-13 MHz	6-10	High spatial resolution with good penetration. Fan shaped large field of view. Smaller foot-print so more adaptable and usable in smaller craniotomies with potential for intracavitary use depending on resection size.
	Sector array 4-10 MHz	4-8	Small foot-print. Produces trapezoid image allowing wide field of view from a small craniotomy. Resolution lower at depth. Can be used for burr-hole guided surgery for instance for VP shunt placement.
	Matrix phased array 1-8 MHz	5-20	Type of sector array and often used in neurosurgery. Allows direct easy acquisition of a pyramidal 3D US image allowing volumetric reconstruction in any axis and facilitating visualization of adjacent structures. Produces relatively large field of view but resolution and contrast between different structures is poorer versus linear and convex array probes.
	Small linear "Hockey-stick" 6-15 MHz	2-5	Small foot-print, very high resolution but limited penetration. Can be placed directly into the resection cavity for high resolution assessment of superficial residual disease at the resection margin.

Ultrasound waves interactions:

Ultrasound waves interact with tissue in four basic manners:

1. Reflection:

Reflection of a sound wave occurs when the wave passes between two tissues of different acoustic impedances and a fraction of the wave 'bounces' back. This forms one of the major principles of ultrasound imaging as the ultrasound probe detects these reflected waves to form the desired image.

2. Scattering

Scattering occurs when ultrasound waves encounter objects that are small compared to the size of the ultrasound's wavelength(Ma et al., 2015)

3. Refraction

Refraction occurs when sound waves pass from one medium to another with differing propagation velocities. These differing velocities result in refraction, or change in the direction of the original (or incident) sound wave.(Ma et al., 2015)

4. Attenuation

Attenuation is the result of an ultrasound wave losing energy. As the ultrasound wave travels through a medium, the medium absorbs some of the energy of the ultrasound wave. The amount of energy absorption, or acoustic impedance (Z), is determined by the product of the density of the medium and the propagation velocity of the ultrasound wave.

2.4 Ultrasound Applications:

There are some common ultrasound applications in diagnosis:

a) **Pregnancy Monitoring**: Ultrasound is widely used in obstetrics to monitor the development of the fetus during pregnancy. It can determine the age of the fetus, detect multiple pregnancies, assess fetal growth, and identify any abnormalities.

b) **Abdominal Imaging**: Ultrasound can visualize organs within the abdomen, including the liver, gallbladder, pancreas, kidneys, spleen, and bladder. It helps in the diagnosis of conditions such as gallstones, liver disease, kidney stones, abdominal and pelvis masses.

c) **Vascular Imaging:** Ultrasound can evaluate blood flow through blood vessels using a technique called Doppler ultrasound. It helps diagnose conditions such as deep vein thrombosis, peripheral artery disease, carotid artery stenosis, and aneurysms.

d) **Musculoskeletal Imaging:** Ultrasound is used to evaluate soft tissues, muscles, tendons, ligaments, and joints. It helps in diagnosing conditions such as tendonitis, ligament tears, muscle injuries, and joint inflammation.

e) **Breast Imaging:** Breast ultrasound is often used as a complementary imaging modality to mammography in evaluating breast abnormalities. It can help distinguish between fluid-filled cysts and solid masses and guide breast biopsies.

f) **Thyroid Imaging**: Ultrasound is commonly used to evaluate the thyroid gland and detect abnormalities such as nodules, cysts, or enlargement. It helps in the diagnosis of thyroid conditions, including thyroid cancer.

g) **Pelvic Imaging:** Ultrasound is used to examine pelvic organs in both men and women. It helps in diagnosing conditions such as ovarian cysts, uterine fibroids, prostate enlargement, and pelvic inflammatory disease.

h) **Guidance for Procedures:** Ultrasound is used to guide needle placement during various procedures such as biopsies, aspirations, and injections. It provides real-time imaging to help ensure accuracy and safety.

2.2 Ultrasound Application in study of internal body organs volume

Measurement of Organ Dimensions by using Ultrasound modality can accurately measure the dimensions of internal organs such as the liver, kidneys, spleen, uterus and prostate. By obtaining multiple measurements in three different planes, the volume of these organs can be estimated using mathematical formulas. ultrasound imaging plays a crucial role in the assessment of internal organ volume, providing valuable information for diagnostic and therapeutic purposes across various medical specialties especially in radiotherapy also essential for diagnosing diseases, monitoring treatment efficacy, guiding medical procedures, and ensuring optimal patient care across a wide range of medical specialties. So, measuring the volume for internal organs determined reliable and accurate set of three simple measurements planes using two-dimensional (2D) ultrasound for volumetric assessment of liver. Then, performed predictive equation using these three simple measurements, which is simple to perform and easy to calculate, in order to evaluate liver volume and validate these measurements against CT images.(Farghaly et al., 2019)

Sonographic imaging provides a possible alternative method of estimating bladder volume in a non-invasive manner. This study demonstrates that bladder volumes in women with advanced POP (pelvic organ prolapse) can be measured easily by 2D-US (Cassadó et al., 2015)

Ultrasonography (US) of the kidneys has replaced imaging modalities for the evaluation of kidney diseases and provides many advantages over other imaging methods Kidney length and volume are important parameters in clinical settings, such as in acute and chronic renal disease, recurrent urinary tract infection and renal functional reserve after partial nephrectomy, so it can provide information regarding disease progression or stability. US examination is a feasible method for measurement of kidney volume and it is available on daily clinical practice(Okur et al., 2014a)

2.3 Ultrasound Limitations

- Ultrasound is limited by its inability to penetrate air or gas, leading to potentially misleading results. So, it is not ideal for imaging air-filled or bowel-obscured organs, lungs, or bone.(Subedi, 2019)

- Obtaining quality for ultrasound images requires high skills and experience. So, image interpretation can vary based on the operator's expertise.
- Can be less effective for obese patients due to limited penetration and increased depth.

Chapter III

Methodology and Instrumentation

3.1 Study Sample

This study was performed at Yamamah Hospital, Department of medical imaging and at Hirbawi medical center – Beit Jala which performed the MRI for the two male and female pilots in this study from July 2022 to December 2022. Research and Ethical approval are granted after institutional review at Yamamah Hospital and Al-Quds University.

A total of twenty participants volunteers (9 males and 11 females) with no symptoms were investigated for measurement of abdomen and pelvic internal organs by Ultrasound, the participants data are listed below in table 3.1.

Table 3.1: Demographic Data of participants

PARTICIPANTS	AGE	BMI	HEIGHT	WEIGHT
1. FEMALE	30	24.5	163	65
2. FEMALE	47	28	166	77.2
3. FEMALE	43	25.1	167	70
4. FEMALE	31	23.4	166	64.5
5. FEMALE	35	24.9	164	67
6. FEMALE	50	26	164	70
7. FEMALE	39	27.2	167	76
8. FEMALE	44	27.7	170	80
9. FEMALE	34	24.7	166	68
10. FEMALE	37	24.2	164	65
11. FEMALE	33	25.5	162	67
12. MALE	30	27.2	185	93
13. MALE	58	28.9	185	99
14. MALE	30	24.4	173	73

15. MALE	51	25.6	169	73
16. MALE	42	24.7	180	80
17. MALE	32	25.1	173	75
18. MALE	34	26.8	178	85
19. MALE	45	26.1	174	79
20. MALE	60	28.1	182	93

The mean age for male participants was 40.44±11.83 years (x±SD), and the mean body mass index (BMI) was 26.32±1.549, mean of height and weight were 177.66±5.7445 cm, 83.33±9.669 kg respectively. For females, the mean age was 38.45±6.698 years (x±SD), and the mean body mass index (BMI) was 25.56±1.498, mean of height and weight were 165.3± 2.248cm, 69.97±5.385 kg respectively.

Participation form in medical health activities (Appendix A), written in English and Arabic languages containing participant personal data, medical condition of the participant (if they have any chronic disease like hypertension, diabetes, or any cancers and if they did any previous surgery in the abdomen or pelvis which is the area of interest, also if they have knowledge of any presence of fatty liver or kidney stones). The Informed consent form for the USG exams were given to each participant and filled out together with the radiation technologist. This informed consent form explaining the purpose, procedures, risks, and benefits of the study provided and signed by each participant (Appendix B) and answered all their questions to be sure that the idea was delivered to all participants clearly. In addition, instructions were given to participants in both Arabic and English languages (Appendix C). The instructions for all participants were explained by the radiation technologist. They were requested to arrive at the clinic on time, then asked to be fast for 8 hours and don’t eat any fatty in the morning if the exam in the afternoon. But if they have any medications, they can take them with water. Then, all participants must drink at least 1 Litter of water before the Ultrasound exam to ensure that the urinary bladder is almost full. After that, we make sure that all the participants carried out all the instructions by filling out a special questionnaire for participants before entering the examination. (Appendix A).

3.2 Inclusion ad Exclusion criteria

The inclusion criteria for this study were for healthy adult people of males and females and age ranging from 30-70 years old with different body mass index (BMI). The exclusion criteria were the people who did not met selected age range. Also, the persons who had hypertension, diabetes, cancer or chronic diseases, pregnant women and persons who underwent surgeries in abdominal and pelvic organs of interest.

3.3 Instruments

The Instruments that used in this study are two different modalities:

A. Ultrasonography (USG) Machine

The Ultrasound modality which all the images will be performed by a GE Ultrasound system (GE Healthcare, VERSANA BALANCE) set to an abdominal imaging protocol, with a 3.5-5 MHz convex transducer probe. Scanning parameters (depth, gain and Time Gain Compensation) will be optimized for each participant. Linear transducer will be used for testicular measurements (6-13 MHz).

B. Magnetic resonance imaging machine (MRI)

MRI scan performed by Semiens Magnetom Sempra (2019), the field strength 1.5 Tesla with high quality and expand clinical capabilities, Bore size 60 cm, Helium consumption zero Helium boil-off technology, shimming passive and active and system length 171 cm.

3.4 Geometry of abdominal pelvic organs measurement

All participants will be scanned in two different positions; in supine and sitting position for the following abdominal and pelvic organs: liver, spleen, kidneys, gallbladder, uterus and ovaries (for female participants), testicles, and prostate (for male participants). For the supine posture, the subject is lying on the back horizontally with the face and torso facing up, while for the seated posture, the participants will seat on a special designed geometry folding chair which will be described further.

3.5 Folding Chair

The participants in the study will be seated in a unique folding chair with a backrest, positioned at a 20-degree angle from vertical. The organs for all participants will be scanned at a consistent height from the ground in this position, as shown in Figure 3.1. This geometry of measurement is expected to be used in sitting position light proton therapy using linear proton accelerator system where the gantry will not be available to reduce the cost of traditional proton therapy. So, a special folding chair was constructed for the purpose of this study.

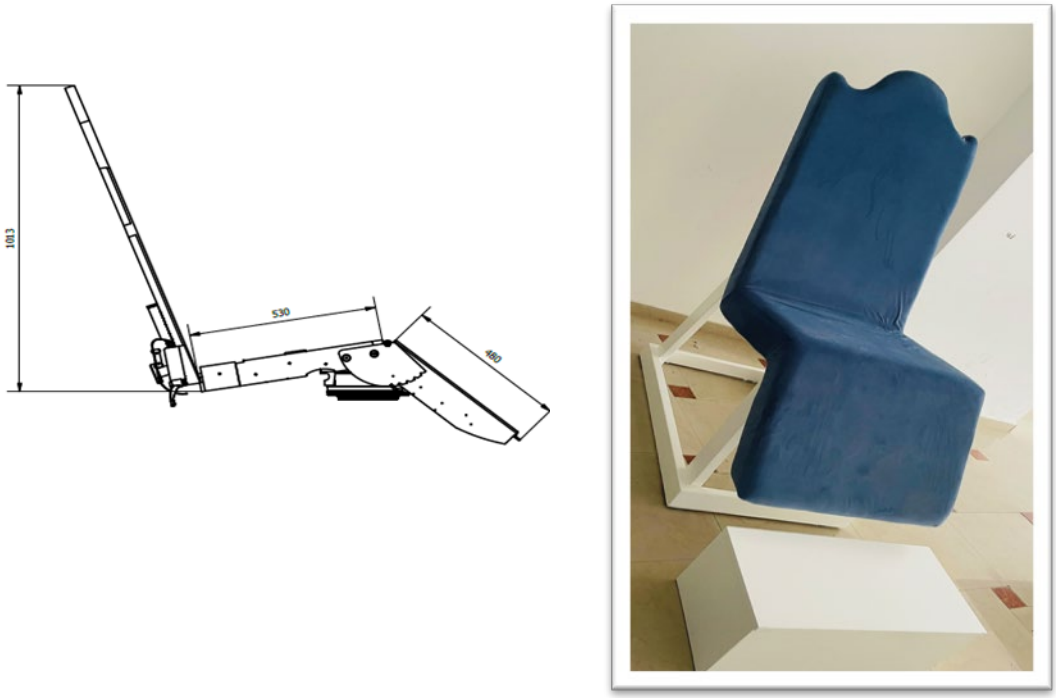

Figure 3.1: Geometry for scanning in sitting position.

3.6 Organ's measurement and volume evaluation protocols

In all protocols, dimensions of the investigated organs were determined manually from the acquired images. Protocols described below will be used in all two positions, supine and sitting. Values of organ dimensions will be extracted directly from the screen. The USG machine considers an ellipsoid shape of all abdominal and pelvic organs and calculates the volume according to the following equation for prolate ellipsoid [12]:

$$\mathbf{V_{ORGAN}\ (cm^3) = \frac{\pi}{6} \times (Length \times anteroposterior\ dimension \times Width)} \quad (1)$$

Variables in brackets represent the maximum possible measured dimension.

All the organs that mentioned before will be discussed in details to show the technique and instructions that were used to measure the three dimensions for each organ then to calculate the volume.

3.6.1 Liver

In both supine and sitting positions, the three maximum dimensions (Anteroposterior, transverse and length) were measured, breath hold after deep inspiration improves the visualization of the dome of the liver. All USG liver images will be acquired with the participant in a state of held inspiration. The image in Figure 3.3 illustrates the method of measuring the dimensions then calculating the volume using equation (1).

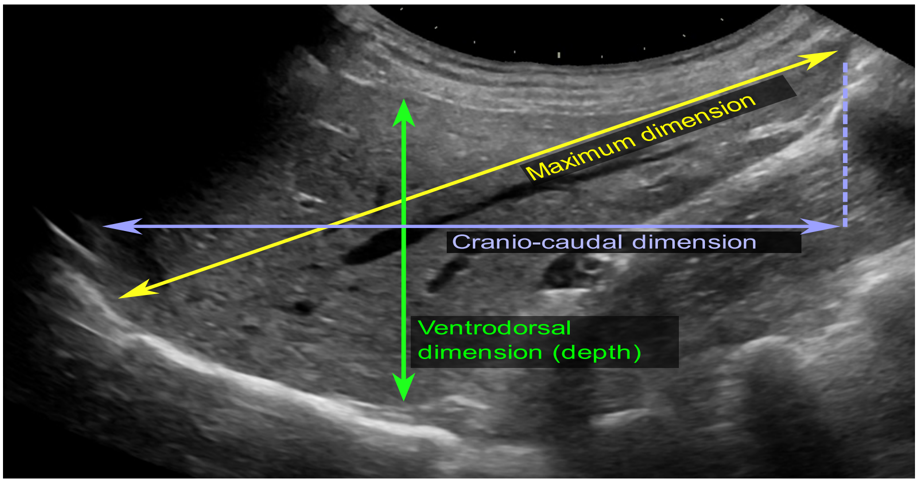

Figure 3.2: Illustration of liver dimensions measurements

3.6.2 Spleen

In both positions the three maximum dimensions (Anteroposterior, transverse and length) were measured, breath holding after deep inspiration improves the visualization of the spleen. All USG images will be acquired with the participant in a state of held inspiration. Turning the probe 90° from the plane of maximal spleen length and to measure the other dimensions. Spleen volume will be calculated by using equation (1). The images in Figure 3.4 illustrates the method of measurement L is the maximum dimension, D is the anteroposterior and T is the transverse.

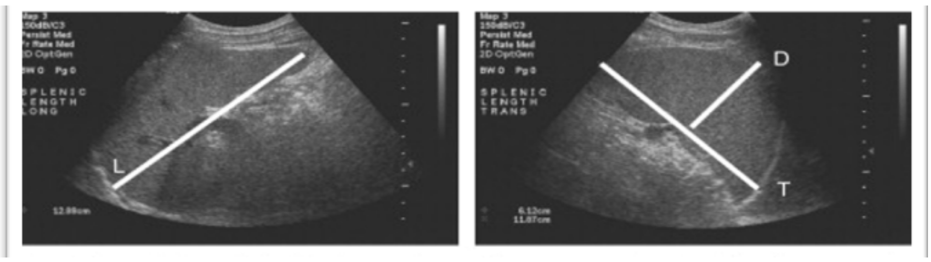

Figure 3.3: Measurements of spleen dimensions (IEEE Robotics and Automation Society. et al., n.d.)

3.6.3 Kidneys

The three maximum dimensions (Anteroposterior, transverse and length) were measured, breath hold after deep inspiration improves the visualization of the kidneys pole. All USG images will be acquired with the participant in a state of held inspiration. Turning the probe 90° from the plane of maximal kidneys length and to measure the other dimensions. Kidney volume will be calculated by using equation (1). The images in Figure 3.5 illustrates the method of measurement L is the maximum dimension, W is the transverse and T is the anteroposterior.

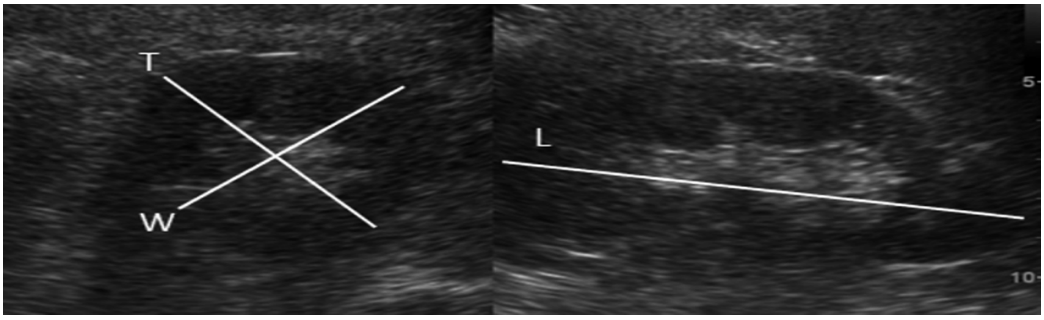

Figure 3.4: Illustrations of kidney measurement (Okur et al., 2014b)

3.6.4 Uterus

A full bladder is required. Participants in the study will be instructed to drink one Litter of water, and one hour prior to their appointment. They cannot empty their bladder until after the scan. Uterine volume is calculated using Equation (1). The images in Figure 3.6 illustrates the method of measuring the dimensions of the uterus.

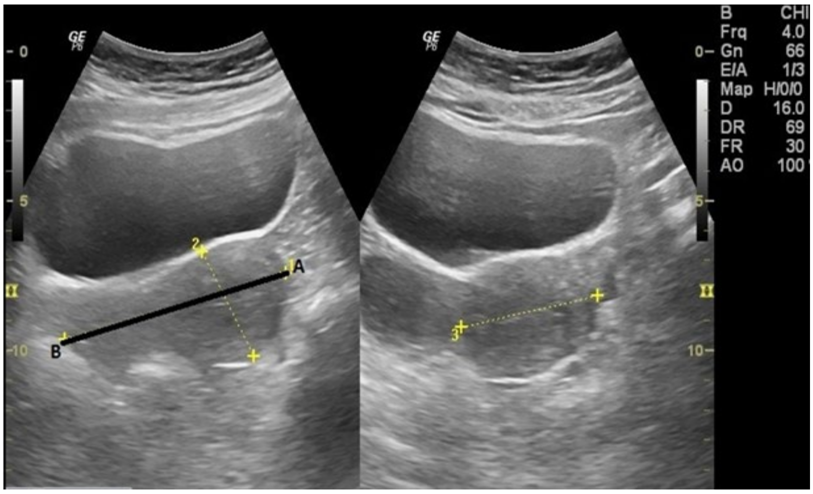

Figure 3.5: Measurements of Uterus (Parmar et al., n.d.)

3.6.5 Testicles

Testicular volume then will be calculated from Equation (1). Figure 3.7 illustrates the measurement of testicles dimensions.

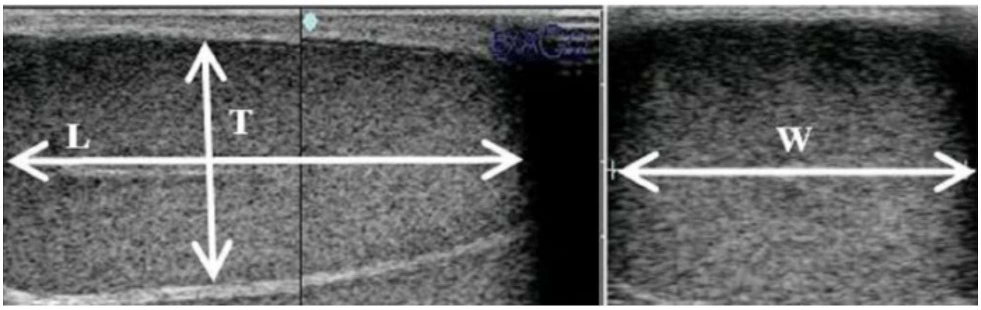

Figure 3.6: Testicle measurements (421-Main Manuscript-2283-1-10-20191231, n.d.

3.6.6 Prostate

A full bladder is required. Participants in the study will be instructed to drink one Litter of water, and one hour prior to their appointment. They cannot empty their bladder until after the scan. Prostate volume is calculated using Equation (1). The images in Figure 3.8 illustrates the method of measuring the prostate dimensions.

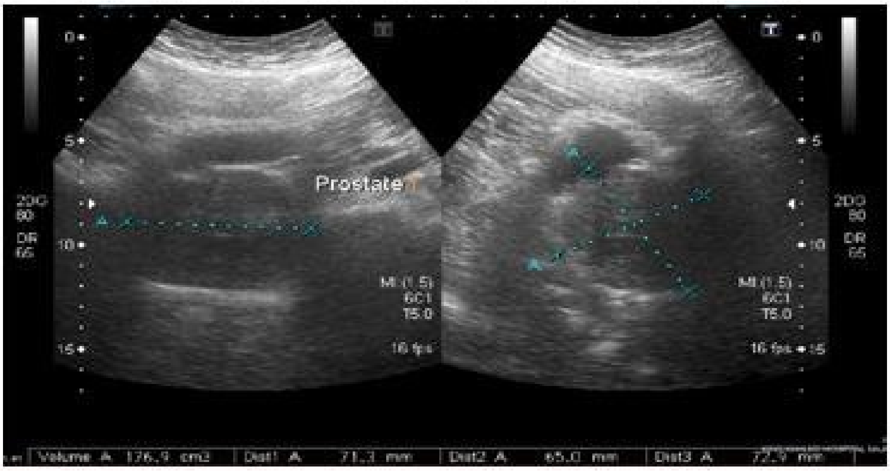

Figure 3.7: Image illustrating the measurement of prostate volume (Musa et al., 2015)

3.6.7 Gallbladder

The subject is ideally fasting about 8 hours to encourage distention of the gallbladder lumen. The gallbladder volume is calculated using equation (1). Figure 3.9 illustrates method of measuring the gallbladder dimensions.

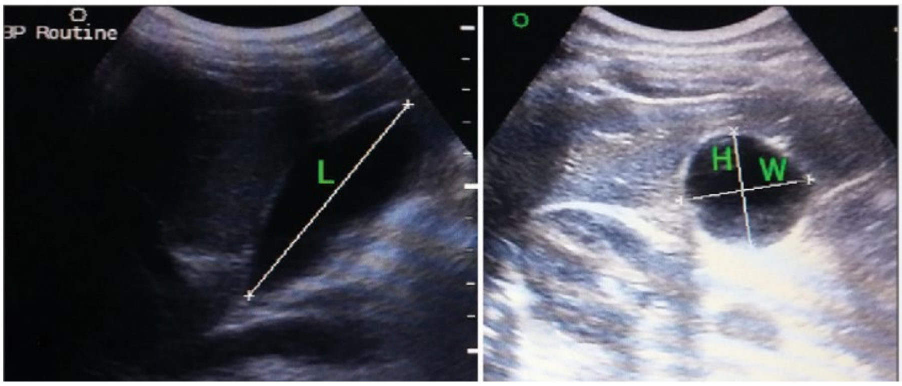

Figure 3.8: Illustration of Gallbladder measurements (Oluseyi, 2016)

Chapter IV

RESULTS AND DISCUSSION

4.1 Pilot study

The golden standard for measuring the dimensions of human abdominal organs is MRI. Prior to the measurement of our study sample (participants), two subjects male and female were investigated by two measurements techniques for internal organs MRI and USG dimensions. The purpose was to compare and evaluate the consistency of USG with MRI. The female tomographic data was: age 43 years, MBI 25.1 kg/m^2, weight 70 kg and 167 cm height. The male was 30 years old, has a BMI of 24.4 kg/m^2, a weight of 73 kg and a height of 173 cm. Before measurements the two pilot subjects underwent the procedure and all requirements of measurement presented in Chapter 3 and filled in all required questionaries and consents.

4.1.1. Abdominal and pelvic organs span measurements.

(A) Male measurements

Abdominal organs spans were measured for 9 organs using MRI and USG techniques for male and female in the pilot study in supine positions.

Table 4.1 and figures 4.1 through 4.3 presents the results of organ span measurement for pilot male subject.

Table 4.1: Results of male organs span measurements using MRI and USG in supine position.

Organ	**Span (cm)**	
	MRI	**USG**
Liver	15.4	15.8
Spleen	8.5	9
Rt kidney	10.6	10.8
Lt kidney	10.4	10.4
Prostate	2.4	2.8
UB	6.5	6.9
GB	6.3	6
Rt testicle	3.3	3.5
Lt testicle	3.6	3.9

There is a good agreement between the two measuring techniques. Literatures reported for example a liver span by ultrasonography is usually < 16 cm in the midclavicular line. Median liver span in a large published study (2080 individuals) was about 14.5 cm for males and 13.4 for females(Kratzer et al., 2003). Our results are within the range of values published in literature. The span of abdominal organs is influenced by BMI, height, sex, and age.

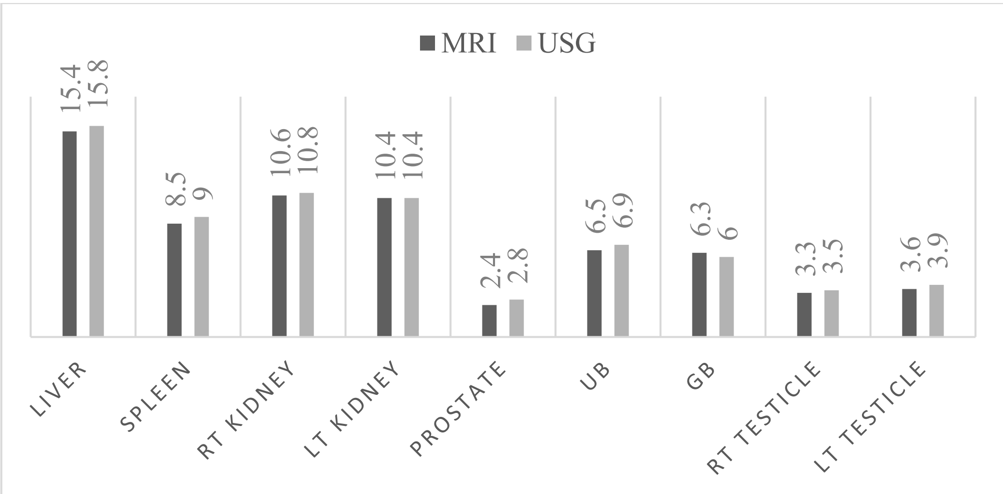

Figure 4.1 Comparison between abdominal organ spans measured by MRI and USG for the male in our pilot study.

Figure 4.2 shows a scatter plot of MRI vs USG of organs span measured by the two techniques. The coefficient of determination R^2 is about 1 which indicates a very good correlation between the two techniques. Figure 4.3 shows the normal probability plot of difference in male span organs measurements between MRI and USG in supine position. Mean difference (bias) is about - 0.23. The lower CI at 95% confidence level = – 0.8 and the upper CI at 95% confidence level is 0.33. Small mean of difference means consistency of the two methods.

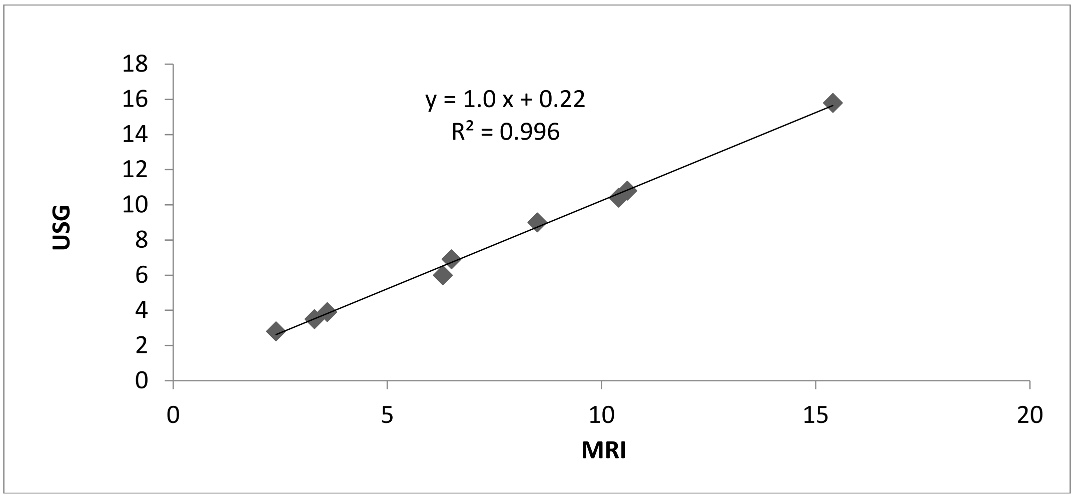

Figure 4.2. Correlation of MRI with USG of male organs span in supine position measured by the two techniques.

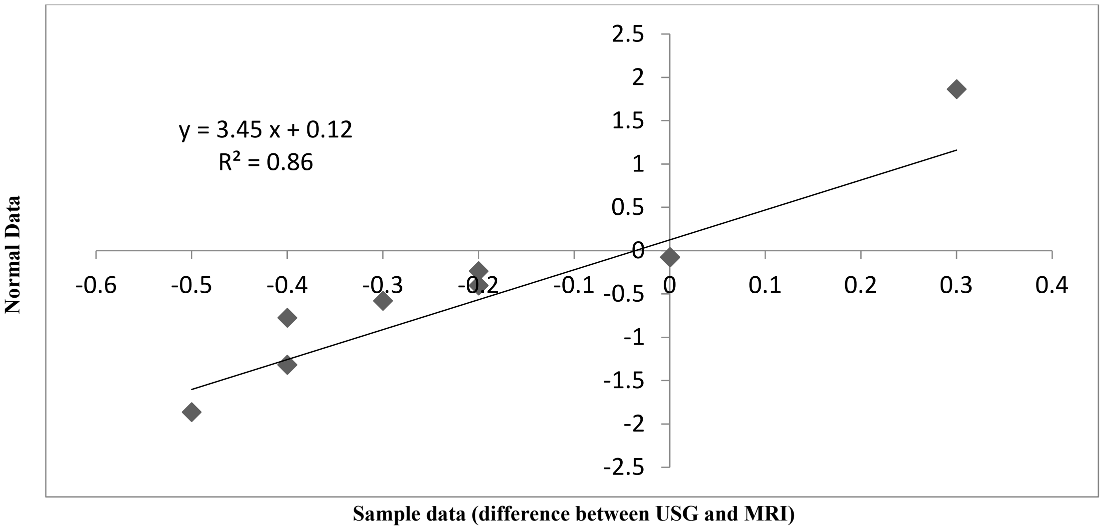

Figure 4.3.: Normal probability plot of difference in organs span between the two techniques for the male organs investigated in the pilot study.

(B) Female measurements (abdominal and pelvic organs span)

As in the case of male, female subject involved in the pilot study was measured from abdominal organs in supine position by both MRI and USG techniques under the same conditions of measurement procedures as mentioned in the methodology. Table 4.2 and figures 4.4, 4.5 and 4.6 present the results and analysis of measurements of the female abdominal and pelvic organs spans.

Table 4.2. Female abdominal and pelvic organs span measured by MRI and USG.

Organ	**Span (cm)**	
	MRI	**USG**
Liver	14.02	14
Spleen	9.2	9.4
Rt kidney	9.8	9.7
Lt kidney	11	10.5
Uterus	7.4	7.5
UB	5.3	5.5
GB	5.4	5.5
Rt ovary	3	2.8
Lt ovary	2.3	2.5

The absolute difference in organ span determination between the two techniques is small for most organs with a minimal difference in the measurement of the liver (about 0.02 cm).

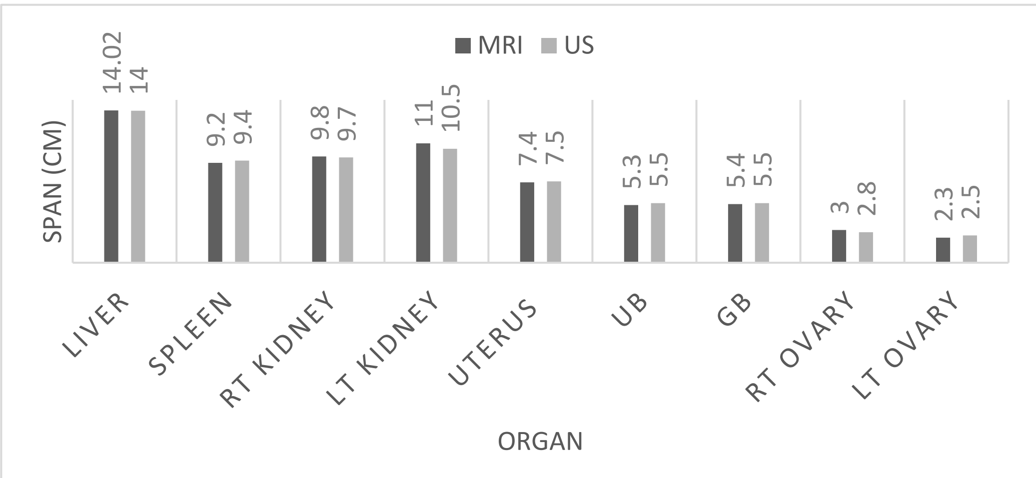

Figure 4.4. Female organs span measured by MRI and USG in supine position.

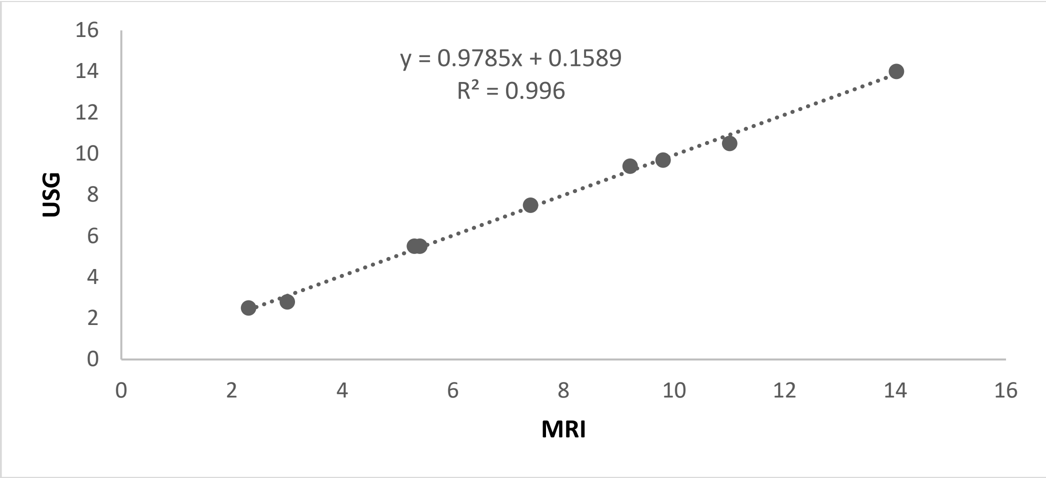

Figure 4.5. Correlation between MRI and USG of female organs span in supine position measured by the two techniques.

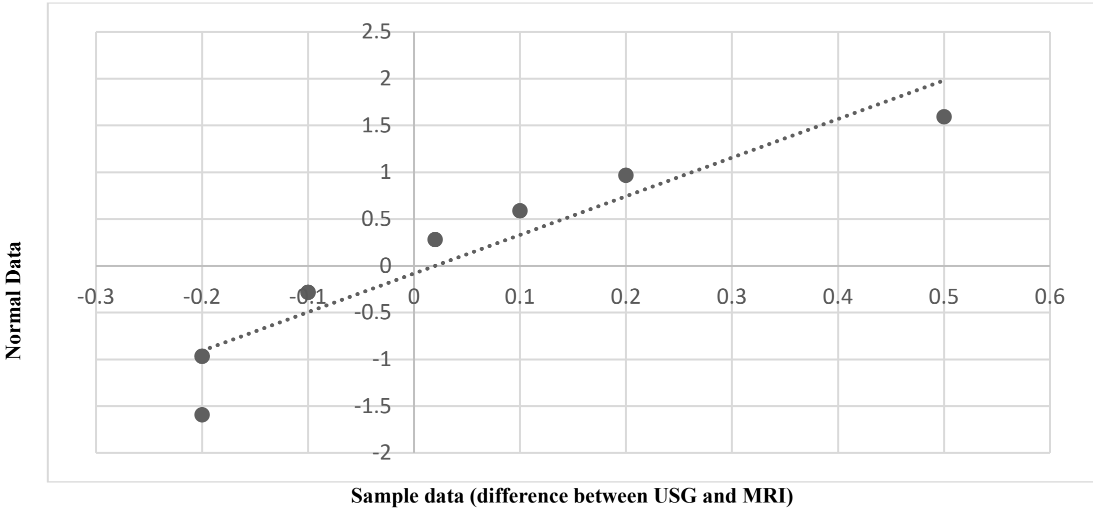

Figure 4.6. Normal probability plot of difference in organs span between the two techniques for the female organs investigated in the pilot study.

Mean difference (bias) is about 0.0012, the lower CI at 95% confidence level is – 0.33, upper CI at 95% confidence level is 0.33. The normal probability plot of difference between data obtained by the two MRI and USG techniques is linear. The differences are normally distributed then, mean difference is close to zero and differences between the two methods are expected to be within the range of values between upper and lower confidence intervals indicating a consistency between the two methods in the determination of abdominal and pelvic organs span. By ultrasound, a normal liver span is usually <16 cm in the midclavicular line; however, liver size varies with sex and body size. For example, in a study including 2080 individuals, the median liver span (as measured by transabdominal ultrasound in the midclavicular line) for males was 14.5 cm and for females was 13.4 cm. (Kratzer et al., 2003).Body mass index and body height are the most important factors associated with the diameter of the liver measured at the midclavicular line.(Kratzer et al., 2003)

4.1.2. Abdominal and pelvic organs volume measurements.

Abdominal and pelvic organs volumes were also evaluated using the MRI and USG techniques for the male and female subject organs investigated in the pilot study. Measurements and evaluation of volumes were conducted according to the protocol described earlier in this study. For volume evaluation the following equation was used, assuming ellipsoidal shape of organs:

$$\textbf{Volume} = \frac{\pi}{6} \text{ x (MaxAP x MaxTransverse x MaxLength)} \quad (1)$$

(A) Male organs volumes measurements in supine position.

Results of male organs volume are presented in table 4.3 and figures 4.7 to 4.10.

Table 4.3: Male abdominal organ volumes evaluated using MRI and USG techniques in supine position.

Organ	V(cm^3) MRI	V(cm^3) USG
Liver	1592	1583.34
Spleen	233.81	232
Right Kidney	122.6	129.7
Left Kidney	157.4	160.5
Prostate	8.9	11.7
UB	150.4	149.2
GB	10.3	12.7
Right Testicle	10.4	9.8
Left Testicle	11.8	10.7

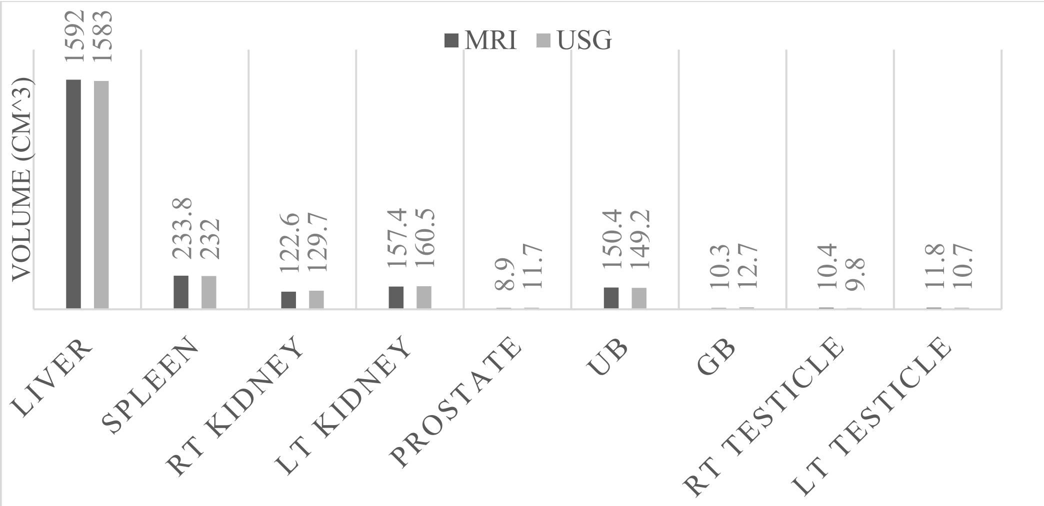

Figure 4.7. Comparison between male organs volumes measured evaluated using MRI and USG techniques in supine position for male pilot.

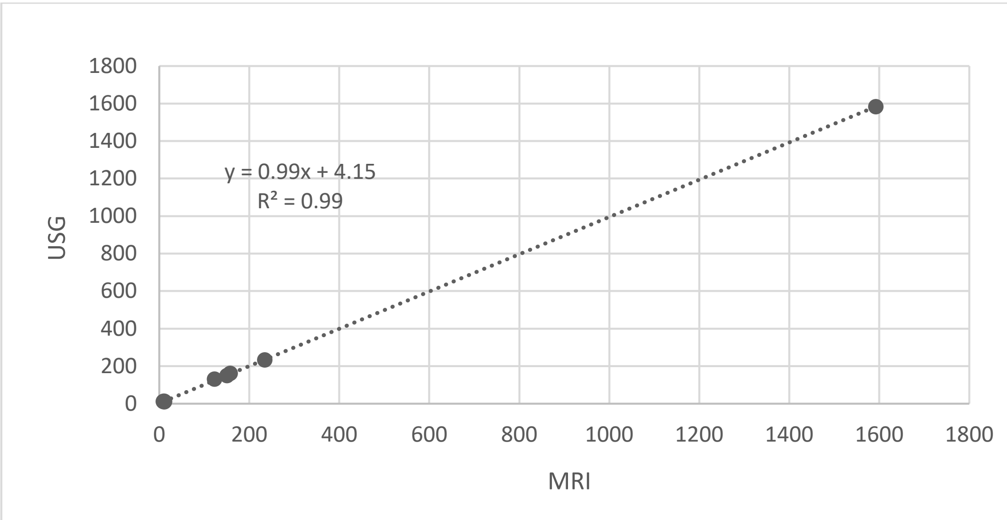

Figure 4.8. Scatter plot of male organs volumes values evaluated using MRI and USG techniques in supine position (pilot).

Table 4.3 and figure 4.8 show strong correlation between the two methods. Figure 4.9 shows a normal probability plot of differences between organs volumes evaluated by the two different techniques. The linearity of this relationship also supports the consistency between the MRI and USG techniques in the evaluation of abdominal and pelvic organs volumes.

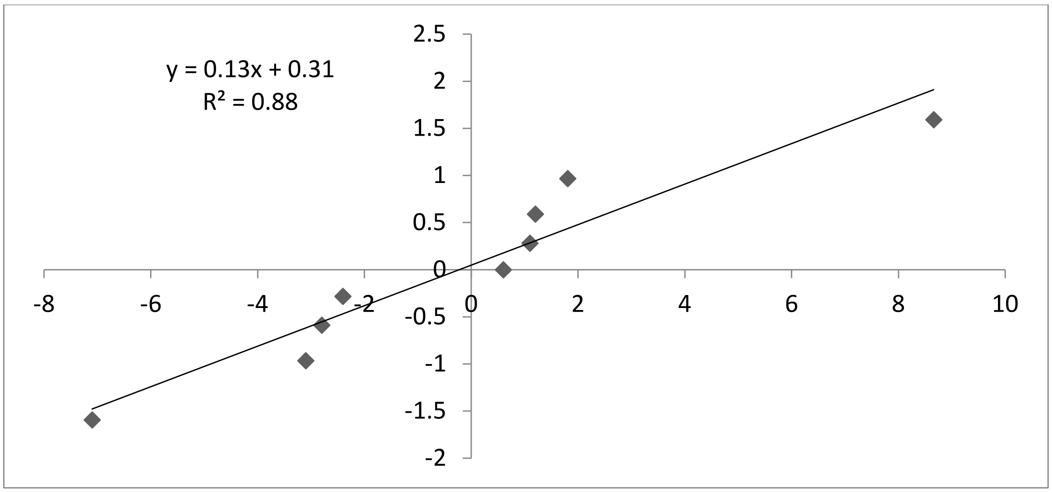

Figure 4.9. Normal probability plot of difference in organs volume between the two techniques for the male organs investigated in the pilot study.

To validate the consistency between MRI as the golden standard technique in organ studies and USG technique which will be used in this study for organ volume and effect of posture studies, a Bland – Altman correlation analysis was applied. This technique is used for validation of a new measurement method for application to medical practice. The Bland-Altman analysis is a frequently applied technique in studies that investigate the agreement between two methods of the same medical measurement.

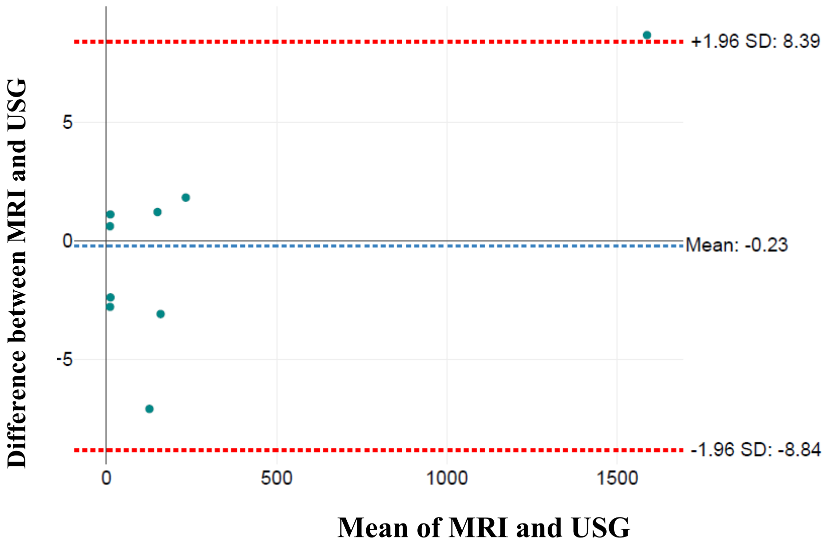

Figure 4.10. Bland - Altman validation of the consistency of USG with MRI technique in organs volumes evaluation for male pilot.

The mean difference between MRI & USG = - 0.23, Lower CI at 95% confidence level = - 8.8 and Upper CI at 95% confidence level = 8.38.

Comparison of liver volume evaluation with Child's Equation in supine position:

Child's Equation is considered the most accurate for estimating liver volume using 2D Ultrasound (Izranov et al., 2018)

Child's Equation for liver volume evaluation:

$$\mathbf{V = 343.71 + 0.84\ X\ (APRL\ X\ APLL\ X\ max\ LRL),} \qquad \mathbf{(2)}$$

where: APRL = AP diameter of the right lobe, APLL = AP diameter of the left lobe and max LRL = maximal diameter of the right lobe. Table 4.4 presents liver data measured on the male in pilot study for evaluation of liver volume adopted in this study assuming ellipsoidal shape of the liver and by using Child's Equation. Results of male liver volume (in our pilot study) evaluated by the two methods in supine position are also presented in the table 4.4.

Table 4.4. Male liver volume evaluation using two methods, adopted in this study and according to Child's Equation.

Organ LIVER	Male in pilot study BMI = 24.4							
	Max. L (cm)	Max. AP (cm)	Max. TR (cm)	Volume (cm^3)	APRT (cm)	APLL (cm)	MaxRLL (cm)	Volume (cm^3)
Supine	15.8	14.6	13.2	1583	10	9.5	15.4	1575

The difference between liver volume evaluated in this study assuming the ellipsoidal shape of the liver and using Child's equation is 8 cm^3. Liver volume evaluation adopted in this study is in good agreement with the results of volume evaluation according to Child's Equation (Difference of about 0.6%). The same evaluation comparison was carried out on a liver of a male participant of BMI = 26.5 $kg.m^{-2}$ resulted in a difference of about only 0.46% only.

(B) Female organs volumes measurements in supine position.

Abdominal and pelvic organs of the female subject involved in the pilot study were also measured for volume evaluation in supine position by MRI and USG techniques. Results are presented in table 4.5, and figures 4.11 to 4.14. Like in the case of male subject, analysis of results indicates strong correlation between the MRI and USG techniques in the evaluation of abdominal and pelvic organs volumes of female participant in supine position.

Figure 4.11. Comparison between MRI and USG techniques in measuring the abdominal and pelvic volumes of female organs.

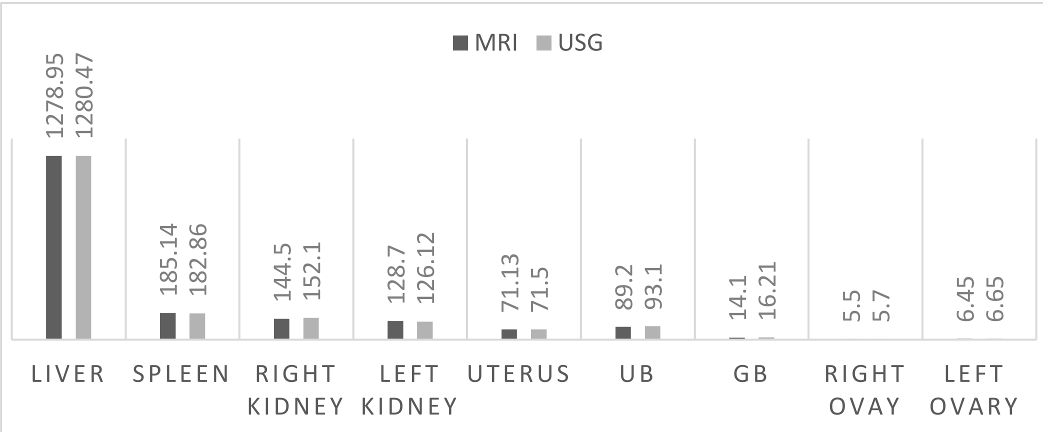

Table 4.5: Female (pilot) organs volumes evaluated by MRI and USG in supine position.

Organ	V(cm^3)	V(cm^3)
	MRI	USG
Liver	1278.95	1280.47
Spleen	185.14	182.86
Right Kidney	144.5	152.1
Left Kidney	128.7	126.12
Uterus	71.13	71.5
UB	89.2	93
GB	14.10	16.21
Right Ovary	5.5	5.7
Left Ovary	6.45	6.65

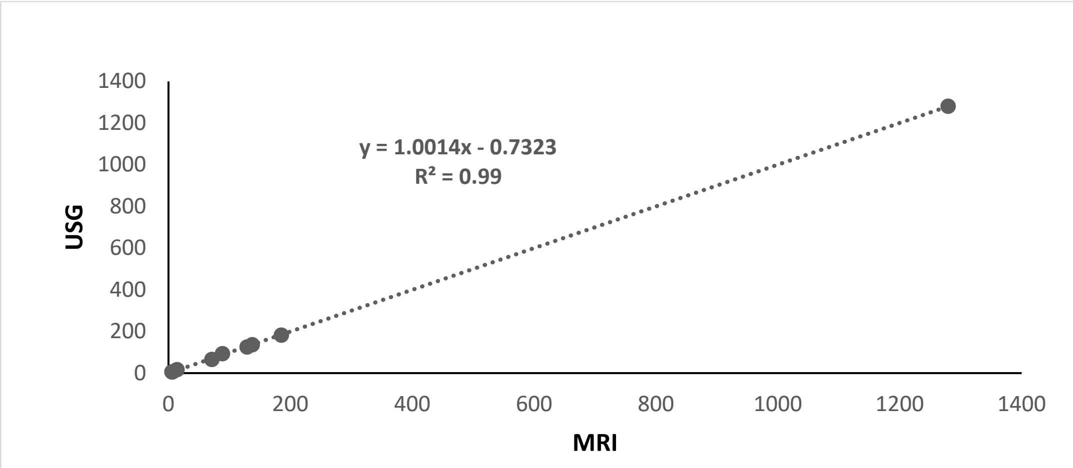

Figure 4.12. Correlation between MRI and USG (female organs volume evaluation in supine position)

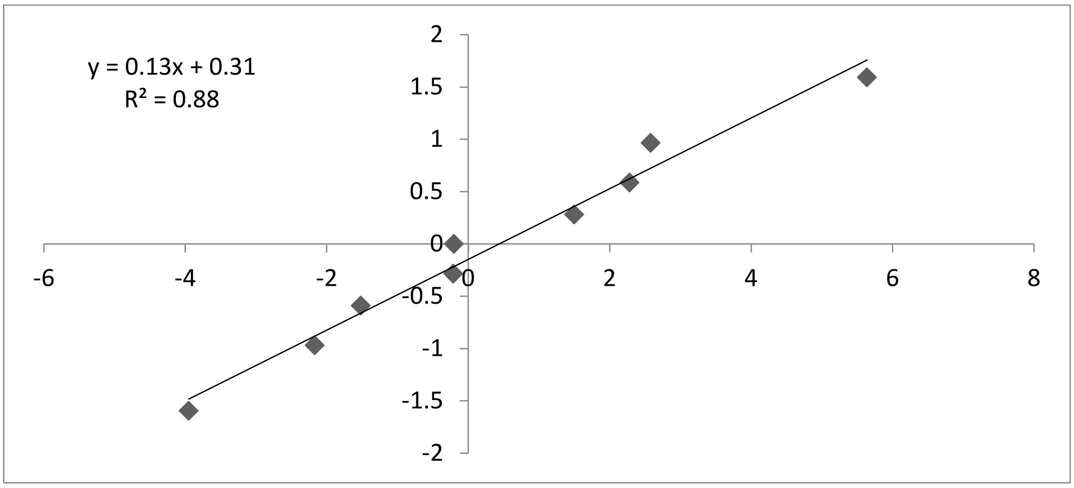

Figure 4.13. Normal probability plot of difference in organs volume evaluation between MRI and USG techniques for female in supine position.

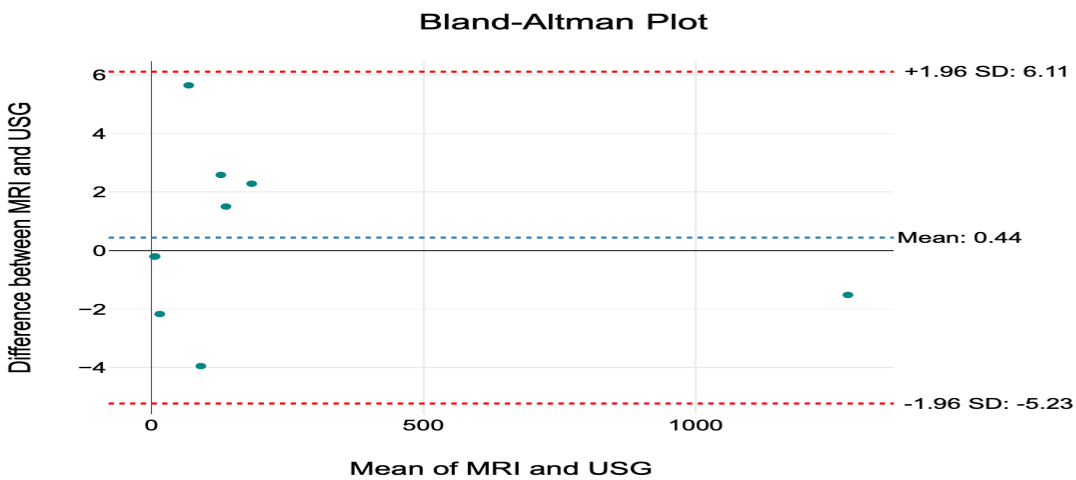

Figure 4.14. Bland-Altman analysis of difference between MRI and USG for the evaluation of organs volume in supine position for female pilot

The mean difference = 0.44, the lower confidence interval at 95% confidence level = -5.23 while the upper CI at 95% CL is 6.11. In both cases, male and female measurements, the mean differences (biases) are small, and the 95% limits of agreements lies within a narrow interval (lower CI, upper CI). The Bland-Altman analysis therefore supports the consistency between USG and MRI modalities in the measurement of the size of abdominal and pelvic organs. Even though, this correlation was investigated by USG only on 2 participants in the pilot study; large scale studies support this result with CT as well (Farghaly et al., 2019)

4.2. Results of Ultrasonography studies on all participants (subjects).

4.2.1 Organs measurements in supine and sitting positions.

First attempt to study the organ volume change and deformation in different directions from supine to seated posture was performed with a female subject aged 30 years with BMI =24.5 kg.m^{-2}, weight = 65 kg and height = 163 cm. Table 4.6 presents dimensions of the organs of this female measured by USG in supine and sitting positions.

Table 4.6. Female organ dimensions measurements by USG in supine and sitting positions.

BMI 24.5	**SUPINE POSITION**				**SITTING POSITION**			
FEMALE	**AP**	**TRA**	**LENGHTH**	**V(cm^{3})**	**AP**	**TRA**	**LENGHTH**	**V(cm^{3})**
LIVER	12	12.5	15.2	1185	11.8	12.2	15	1122
SPLEEN	9.1	5.6	10.8	286	10	4.7	11.3	276
RT KIDNEY	5.2	5.2	11.8	166	5.6	4.6	10	134
LT KIDNEY	5.2	4.5	10.9	133	4.8	3.6	12	108
UTERUS	4.4	5	5.5	63	3.8	4	7.2	57
UB	4.1	6.9	7.5	110	3.4	7.5	6.5	86
GB	2	1.3	6.5	9	1.3	1	5	3.4
RT OVARY	2.4	2.1	1.8	5	1.5	2.3	1.3	2.3
LT OVARY	2.1	2.6	2.4	7	1.7	2	2.3	4

The data presented in table 4.6 shows in for most organs the dimensions and volumes are compressed in seated posture. Total volumes of all organs are smaller in sitting position. The amount of volume change however varies from one organ to another depending on the structure, size, weight and compressibility of the organ. For example, the size of the liver is decreased in sitting position by 63 cm^3 in the case of this female (about 6%), left ovary by about 42% of its size in supine position, right ovary by about 54%. In a male of BMI 24.4, age 30 years the deformation of the liver in seated posture was as follows Figure 4.15: 1.3 cm compression in length (maxL), 0.2 cm compression in transverse (TR) and 3.3 compression in depth (AP).

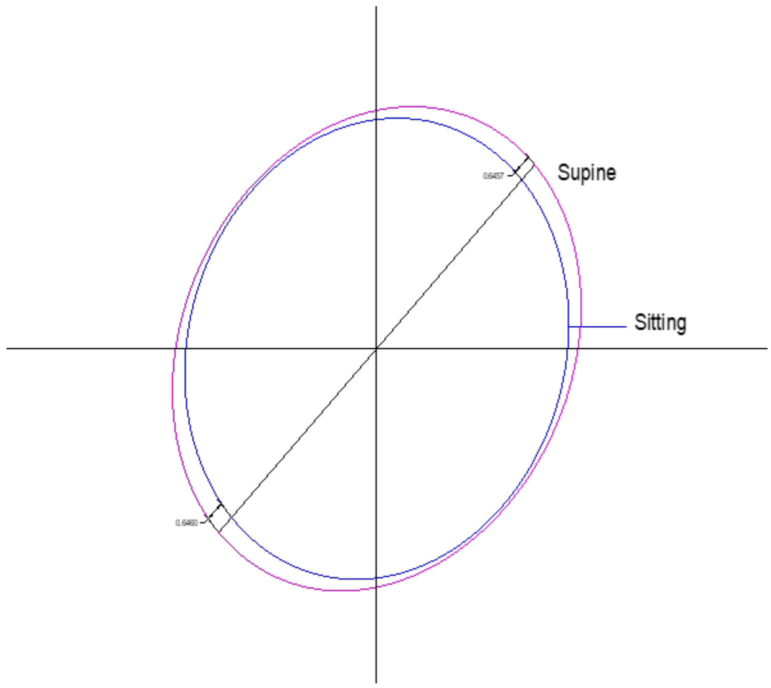

Figure 4.15. Illustration of a two-dimensional compression in a male liver volume (Max Length and TR) in seated posture. Compression in AP is 3.3 cm.

The illustrations show a common central position of the organ which is not the real situation, it might be shifted from its original anatomical position as a result of posture change under the influence of gravity. During measurements the positions of the transducer giving the maximum dimensions of organs span in supine and seated postures were marked on the skin of the subject being measured and they were in different points separated by a distance depending on the subject characteristics.

Measurements on a female subject with BMI 25.1 resulted in data presented in table 4.7 shows the position of these points from a straight line connecting the Xiphoid and Umbilicus of the investigated subject in the two postures. There is about 1 cm shift between the two positions according to this line.

Table 4.7. Liver dimensions measured in supine and sitting positions for a female subject.

Female BMI 25.1	**Max. Length**	**AP**	**TR**	**Distance from Xiphoid line (cm)**
Supine	**14**	**14.3**	**12.3**	**11**
Sitting	**15.6**	**10**	**12.8**	**10**

Table 4.7 presents all measurements conducted by USG on every single organ. Herein we are presented only the two tables representing the results obtained from subjects, male and female involved in the pilot study.

Table 4.8: Organs dimensions, volumes in supine and sitting postures, and differences in organs span and total volumes assuming ellipsoidal shape of organs for a male subject.

ORGAN / POSTURE	Male (pilot), BMI=24.4, Height = 173, Weight = 73 kg, Age 30 years				
LIVER	MAX L	MAX AP	MAX. TR	V(cm^3)	Organ volume deformation
SUPINE	15.8	14.6	13.2	1583.34	Compression in all directions
SITTING	14.5	11.3	13	1114	
dx (cm), dV(cm^3)*	1.3	3.3	0.2	469.34	
SPLEEN	MAX L	MAX. AP	MAX. TR	V(cm^3)	Compression in all directions
SUPINE	9	11	4.5	233	
SITTING	8.5	9.3	4.3	177.7	
dx(cm), dV	0.5	1.7	0.1	55.3	
RT KIDNEY	MAX L	MAX AP	MAX. TR	V(cm^3)	Compression in span , AP, expansion in TR
SUPINE	10.8	5.5	4.2	130.5	
SITTING	9	5	4.5	106	
dx(cm), dV	1.8	0.5	-0.3	24.5	
LT KIDNEY	MAX L	MAX AP	MAX. TR	V (cm^3)	Compression in all direction
SUPINE	10.4	5.6	5.3	161.4	
SITTING	10	5.5	4.3	123.6	
dx(cm)	0.4	0.1	1	37.8	
PROSTATE	MAX L	MAX AP	MAX. TR	V(cm^3)	No change in volume
SUPINE	2.8	2.3	3.5	11.72	
SITTING	2.8	2.3	3.5	11.72	
dx(cm), dV	0	0	0	0	
RT TESTICLE	MAX L	MAX AP	MAX. TR	V(cm^3)	Compression in all directions
SUPINE	3.5	3	1.8	9.8	
SITTING	3.4	3.1	1.6	8.8	
dx(cm), dV	0.1	0.1	0.2	1	
LT TESTICLE	MAX L	MAX AP	MAX. TR	V(cm^3)	Compression in span and TR, expansion in AP
SUPINE	3.9	2.8	1.9	10.7	
SITTING	3.6	3.2	1.4	8.3	
dx(cm), dV	0.3	- 0.4	0.5	2.4	
GB	MAX L	MAX AP	MAX. TR	V(cm^3)	Compression in all directions
SUPINE	6	2.4	1.7	12.72	
SITTING	5	1.9	1.5	7.41	
dx (cm), dV	1	0.5	0.2	5.31	
UB*	MAX L	MAX AP	MAX. TR	V(cm^3)	Compression in span, expansion in TR and AP
SUPINE	6.9	5.2	8	149.26	
SITTING	6.5	5.3	8.4	151.30	
dx(cm), dV	0.4	-0.1	-0.4	-2.10	

* dx(cm), dV(cm^3) = Difference in Lmax, APmax, TRmax respectively difference in Volume between supine & sitting posture

Table 4.9: Organs dimensions, volumes in supine and sitting postures, and differences in organs span and total volumes assuming ellipsoidal shape of organs for a female subject.

ORGAN / POSTURE	Female (pilot), BMI=25.1, Height = 167, Weight = 70 kg				
LIVER	MAX L	MAX AP	MAX. TR	V(cm^3)	Organ volume deformation
SUPINE	14	14.3	12.3	1280.47	Expansion in span and TR, compression in AP
SITTING	15.6	10	12.8	1038.33	
dx (cm), dV(cm^3)*	-1.6	4.3	-0.5	242.14	
SPLEEN	MAX L	MAX. AP	MAX. TR	V(cm^3)	Compression in span and TR, expansion in AP
SUPINE	9.6	9	4.1	182.80	
SITTING	9.2	9.3	3.4	151.27	
dx(cm), dV	0.4	-0.3	0.7	31.53	
RT KIDNEY	MAX L	MAX AP	MAX. TR	V(cm^3)	Compression in all directions
SUPINE	10	6.5	4.5	152.1	
SITTING	9.9	6.3	3.9	127.2	
dx(cm),dV	0.1	0.2	0.6	24.9	
LT KIDNEY	MAX L	MAX AP	MAX. TR	V (cm^3)	Expansion in span and TR, compression in AP
SUPINE	10.5	5.5	4.2	126.8	
SITTING	10.6	4.5	5	124.02	
dx(cm), dV	-0.1	1.0	-0.8	2.79	
Uterus	MAX L	MAX AP	MAX. TR	V(cm^3)	Compression in span and AP, expansion in TR
SUPINE	7.5	4.8	3.8	71.52	
SITTING	6	3.8	4.5	53.65	
dx(x), dV	1.5	1	-0.7	17.8	
RT Ovary	MAX L	MAX AP	MAX. TR	V(cm^3)	Expansion in span, compression in AP and TR
SUPINE	2	2	3	6.24	
SITTING	2.6	1.7	2.4	5.51	
dx(cm), dV	-0.6	0.3	0.6	0.73	
LT Ovary	MAX L	MAX AP	MAX. TR	V(cm^3)	Compression in span and TR, expansion in AP
SUPINE	2.5	1.6	3.2	6.7	
SITTING	1.8	1.9	2.5	4.44	
dx(cm), dV	0.7	-0.3	0.7	2.25	
GB	MAX L	MAX AP	MAX. TR	V(cm^3)	Compression in span and AP, expansion in TR
SUPINE	5	3	2.4	18.72	
SITTING	1.8	2.2	4	8.2	
dx (cm), dV	3.2	0.8	-1.6	10.52	
UB	MAX L	MAX AP	MAX. TR	V(cm^3)	Compression in span and AP, expansion in TR, small decrease in volume
SUPINE	8	6	7.5	92.6	
SITTING	5.5	3.6	9	93.2	
dx(cm), dV	2.5	2.4	-1.5	-0.6	

* dx(cm), dV(cm^3) = Difference in Lmax, APmax, TRmax respectively difference in Volume between supine & sitting posture.

4.2.2. Results of organs span measurements for all subjects.

The generic formula for organs volume measurements is given by equation (1) which is used in organ volume estimation by different techniques (MRI, CT and USG). Therefore, measuring the span of the organ (maximum length) precisely is of particular importance because it has the main effect on volume calculation. The results of span measurements in supine and sitting positions for liver, spleen, right and left kidneys, gallbladder and right and left ovaries are presented in tables 4.10 through 4.15.

Table 4.10. Liver span for females and males in supine and sitting positions.

Organ Liver	**BMI (kg/m^2)**	**Age (y)**	**$SPAN_{supine}$ (cm)**	**$SPAN_{sitting}$ (cm)**
Females	23.4	31	14.8	15.1
	24.2	37	13.5	12.7
	24.5	30	15.2	15
	24.7	34	15	14.4
	24.9	35	14.8	13.8
	25.1	43	14	15.6
	25.5	33	13.7	13.1
	26	50	14.4	13.6
	27.2	39	14.5	13.8
	27.7	44	16	15.5
	28	47	14	14.8
Males	**BMI (kg/m^2)**	**Age (y)**	**$SPAN_{supine}$ (cm)**	**$SPAN_{sitting}$ (cm)**
	24.4	30	15.8	14.5
	24.7	42	16	15
	25.1	32	15.9	15
	25.6	51	16.8	16.6
	26.1	45	15.3	14.8
	26.8	34	15.8	15.2
	27.2	30	17.5	15.8
	28.1	60	16.2	15.4
	28.9	58	20	18

Mean liver span for male participants in supine position was 16.58±1.43 while in sitting position was 15.58±1.09 cm. For females participants was 14.53 ± 0.73 cm and 14.31 ±

0.98 respectively. Average decrease in span between supine and setting position for all subjects was 4 %

Table 4.11. Spleen span for females and males in supine and sitting positions

Organ Spleen	BMI (kg/m^2)	Age (y)	$SPAN_{supine}$ (cm)	$SPAN_{sitting}$ (cm)
Females	23.4	31	12.5	10.5
	24.2	37	10.4	9.9
	24.5	30	10.8	11.3
	24.7	34	11.6	11
	24.9	35	12	10.1
	25.1	43	9.6	9.2
	25.5	33	9.5	9
	26	50	10.5	9.5
	27.2	39	10.8	9.8
	27.7	44	11.6	10.5
	28	47	11.4	9.8
Males	**BMI (kg/m^2)**	**Age (y)**	**$SPAN_{supine}$ (cm)**	**$SPAN_{sitting}$ (cm)**
	24.4	30	9	8.5
	24.7	42	13.9	11.2
	25.1	32	11.5	10.9
	25.6	51	11	11.7
	26.1	45	13.1	12.6
	26.8	34	13.5	12.8
	27.2	30	11.4	10.5
	28.1	60	13.7	13.1
	28.9	58	14	14.2

Mean splenic span for male participants in supine position was 12.34± 1.71 while in sitting position was 11.72± 1.69 cm. For females participants was 10.18 ± 0.95 cm and 10.05 ± 0.72 respectively. Average decrease in span between supine and sitting position for all subjects was 7 %

Table 4.12. Right kidney span for females and males in supine and sitting positions

Organ RT Kidney	BMI (kg/m^2)	Age (y)	$SPAN_{supine}$ (cm)	$SPAN_{sitting}$ (cm)
Females	23.4	31	10.8	10.6
	24.2	37	10	9.5
	24.5	30	11.8	10
	24.7	34	10	9.5
	24.9	35	10	9.3
	25.1	43	10	9.9
	25.5	33	9.8	9.2
	26	50	10.8	10
	27.2	39	11.4	10.8
	27.7	44	11.6	10.8
	28	47	11	10.6
Males	**BMI (kg/m^2)**	**Age (y)**	**$SPAN_{supine}$ (cm)**	**$SPAN_{sitting}$ (cm)**
	24.4	30	10.8	9
	24.7	42	11.8	10.7
	25.1	32	10	9.5
	25.6	51	10	10.4
	26.1	45	11.8	11
	26.8	34	12.3	11.7
	27.2	30	11.4	12
	28.1	60	12.6	12
	28.9	58	13	12.3

Mean RT Kidney span for male participants in supine position was 11.52 ± 1.08 while in sitting position was 10.95± 1.16 cm. For females participants was 10.65 ± 0.73 cm and 10.02 ± 0.60 respectively. Average decrease in span between supine and sitting position for all subjects was 6 %

Table 4.13. Left kidney span for females and males in supine and sitting positions

Organ LT Kidney	**BMI (kg/m^2)**	**Age (y)**	**$SPAN_{supine}$ (cm)**	**$SPAN_{sitting}$ (cm)**
Females	23.4	31	11	9.8
	24.2	37	10.5	10
	24.5	30	10.9	12
	24.7	34	11	10.5
	24.9	35	10.2	9.6
	25.1	43	10.5	10.6
	25.5	33	11	10.6
	26	50	11.2	10.8
	27.2	39	10.3	10
	27.7	44	11.7	11
	28	47	10.5	10
Males	**BMI (kg/m^2)**	**Age (y)**	**$SPAN_{supine}$ (cm)**	**$SPAN_{sitting}$ (cm)**
	24.4	30	10.4	10
	24.7	42	11.5	11.3
	25.1	32	10.1	9.4
	25.6	51	10.7	10
	26.1	45	11.6	11
	26.8	34	12	11.5
	27.2	30	11.5	11
	28.1	60	13.1	12.5
	28.9	58	13.7	13

Mean LT Kidney span for male participants in supine position was 11.62± 1.20 while in sitting position was 11.07± 1.18 cm. For females participants was 10.8 ± 0.44 cm and 10.44 ± 0.68 respectively. Average decrease in span between supine and sitting position for all subjects was 4 %

Table 4.14. Gallbladder span for females and males in supine and sitting positions

Organ GB	BMI (kg/m^2)	Age (y)	$SPAN_{supine}$ (cm)	$SPAN_{sitting}$ (cm)
Females	23.4	31	5	3.2
	24.2	37	6	5.5
	24.5	30	6.5	6
	24.7	34	6.3	5.8
	24.9	35	7	4.8
	25.1	43	5	1.8
	25.5	33	5.5	5
	26	50	5	4
	27.2	39	3.2	3
	27.7	44	3.5	3
	28	47	3.3	3.5
Males	**BMI (kg/m^2)**	**Age (y)**	**$SPAN_{supine}$ (cm)**	**$SPAN_{sitting}$ (cm)**
	24.4	30	6	5
	24.7	42	7	6.8
	25.1	32	7	6.6
	25.6	51	8	6.5
	26.1	45	5.1	4.6
	26.8	34	5.5	5
	27.2	30	6.8	6.6
	28.1	60	8.7	8
	28.9	58	9	5.6

Mean gallbladder span for male participants in supine position was 6.76 ± 1.36 while in sitting position was 6.08± 1.1 cm. For females participants was 5.11 ± 1.31 cm and 4.14 ± 1.36 respectively. Average decrease in span between supine and sitting position for all subjects was 16 %

Table 4.15. Right and left ovaries span measured in supine and setting positions.

Organ RT Ovary	**BMI (kg/m^2)**	**Age (y)**	**$SPAN_{supine}$ (cm)**	**$SPAN_{sitting}$ (cm)**
Females	23.4	31	2.5	2
	24.2	37	2.4	1.9
	24.5	30	1.8	1.3
	24.7	34	2.5	2
	24.9	35	2	1.6
	25.1	43	2	2.6
	25.5	33	2	1.7
	26	50	2.2	1.9
	27.2	39	2.1	1.9
	27.7	44	2.2	2
	28	47	2.1	1.9
Organ LT Ovary	**BMI (kg/m^2)**	**Age (y)**	**$SPAN_{supine}$ (cm)**	**$SPAN_{sitting}$ (cm)**
Females	23.4	31	2.1	1.5
	24.2	37	2.5	2
	24.5	30	2.4	2.3
	24.7	34	2.4	2.1
	24.9	35	2.2	1.8
	25.1	43	2.5	1.8
	25.5	33	1.9	1.7
	26	50	2.3	2.1
	27.2	39	2.3	2
	27.7	44	2.5	2.1
	28	47	2	1.8

Mean RT ovary span for female participants in supine position was 2.16 ± 0.22 while in sitting position was 1.90± 0.32 cm, for LT ovary was 2.28 ± 0.21 cm and 1.93 ± 0.23 respectively. Average decrease in span for RT ovary and LT ovary between supine and sitting position for all subjects was 13 % and 16% respectively.

Paired t-tests (two tailed) were used to analyze the difference in the spans of organs between supine and sitting positions at 95% confidence level. For right kidney females span for example the p-value was 0.0008, the difference is significant at $p<0.05$. For right ovary span differences, the result was also significant ($p = 0.02$).

Table 4.16 shows a comparison of organs span measured in this work and published in literature. In general, there is a good agreement with published values for different organs in spite the fact that our sample is small compared to these published works.

Table 4.16. Results of organ spans measured in this work compared with those published in literature. The table continues on the next page in supine position

Liver Span (cm)	(Kratzer et al., 2003)	(K. Islam, 2019)	(Patzak et al., 2014)	**This study (2024)**
Measured By USG	Average for adult males 14.0 ± 1.7 cm, Average for adult females 13.5 ± 1.7 cm	Average for adult males 15.1 ± 1.5 cm, Average for adult females 14.9 ± 1.6 cm	Average for adult males 15.1 ± 1.5 cm. Average for adult females 14.9 ± 1.6 cm	Average for males 16.58 ±1.43 cm Range 15.3-20 cm Average for females 14.5 ±0.7 cm Range 12.7-15.6 cm
Spleen Span (cm)	(Fateh et al., 2023)	(Badran et al., 2015)	(Ehimwenma & Tagbo, 2011)	**This study (2024)**
Measured By USG	Average for all subjects 10.685±1.283 cm For Males 11.266±1.160cm For Females 10.141 ±1.149cm	Average for all subjects 10.72±1.37 cm For Males 11.09±1.37 cm For Females 10.25±1.22 cm	Average for males 11.1±0.9 cm For Females 10.1 ±0.7 cm	Average for males 12.34 ±1.7 cm Range for males 9-14 Average for females 10.18 ±0.95 cm Range for females 9.5-12.5 cm
RT Kidney Span (cm)	(El-Reshaid & Abdul-Fattah, 2014)	(Oyuela-Carrasco et al., 2009)	(Raza et al., 2011)	**This study (2024)**
Measured By USG	Average of RT kidney 10.68 ± 1.4 cm	Average of RT kidney 10.3 ±0.06 cm	Average of the RT kidney 10.16±0.89 cm	Average for males 11.52 ±1.08 cm Range for males 10 -13 cm Average for females 10.65±0.73 cm Range for females 9.8-11.8cm

LT Kidney Span (cm)	(El-Reshaid & Abdul-Fattah, 2014)	(Oyuela-Carrasco et al., 2009)	(Raza et al., 2011)	**This study (2024)**
Measured By USG	Average of LT Kidney 10.71 ± 1.0 cm	Average for LT Kidney 10.58±0.75 cm	For the LT Kidney 10.27±0.92 cm	Average for LT Kidney for males 11.62±1.20 cm Range for males 10.1-13.7 Females 10.8±0.44 cm Range for females 10.2-11.7 cm
Gallbladder Span (cm)	(Jamal et al., 2022)	(Chavva & Karpur, 2018)	-	**This study (2024)**
Measured By USG	Average for all subjects 6.51 ± 0.61 cm For males 6.54 ±0.621 For females 6.64 ± 0.60	Average for all subjects 6.19 ± 1.09 For males 6.26±0.19 cm For females 6.09±0.18 cm	-	Average for males 6.70±1.35 cm Range 5.1-9 cm Average for females 5.11±1.31 cm Range 3.2- 7 cm
Ovaries Span (cm)	(Arya et al., 2023)	-	-	**This study (2024)**
Measured By USG	Average for right ovary 3.12± 0.29 Average for left ovary 3.08± 0.45	-	-	Average for right ovaries 2.16±0.21 cm Range 1.8-2.5 cm Average for left ovaries 2.28± 0.20 cm Range For LT Ovary 1.9-2.5 cm

4.2.3. Results of volume estimation and changes between supine and sitting postures of abdominal and pelvic organs

(1) LIVER

Table 4.17. Change in liver volume in supine and sitting postures for males & females (volume is calculated assuming ellipsoidal liver shape)

Organ LIVER	BMI (kg/m²)	Age (y)	V_{supine} (cm³)	$V_{sitting}$ (cm³)	Ratio V_{st}/V_{su}	% Decrease
Females	23.4	31	1393.3	980	0.70	30
	24.2	37	1297.36	1058.02	0.80	20
	24.5	30	1185.6	1122.88	0.95	5
	24.7	34	1397.03	1217.79	0.87	13
	24.9	35	1340.12	1127.35	0.84	16
	25.1	43	1280.5	1038.33	0.81	19
	25.5	33	1215.55	984.12	0.80	20
	26	50	1427.79	1174.32	0.82	18
	27.2	39	1320.13	1135.29	0.85	15
	27.7	44	1557.43	1378.10	0.88	12
	28	47	1324.96	1232.51	0.93	7
Males	**BMI (kg/m²)**	**Age (y)**	**V_{supine} (cm³)**	**$V_{sitting}$ (cm³)**	**Ratio V_{st}/V_{su}**	**% Decrease**
	24.4	30	1583.34	1114	0.70	30
	24.7	42	1988.23	1524.59	0.76	24
	25.1	32	1909.94	1650.74	0.86	14
	25.6	51	2484.31*	1578.3	0.63	36
	26.1	45	1660.39	1461.38	0.88	12
	26.8	34	1798.11	1519.64	0.84	16
	27.2	30	2111.2	1417.26	0.67	33
	28.1	60	1817.37	1543.99	0.84	16
	28.9	58	2496*	2261	0.90	10

*Fatty liver detected

Liver mean volume for male participants in supine position was 1919 ± 284 cm³, while in sitting position was 1476 ± 126 cm³. For females participants was 1340 ± 103 cm³ and 1132 ± 117 respectively. For all subjects the liver volume in sitting position is less than that in supine position. The change in male liver volume between supine and sitting position varies among participants with an average decrease of about 23%. In females this decrease is about 16%. Reported mean liver volume on ultrasound by (Farghaly et al., 2019) (n=100) in male was

1606.10 ± 398.04 cm^3, while in females was 1538.10 ± 233.42 cm^3. For our small sample size, we have higher averages. In case of males two patients with the highest measured values a fatty liver was detected which may be the reason for higher liver volume.

(2) SPLEEN

Table 4.18. Change in spleen volume in supine and sitting postures for males & females (Splenic volume was calculated using equation (1))

Organ Spleen	**BMI (kg/m^2)**	**Age (y)**	**V_{supine} (cm^3)**	**$V_{sitting}$ (cm^3)**	**Ratio V_{st}/V_{su}**	**% Decrease**
Females	23.4	31	270.6	176.75	0.65	35
	24.2	37	276.74	216.22	0.78	22
	24.5	30	286.2	276	0.96	4
	24.7	34	254.80	201.12	0.78	22
	24.9	35	269	183.61	0.68	32
	25.1	43	182.86	151.27	0.83	17
	25.5	33	170.91	128.50	0.75	25
	26	50	247.55	164.95	0.66	34
	27.2	39	228.30	159.91	0.70	30
	27.7	44	273	199.89	0.73	27
	28	47	249	159.8	0.64	36
Males	**BMI (kg/m^2)**	**Age (y)**	**V_{supine} (cm^3)**	**$V_{sitting}$ (cm^3)**	**Ratio V_{st}/V_{su}**	**% Decrease**
	24.4	30	233	177.7	0.76	24
	24.7	42	453	290	0.64	36
	25.1	32	284.96	223.46	0.78	22
	25.6	51	319	253.3	0.79	21
	26.1	45	363.87	276.77	0.76	24
	26.8	34	416.56	310.88	0.74	26
	27.2	30	279.6	224	0.80	20
	28.1	60	673.08	577.15	0.85	15
	28.9	58	745	445.3	0.60	40

The mean splenic volume for males in supine position was 418.67± 179.24 cm^3, while in sitting position was 308.73± 125.88 cm^3. The splenic volume decreases for males in average by about 25% between supine and sitting positions, while mean splenic volume for females in supine position is 246 ± 38 cm^3, while in sitting position is 183 ± 40 cm^3.The splenic volume decreases in average by about 26% between supine and sitting positions. Mean male spleen volume on ultrasound reported in a study (n=300, mean age 50.58), was 200.611±47.95, while for females was 149.907± 44.05, for all subjects was 174.40±52.45 cm^3.(Fateh et al., 2023). The spleen has a homogenous appearance, when it becomes enlarged, it loses this shape, it becomes very rounded, sometimes appears extending beyond the left kidney.

(3) RIGHT KIDNEY

Table 4.19. Change in right kidney volume in supine and sitting postures for males & females (Volume was calculated using equation (1))

Organ Rt Kidney	BMI (kg/m^2)	Age (y)	V_{supine} (cm^3)	$V_{sitting}$ (cm^3)	Ratio V_{st}/V_{su}	% Decrease
Females	23.4	31	211.47	129.50	0.61	39
	24.2	37	156.9	120.73	0.76	24
	24.5	30	165.9	133.95	0.80	20
	24.7	34	155.33	121.72	0.78	22
	24.9	35	159.53	131.85	0.83	17
	25.1	43	152.1	126.4	0.83	17
	25.5	33	130.39	103.73	0.79	21
	26	50	183.57	139.43	0.75	25
	27.2	39	165.39	131.04	0.79	21
	27.7	44	182	122	0.67	33
	28	47	171.6	114.1	0.66	34
Males	**BMI (kg/m^2)**	**Age (y)**	**V_{supine} (cm^3)**	**$V_{sitting}$ (cm^3)**	**Ratio V_{st}/V_{su}**	**% Decrease**
	24.4	30	129.7	106	0.82	18
	24.7	42	166.62	147.02	0.88	12
	25.1	32	160.77	116.75	0.72	28
	25.6	51	173.21	141.20	0.81	19
	26.1	45	182.05	126.16	0.69	31
	26.8	34	226.95	145.94	0.64	36
	27.2	30	165.78	134.78	0.81	19
	28.1	60	182.73	133.80	0.73	27
	28.9	58	209.56	175	0.83	17

For males, the mean right kidney volume was 177.5 ± 28.2 cm^3 in supine position and 136.3±19.8 cm^3 in sitting, while the average decrease was 23% while, the mean right kidney volume for females in supine position was 166.7 ±20.2 cm^3, in sitting was 125±10 cm^3 and average decrease in volume was 25%.

(4) LEFT KIDNEY

Table 4.20. Change in left kidney volume in supine and sitting postures for males & females.

Organ LT Kidney	BMI (kg/m^2)	Age (y)	V_{supine} (cm^3)	$V_{sitting}$ (cm^3)	Ratio V_{st}/V_{su}	% Decrease
Females	23.4	31	199.74	133.50	0.66	33
	24.2	37	134.54	94.45	0.70	39
	24.5	30	132.63	107.82	0.81	19
	24.7	34	152.45	121.08	0.79	21
	24.9	35	142.94	124	0.87	13
	25.1	43	126.12	124.02	0.98	2
	25.5	33	135.19	107.10	0.79	21
	26	50	155.34	114.32	0.73	27
	27.2	39	140.59	106.69	0.75	25
	27.7	44	190.91	134.96	0.70	30
	28	47	153.97	117.31	0.76	24
Males	**BMI (kg/m^2)**	**Age (y)**	**V_{supine} (cm^3)**	**$V_{sitting}$ (cm^3)**	**Ratio V_{st}/V_{su}**	**% Decrease**
	24.4	30	161.4	123.6	0.76	24
	24.7	42	180.43	133.32	0.73	27
	25.1	32	165.17	117.98	0.71	29
	25.6	51	208.17	149.68	0.72	28
	26.1	45	222.04	186.85	0.84	16
	26.8	34	285.93	219.76	0.77	23
	27.2	30	199.38	153.50	0.77	23
	28.1	60	220.33	154.28	0.70	30
	28.9	58	249.34	182.18	0.73	27

For males, the mean left kidney volume was 210.2 ± 40.2.2 cm^3 in supine position and 158 ±33 cm^3 in sitting, while the average decrease in volume was 25%. The mean left kidney volume for females in supine position was 151.3 ± 23.8 cm^3, in sitting was 116.8±12.3 cm^3 and average decrease in volume was 23%. Kidney dimensions are typically measured sonographically and used to calculate estimated volume. MRI and CT measurements have been shown to generally correlate well with ultrasonography. (Braconnier et al., 2020),(Cheong et al., 2007b). The most important influencing factors are BMI, height, gender, age, position of the kidneys, stenoses and number of renal arteries (Glodny et al., 2009) .The mean pole-to-pole length of an adult human kidney is 10-13 cm.

(5) Ovaries

Table 4.21. Volumes of right and left ovaries in supine and sitting position

Organ RT Ovary	**BMI (kg/m^2)**	**Age (y)**	**Volume $_{supine}$ (cm)**	**Volume $_{sitting}$ (cm)**	**Ratio**	**% Decrease**
Females	23.4	31	5.75	4.14	0.72	28
	24.2	37	5.02	3.58	0.71	29
	24.5	30	4.71	2.33	0.50	50
	24.7	34	5.23	3.57	0.68	32
	24.9	35	4.33	2	0.46	54
	25.1	43	6.24	5.51	0.89	11
	25.5	33	6.48	4.55	0.70	30
	26	50	6.21	4.13	0.67	33
	27.2	39	4.59	3.02	0.66	34
	27.7	44	4.14	3.01	0.73	27
	28	47	3.52	2.66	0.76	24
Organ LT Ovary	**BMI (kg/m^2)**	**Age (y)**	**Volume $_{supine}$ (cm)**	**Volume $_{sitting}$ (cm)**	**Ratio**	**% Decrease**
Females	23.4	31	3.8	2.11	0.56	44
	24.2	37	6.27	4.17	0.67	33
	24.5	30	6.81	4.06	0.60	40
	24.7	34	5.79	3.75	0.65	35
	24.9	35	4.6	2.71	0.59	41
	25.1	43	6.7	4.44	0.66	34
	25.5	33	6.99	5.15	0.74	26
	26	50	7.08	4.51	0.64	36
	27.2	39	4.79	3.01	0.63	37
	27.7	44	6.01	3.73	0.62	38
	28	47	5.26	2.62	0.50	50

The mean volume of right ovary in supine position is 5.11 ± 0.96 $cm^{3,}$ in sitting position 3.50 ± 0.10 cm^3 with an average decrease in volume by about 33%. The mean volume of left ovary in supine position is 5.82 ± 1.09 $cm^{3,}$ in sitting position 3.66 ± 0.93 cm^3 with an average decrease in volume by about 38%.

(6) Uterus

The Uterus volume varies between subjects in supine and sitting positions. The average volume in supine position was 69.70± 29.02 cm^3 (range 36.2 - 124.21 cm). In sitting position the average uterus volume was 51.76 ±20.24 cm^3 (range 23.22- 85.31 cm). The average decrease in volume for all subjects between supine and sitting position was about 25 %.

(7) Testicles

The mean volume of right testicle in supine position is 16.68± 5.43 cm^3 (range 9.8- 28.69 cm), in sitting position 11.98 ± 3.46 cm^3 with an average decrease in volume by about 28%. The mean volume of left testicle in supine position was 16.16± 5.27 cm^3 (range 10.7- 28.29 $cm^)$. In sitting position 11.09 ± 3.25cm^3 (range 7.9- 18.89 cm) with an average decrease in volume by about 31%. For testicles, the high percentage in average decrease volume between two postures due to testicles considered as a sac containing fluid not a solid organ, so the testicles are movable organs.

(8) Prostate

The Prostate volume varies between subjects in supine and sitting positions. The average volume in supine position was 19 ± 7 cm^3 (range 11-29 $cm^)$. In sitting position the average prostate volume was 12±5 cm^3 (range 7-20 cm). The average decrease in volume for all subjects between supine and sitting position was about 36%. The relatively larger decrease between supine and sitting for this organ may be caused by the location of the prostate just below the urinary bladder which cause pressure on the prostate while the subject is in sitting position.

(9) Urinary Bladder

The urinary bladder volume varies between subjects in supine and sitting positions. The average female volume in supine position was 160.98± 48.07 cm^3 (range 92.6- 244.8 cm). In sitting position the average volume was 109.22 ± 38.93 cm^3 (range 46.2- 171.7cm). The average decrease in volume for all female subjects between supine and sitting position was about 32%, while the average male volume in supine position was 183.61± 61.71 cm^3 (range 114.2- 286.54 cm). In sitting position the average volume was 129.66± 46.18 cm^3 (range 55.35- 197.8 cm). The average decrease in volume for all male subjects between supine and sitting position was about 29%

(10) Gallbladder

The Gallbladder volume varies between subjects in supine and sitting positions. The average female volume in supine position was 12.09 ± 4.46 cm^3 (range 7.21- 20.13 cm). In sitting position the average volume was 6.37 ± 1.99 cm^3 (range 2.6- 8.2 cm). The average decrease in volume for all female subjects between supine and sitting position was about 46%, while the average male volume in supine position was 17.07± 7.79 cm^3 (range 6.4-29.93 cm). In sitting position the average volume was 10± 4.8 cm^3 (range 3.46- 19.03 cm). The average decrease in volume for all male subjects between supine and sitting position was about 42%

For all organs in no subject, the volume of any organ in sitting position was equal or greater than that in supine position and the average decrease in volume between supine and sitting positions for all investigated organs was about 28%. To analyze the differences in organ volume between supine and sitting positions, paired t-tests (two-tailed) as well as were used for different organs separately for males and females and also for main organs together for both genders (for liver, spleen, right kidney and left kidney). For individual organs as well as for the main four organs also Wilcoxon Signed rank (the non-parametric version of the paired t-test) tests were used. The two tests gave similar results. For female right kidney volume difference, the two tailed p-value was 0.00001, for males liver volume the p-value was 0.0008. For female spleen volume differences analysis between supine and sitting positions p-value was 1.3×10^{-5}. For differences analysis in volumes including four main organs mentioned above (n=80 all the 4 organ volumes of all participants) a paired two tallied t-test and Wilcoxon signed rank test both gave a p-value < 0.00001. Both tests indicate a strong significant result in volumes difference at 95%.

4.2.4. Organ volume deformation

Volume of all organs was evaluated assuming ellipsoidal form using equation 1. Measurements however were conducted for realistic organs. Maximum organs dimensions were used in the calculations of organ volumes (span, AP and TR). These dimensions were measured for all organs in the tow investigated postures. Therefore, the deformation of any organ is the change in the value of any of the mentioned directions when changing the posture from supine to seated. The average change in span of organs from supine to seated posture ranges from 7% for spleen to 16% for left ovary. The average AP change varied from about 9% for right kidney to about 15% for right ovary. For transverse average change the range was from 7% for spleen to 11% for right kidney. Therefore, the deformation of volume occurred in all directions mainly in the span of the organs which has the largest influence on the calculation of organ volume.

4.2.5. Conclusion and Recommendation

The importance of this study stems from the following: it is the first attempt to study the organ sizes of healthy adult people in the abdominal and pelvic regions using Ultrasonography (USG), investigate the change in organ volume between the two postures. Also, the study has investigated the consistency of USG with MRI (considered the gold standard) in determining the size of abdominal organs and has found a very good agreement between the two modalities confirmed by different statistical analysis. For all subjects investigated in the study, all the measured organ volumes in sitting position were significantly less than that in supine position and the average decrease in volume between the two positions for all investigated organs was about 28%. The method showed that it is enough accurate to detect the change in organs size in different postures. In general, this work provides a good opportunity to investigate the importance of measuring the human body organs volumes in different clinical applications and can be considered as a first step and an accurate technique for the study of anthropometrical characteristics of the Palestinian population. The limitation of this study is the availability of volunteers therefore we recommend, based on the results of this study a nationwide investigation of the anthropometrical characteristics of our population.

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APENDIX (A)

PARTICIPATION FORM IN MEDICAL RESEARCH ACTIVITY

Project: Determination of Body Volume of Abdominal and Pelvic Organs Using Ultrasonography

نموذج مشاركة في نشاط بحثي طبي (تصوير أعضاء الجسم بالموجات فوق الصوتية)

ALL INFORMATION OBTAINED IN THIS FORM IS CONFIDENTIAL AND WILL BE USED FOR RESEARCH PURPOSES ONLY. جميع المعلومات الواردة في هذا الاستبيان يتم التعامل معها بسرية تامة وتستخدم لأغراض البحث العلمي فقط

I. General Information (معلومات عامة)

<table>
<tr><td colspan="2">Participant's Data
(معلومات المشارك)</td></tr>
<tr><td>Reference number :
الرقم المرجعي</td><td rowspan="2">Name الأسم</td></tr>
<tr><td>Participant No. الرقم التسلسلي</td></tr>
<tr><td>Address
العنوان</td><td>Cellular number الهاتف الخلوي</td></tr>
<tr><td>Weight (kg)
الوزن</td><td>Date of birth تاريخ الميلاد</td></tr>
<tr><td>Height
(m)
الطول</td><td rowspan="2">Comments ملاحظات</td></tr>
<tr><td>BMI ($kg.m^{-2}$) مؤشر كتلة الجسم</td></tr>
</table>

II. Medical condition (الوضع الصحي)

	Questions to be answered by the participant (يرجى الإجابة على جميع الأسئلة الواردة ادناه)
1	Do you have Hypertension? هل تعاني من ارتفاع ضغط الدم؟ Yes No
2	Do you have Diabetes? هل تعاني من مرض السكري؟ Yes No
3	Is there any previous surgery for abdomen or pelvis? هل لديك اي عمليات جراحية سابقة في البطن او الحوض؟ Yes No If yes what is/are the surgery/ surgeries? اذا كانت الاجابة نعم ما هي العمليات؟
4	Do you have any history of cancer? هل عانيت سابقا او تعاني حاليا من مرض السرطان؟ Yes No If yes what is the type of cancer? ؟ اذا نعم ما هو نوع السرطان
5	Did you do any prior medical imaging exam (ultrasound, CT or MRI)? هل تم عمل اي فحص من قبل سواء صورة تلفزيون , طبقية محوري او رنين مناطيسي؟ Yes No If yes what is the exam and modality? اذا نعم ما هو الفحص وباستخدام اي جهاز تم؟
6	Do you have any fatty liver? هل تعاني من دهون على الكبد؟ Yes No Don't know
7	Do you have any kidneys' cyst? هل تعاني من أكياس على الكلى؟ Yes No Don't know
8	Are you pregnant? هل يوجد حمل ؟ Yes No Not applicable
9	Have you ever been participated in medical trials before? هل سبق لك أن شاركت في تجارب طبية ؟ Yes No If yes what kind of trials? اذا كان الجواب نعم فما هي؟

III. Preparation for ultrasound exams (التأكد من الجهوزية لإجراء الفحص صوتية)

Please answer the following questions يرجى الإجابة على جميع الأسئلة المدرجة ادناه	
1	Did you have any meals or drinks eight hours before the exam? هل تناولت اي وجبة غذائية او شربت شيئا في الثمان ساعات الاخيرة قبل الفحص؟ Yes No
2	Did you drink approximately a 1L of water before the exam? هل تم شرب ما يقارب لتر واحد من المياه قبل الفحص؟ Yes No
3	Is your bladder full? هل مثانتك ممتلئة قبل الدخول الى الفحص؟ Yes No

I declare that all information I provided in this participation form is true. (اصرح بان جميع المعلومات الواردة في هذا النموذج صحيحة)	
Participant Signature توقيع المشترك	Date التاريخ

Name and signature of radiation technologist اسم وتوقيع فني الاشعة	Date التاريخ

APENDIX(B)

INFORMED CONSENT FORM PARTICIPATION IN MEDICAL RESEARCH ACTIVITIES

Participant Name: ……………………………………………………………………

Reference number: …………………………………

I. Project Title

The effect of posture on position of the abdominal and pelvic organs using USG

II. My participation will involve the following:

I will be scanned for abdominal and pelvic organs by Ultrasonography in supine, setting and standing position

After signing this consent form which means that you have read this form then you have received oral communications of all the information provided in this form. You should understand all the information and have had any questions that have answered regarding this procedure, so you agree that you:

1. I agree to participate in the research study being conducted by student Jessica Badawi, a Master program student under the supervision of Prof. Adnan Lahham and Dr. Nader Sarhan.
2. The study shall be conducted in Al- Yamamah hospital in Bethlehem.
3. I have been informed of how long the procedure will take which is about one and half hour.
4. I understand that there is no risk that might be associated with this research.
5. I understand that the possible benefits to myself or society from this research are:
    a. Scanning of my body with Ultrasonography will provide valuable information about the health conditions of some of my body organs
    b. My participation is beneficial for the whole society particularly for the study of the anthropometrical characteristics of the Palestinian population.
6. Have been explained the preparation for the procedure to the participant in details
7. I understand that my participation is voluntary and that I may refuse to participate and/or withdraw my consent and discontinue participation in the project or activity at any time without penalty or loss of benefits to which I am otherwise entitled.
8. I understand that the investigator(s) will take all reasonable measures to protect the confidentiality of my records and my identity will not be revealed in any publication that may result from this project.
9. I understand that I am responsible for immediately telling the radiologist or the technologist if I am having any discomfort during the procedure
10. I am sound mind and not under the influence of alcohol or hallucinogenic drugs
11. In the event of such an abnormality being discovered during the scan, I agree that I should be informed of the abnormality by the researchers about any findings concerning my health conditions found during the course of my participation in this research.

I declare, I have received a copy of this informed consent form which I have read and understand. I have no reservations then i hereby consent to participate in the research described.

Participant's Signature: Date:
Witness: Name & signature: Date:

For researchers use only: I have explained and defined in detail the research procedure in which the subject has consented to participate. Having explained this and answered any questions, I am cosigning this form and accepting this person's consent. Researcher name: Signature: Date:

CONSENCT FORM ARABIC

موافقة على المشاركة في فحوصات طبية لأغراض البحث العلمي اسم المشارك : .... الرقم :..

أ. عنوان المشروع:

قياس حجم أعضاء الجسم في منطقتي البطن والحوض باستخدام تقنية التصوير بالموجات فوق الصوتية

ب. الهدف من البحث
معرفة حجوم وابعاد الأعضاء الداخلية لعينة من الشعب الفلسطيني وذلك لأهمية هذا الموضوع في دراسة الخصائص المورفولوجية للجمهور والاستخدام في علاج مرضى السرطان بالإشعاع المؤين.

ج. مشاركتي في هذا البحث تشمل ما يلي:
اجراء فحوصات لبعض الأعضاء الداخلية بالموجات فوق الصوتية في ثلاث وضعيات مختلفة وهي الاستلقاء والجلوس والوقوف.

ان التوقيع على هذه الاتفاقية يعني بانك قد قرات جميع ما ورد فيها من معلومات وانه تمت الإجابة الشفوية على جميع الاسئلة التي طرحتها على الباحثين وانك فهمت دورك في هذا البحث وبتوقيعك توافق على ما يلي:

1. أوافق على الدراسة البحثية التي تجريها الطالبة جيسيكا بدوي تحت اشراف كل من أ.د عدنان اللحام و د. نادر سرحان
2. ان هذه الدراسة البحثية سيتم اجرائها في مستشفى اليمامة
3. الفترة اللازمة لمشاركتي في البحث قد تصل الى ساعة ونصف الساعة
4. لقد فهمت بان المشاركة في هذا البحث لا تسبب لي أية اضرار صحية محتملة
5. لقد فهمت بان مشاركتي مفيدة من ناحيتين وهما: الحصول على معلومات مجانية عن وضعي الصحي وكذلك المشاركة في بحث علمي يساعد في تطوير دراسة تخص الشعب الفلسطيني
6. تم اعلامي وتوعيتي بكيفية التحضير لإجراء الفحوصات
7. اعلم بان مشاركتي في هذا البحث هي مشاركة طوعية بمحض ارادتي ومن حقي ان ارفض هذه المشاركة في أي وقت خلال فترة اجراء البحث
8. لقد فهمت ان الباحثين سيتعاملون بسريه تامة مع المعلومات الخاصة بي وان شخصيتي لن تظهر في أي تقرير او بحث علمي ينتج عن هذا المشروع
9. أؤكد بانني بكامل وعيي واتمتع بكامل قواي العقلية
10. في حال تبين وجود أي مرض في جسمي اثناء فترة الفحص أوافق ان يتم اعلامي عن ذلك من قبل الباحثين

اقر بانني استلمت نسخة من هذه الموافقة التي قراتها و فهمتها ولا يوجد لدي أي تحفظ للمشاركة في هذا المشروع البحثي . توقيع المشارك : .... التاريخ: .... اسم وتوقيع الشاهد : .... التاريخ: ....

لاستعمال الباحثين فقط لقد قمت بشرح مفصل لطبيعة وإجراءات البحث للمشارك وتمت الإجابة على جميع استفساراته وعليه فانني اقبل مشاركة هذا المتطوع وعلى ذلك أوقع: اسم الباحث وتوقيعه: .... التاريخ: ....

APENDIX (C)

INSTRUCTIONS FOR PARTICIPANTS

(abdominal & pelvic ultrasound)

The effect of posture on position of the abdominal and pelvic organs using USG

1. All participants are requested to arrive at the clinic exactly at the scheduled time
2. Do not eat any solid or liquid food 8 hours before the exam (at midnight if your exam is in the morning). However, you can take your medicine with a little water if applicable.
3. If your exam is after 13:00, do not eat fatty food in the morning (muffins, eggs, cheese, butters made of peanuts or nuts, butter or margarine).
4. You must have a full bladder when you arrive at the clinic. Make sure you drink about 1 liter of water or juice 75 minutes before the exam and don't urinate, unless the doctor directs otherwise.

تعليمات للمشاركين (الصور التلفزيونية للبطن والحوض)

1. على جميع المشاركين الالتزام بالوقت المحدد لإجراء الفحص.
2. لا يجوز تناول الطعام والشراب ثمانية ساعات قبل الفحص اي عند منتصف الليل اذا كان الفحص في الصباح، ويستطيع من يتناول ادوية ان يتناول ذلك مع قليل من الماء.
3. اذا كان الفحص بعد الواحدة ظهرا لا يجوز للمشارك تناول أغذية دسمة في الصباح مثل (الكعك، جبنة، بيض، زبدة او مرغرين)
4. يجب على المشارك ان يحافظ على مثانة ممتلئة عند حضوره لإجراء الفحص . يجب التأكد من شرب حوالي لتر واحد من الماء او العصائر قبل اجراء الفحص بحوالي 75 دقيقة وعدم التبول مالم يسمح الطبيب بذلك.

Alayyad Health Co. | **شركة العياد هيلث للخدمات الطبية**

Al – Yamamah Hospital | **مستشفى اليمامة**

Bethlehem – Alkhader | **بيت لحم – الخضر**

Research & Ethical Approval Letter

Reference No: 01/YREL/2021 Date: July 25, 2021

Dear researchers;

Prof. Adnan Lahham
Dr. Nader Sarhan and
Miss. Jessica Badawi

After reviewing your application for research and ethical approval of the project entitled "Determination of body volume of abdominal and pelvic organs using ultrasonography", the responsible Committee formed by the medical Director of the hospital confirms that your application is in accordance with the ethical policies applied at our hospital.

This letter will be valid for one year only.

Sincerely,

Dr. Osama Al-Bud
Medical Director of the Hospital

Cc. file

دراسة تأثير الوضعية على حجم أعضاء البطن والحوض باستخدام الموجات فوق الصوتية

إعداد: جيسيكا سليم جريس بدوي
المشرف: الاستاذ الدكتور عدنان اللحام

الملخص

تعتبر دراسة حجوم أعضاء جسم الإنسان ومواقعها السريرية ذات أهمية خاصة في التطبيقات السريرية المختلفة بما في ذلك التشخيص والعلاج. هذا النوع من الدراسات مهم أيضا في التحقق من الخصائص المتعلقة بقياسات السكان أيضا (انثروبومترية). تتناول هذه الأطروحة قياس وتحديد أبعاد وحجوم أعضاء الأشخاص البالغين الأصحاء في مناطق البطن والحوض باستخدام التصوير بالموجات فوق الصوتية (USG) في وضعي الاستلقاء والجلوس وتحديد التغير في حجم الأعضاء الناجم عن الاختلاف بين الوضعين. أجريت الدراسة على عشرين مشاركا من غير المرضى (11 اناث و9 ذكور). تراوحت أعمار جميع الأشخاص بين 30 و70 عاما وذوي مؤشرات كتل اجسام مختلفة. حيث بلغ متوسط مؤشر كتلة الجسم لدى الإناث 25.56 ± 1.49 كجم/م2 وللذكور 26.32 ± 1.55 كجم/م2. قبل قياس أحجام الأعضاء بواسطة USG، أجريت دراسة تجريبية على شخصين ذكر وانثى وذلك للتحقق من دقة استعمال طريقة USG مع تقنية التصوير بالرنين المغناطيسي (MRI) والتي تعتبر المعيار الذهبي في قياس ودراسة أبعاد أعضاء الجسم المختلفة. وقد تم قياس كل من البعد الاعظمي والابعاد الأخرى للأعضاء ذات العلاقة وحساب حجوم الأعضاء للشخصين المشاركين في الدراسة التجريبية من خلال تقنيات التصوير بالرنين المغناطيسي وUSG في وضع الاستلقاء وذلك وفقا للبروتوكولات القياسية المستعملة في كل من التقنيتين. اما الاعضاء التي تم قياسها فهي: الكبد والطحال والكليتين والمبيضين والبروستاتا والمثانة والمرارة والخصيتين. وبينت جميع التحاليل الإحصائية لنتائج جميع قياسات الأعضاء للشخصين بما في ذلك مقارنة الرسوم البيانية، ومخططات الاحتمال الطبيعي للفروق بين التقنيتين، وكذلك تحليل الفروق الإحصائية بين التقنيتين (تحليل بلاند–

ألتمان) جميعها اكدت وجود علاقة قوية بين التصوير بالرنين المغناطيسي وUSG في تحديد أبعاد الأعضاء (الابعاد الاعظمية والحجوم). على سبيل المثال، بلغ معامل الارتباط بين التصوير بالرنين المغناطيسي وUSG في قياس الابعاد الاعظمية لأعضاء البطن والحوض عند الانثى المشاركة في وضع الاستلقاء 0.99. كان متوسط الفرق (التحيز) حوالي 0.0012، وكان CI السفلي عند مستوى ثقة 95٪ − 0.33، وبلغ CI العلوي عند مستوى ثقة 95٪ 0.33. كما تم الحصول على نتائج متوافقة بين التقنيتين للذكر المشارك في الدراسة التجريبية. كذلك تم حساب أحجام الأعضاء من الأبعاد المقاسة (AP والطول والعرض) بافتراض الشكل الإهليلجي للأعضاء. كانت الأحجام المحسوبة للشخصين المشاركين في الدراسة التجريبية متوافقة مع القيم المنشورة في الدراسات الاخرى. كذلك كانت المقارنة بين حجم الكبد المحسوب في الدراسة وباستخدام معادلة Child والتي تعتبر الأكثر دقة لتقدير حجم الكبد باستخدام الموجات فوق الصوتية D2 في توافق جيد جدا (فرق حوالي 0.6٪ بين الحساب الذي اجري في هذه الدراسة والمعادلة المذكورة سابقا). اما القياسات في وضع الجلوس ولجميع عينة الدراسة فقد أجريت فقط باستخدام تقنية USG على كرسي تم تحضيره خصيصا لغرض هذه الدراسة. واظهرت القياسات متوسط البعد الاعظمي للطحال لجميع الإناث في وضع الاستلقاء 10.97 ±0.94 سم، وفي وضع الجلوس 10 ± 0.7 سم. للذكور 12.38 ± 1.70 سم في وضع الاستلقاء و11.72 ± 1.68 سم في وضعية الجلوس يختلف متوسط الانكماش في البعد الاعظمي بين الأعضاء من حوالي 5٪ للطحال إلى حوالي 16٪ للمبيض الأيسر عند النساء. كان هناك فرق ذو دلالة إحصائية بين الابعاد الاعظمية للأعضاء في وضعي الاستلقاء والجلوس . لم يكن حجم أي عضو في وضع الجلوس مساويا أو أكبر من ذلك في وضع الاستلقاء وكان متوسط الانخفاض في الحجم بين أوضاع الاستلقاء والجلوس لجميع الأعضاء التي تم فحصها حوالي 28٪. لتحليل الفروق في حجم الأعضاء بين وضعية الاستلقاء والجلوس، تم استخدام اختبارات t المزدوجة وكذلك تحليل Wilcoxon Signed للأعضاء مختلفة بشكل منفصل للذكور والإناث وأيضا للأعضاء الرئيسية معا لكلا الجنسين (للكبد والطحال والكلى اليمنى والكلى اليسرى). بالنسبة للأعضاء الفردية

وكذلك للأعضاء الأربعة الرئيسية، تم أيضا استخدام اختبارات Wilcoxon Signed أعطى الاختباران نتائج متقاربة بالنسبة لفرق حجم الكلى اليمنى للإناث، كانت القيمة $p < 0.00001$، وبالنسبة لحجم كبد الذكور، كانت القيمة $p = 0.0008$. بالنسبة لتحليل اختلافات حجم الطحال الأنثوي بين وضعيات الاستلقاء والجلوس، كانت القيمة $p = 1.3x10-5$. لتحليل الاختلافات في الأحجام بما في ذلك أربعة أعضاء رئيسية مذكورة أعلاه (ن = 80 جميع أحجام الأعضاء الأربعة لجميع المشاركين)، أعطى كل من اختبار t المزدوج واختبار Wilcoxon الموقع قيمة $p < 0.00001$. يشير كلا الاختبارين إلى اختلاف قوي ذو دلالة إحصائية عند مستوى ثقة بنسبة 95٪. الاختلافات في الابعاد الاعظمية للأعضاء وأحجامها بين أوضاع الاستلقاء والجلوس ذات دلالة إحصائية وبالتالي يمكن اكتشافها وتحديدها عن طريق التصوير بالموجات فوق الصوتية.