Measurement of the Prostate Motion in External Beam Radiotherapy

A Thesis submitted for partial fulfillment for the Academic Requirements of Master degree in Medical Physics

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وراحت الأداة
Dedication

I dedicate my research to my family and friends. A special feeling of gratitude to my loving parents and to my husband. And I hope that I was succeeded satisfy all the wanted information.
Acknowledgement

A special thanks to Dr. Yousif Mohamed Yousif Abdallah my supervisor for his countless hours of reflecting, reading, encouraging, and most of all patience throughout the entire process. I would like to acknowledge and thank my colleagues in the Sudan university of Sciences and technology for allowing me to conduct my research and providing assistance requested. Special thanks go to the members of the Medical Physic Department for their continued support. Finally I would like to thank my teachers, for advices that helped me to complete my study.
Abstract:

Organ motion in Radiotherapy induce an error in the received dose by the tumour therefore this experimental study conducted at different hospitals in Sudan (Radiation and Isotopes Centres of Khartoum (RICK) and Antalya clinic centre in period of 7 months, from May 2014 to December 2014.

The main objective of this study was to detect and measure the periodic physiological prostate motion during external beam radiotherapy (inspiration and expiration) , to accurate and continuous tumor location information , to investigate intrafraction prostate and patient motion during radiation therapy treatments .

The data collected using Image Registration Technique and Point Mapping using Mat Lab program.

The result of the study were (9.19±1.77 mm) for body contour and (4.22±1.07 mm) for prostate.

The motion was significantly attached the dose of radioactive which expected to be given for prostate treatment.
الملخص:

التركيبة النسبية لوزن اليميني: 9.19 ± 1.77 مل.م، والتركيبة النسبية لوزن اليسري: 4.22 ± 1.07 مل.م، إنها نتيجة دراسة ت komt أن تأثير تناوله على تركيبة الوزن في المنطقة.

(Rick أنشأ يسا مواز أو يشا ما زا أو يشا مو زا أو يشا.)

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<td>4DCT</td>
<td>four-dimensional computed tomography</td>
</tr>
<tr>
<td>CT</td>
<td>Computed Tomography</td>
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<tr>
<td>IGRT</td>
<td>image-guided radiation therapy</td>
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<tr>
<td>AP</td>
<td>anterior–posterior</td>
</tr>
<tr>
<td>S-I</td>
<td>superior–inferior</td>
</tr>
<tr>
<td>IMRT</td>
<td>Intensity modulated radiation therapy</td>
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<tr>
<td>GTV</td>
<td>gross tumor volume</td>
</tr>
<tr>
<td>IGTV</td>
<td>internal gross tumor volume</td>
</tr>
<tr>
<td>IGTVMIP</td>
<td>internal gross tumor volume maximum intensity projection</td>
</tr>
<tr>
<td>MIP</td>
<td>maximum intensity projection</td>
</tr>
<tr>
<td>EBRT</td>
<td>External beam radiation therapy</td>
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<tr>
<td>HDR</td>
<td>high-dose rate</td>
</tr>
<tr>
<td>LDR</td>
<td>low-dose rate</td>
</tr>
<tr>
<td>ICRU</td>
<td>International Commission on Radiation Units</td>
</tr>
<tr>
<td>CTV</td>
<td>Clinical Target Volume</td>
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<tr>
<td>NCI</td>
<td>National Cancer Institute</td>
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<tr>
<td>OAR</td>
<td>Organs at Risk</td>
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<td>TCP</td>
<td>Tumors Control Probability</td>
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<tr>
<td>RICK</td>
<td>radiation and isotopes center of Khartoum</td>
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Introduction

1.1. Introduction:

Prostate cancer is the most common cancer in men in the UK, with over 40,000 new cases diagnosed every year, and usually develops slowly. For many men with prostate cancer, treatment is not immediately necessary. If the cancer is at an early stage and not causing symptoms, a policy of “watchful waiting” or “active surveillance” may be adopted. This involves carefully monitoring your condition. Some cases of prostate cancer can be cured if treated in the early stages. Treatment includes surgically removing the prostate, radiotherapy, and hormone therapy. In some cases, the cancer is only diagnosed at a later stage when the cancer has spread to other parts of the body, typically the bones. It cannot be cured and treatment is focused on prolonging life and relieving symptoms. All treatment options carry the risk of significant side effects, including erectile dysfunction and urinary incontinence. For this reason, many men choose to delay treatment until there is a risk the cancer might spread. Radiation therapy may be used as an initial treatment for localized prostate cancer; it may also be used as treatment for cancer that has not been fully removed or has recurred after surgery. In advanced cancer, radiation therapy is used to shrink the size of the tumor and relieve symptoms. 

(EBRT) uses a machine that focuses a beam of radiation directly on the tumor. An EBRT treatment lasts a few minutes and is given 5 times a week over the course of 7-9 weeks. Doctors use imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) to precisely map out where the beams are aimed at the tumor cells. Newer types of EBRT allow doctors to increase radiation doses while minimizing damage to nearby tissue. Higher radiation doses may reduce the risk for cancer recurrence and improve survival outcome. Three-
dimensional conformal radiation therapy (3D-CRT) uses a computerized program and three-dimensional image of the prostate to precisely target the tumor (sharp et.al 2002).

Brach therapy is a type of radiation therapy used mainly for men who have early-stage or localized prostate cancer. It can also be used in combination with external beam therapy. Brach therapy involves implanting radioactive pellets ("seeds") directly into the prostate. Implants can be permanent or temporary. In permanent brachytherapy, the pellets are surgically implanted and sealed in place to continue to deliver low-dose radiation for weeks or months. In temporary brachytherapy, the pellets are deposited and held temporarily in place inside of catheters for a treatment session that lasts 5-15 minutes. The catheters and pellets are then removed. The patient usually receives about 3 treatments over the course of 2 days. With temporary brachytherapy, a higher dose of radiation can be used. In EBRT, beams of radiations are focused on the prostate gland from a machine outside the body. This type of radiation can be used to try to cure earlier stage cancer, or to help relieve symptoms such as bone pain if the cancer has spread to a specific area of bone. To reduce the risk of side effect, Doctors carefully figure out the exact dose of radiation needed and aim the beam as accurately as they can to the carefully outline target. Before treatment start, imaging tests such as MRIs, CT scan or plain X-rays of the pelvis are done to find the exact location of prostate gland. The radiation team may then make some ink marks on patient skin that they will use later as a guide to focus the radiation in the right area. EBRT for prostate cancer is most often given using techniques that let doctors give higher doses of radiation to the prostate gland while reducing the radiation exposure to nearby healthy tissue (Minnehaha, et al. (2010)).
1.2. The problem:

The uncertainties, in the physical realm, can now easily be detected and corrected. What is meant by this is that now, in principle, it is possible to target any clearly visible object in the body with such a precision that only a few mm. Margin is required to account for residual uncertainties such as calibration issues and intrafractional motion. In the past, the net effect of the uncorrected uncertainties often required margins of 1 cm or more, this potential addition of margin can lead to an enormous reduction in the amount of normal tissue that is exposed to a high dose, with a large increase in therapeutic ratio. In addition to this there are many problems due to the absence of IGRT which is used to improve the accuracy of the radiation field placement, and to reduce the exposure of healthy tissue during radiation treatments.

1.3. Objectives:

1.3.1. General objective:

The main objective of this study is to estimate the prostate motion during prostate external beam irradiation.

1.3.2. Specific objective:

- To monitor prostate organ motion in external beam irradiation during inspiration and expiration.
- To estimate the prostate motion in respect to body contour motion .
- To investigate intrafraction prostate and patient motion during radiation therapy treatments.
1.4. Overview of the study:

This study consists of five chapters. Chapter one is introduction, problem of the study, objectives of the study and overview of the study. Chapter two is literature review. Chapter three is materials and Methods. Chapter four is results and chapter five consists of discussion, conclusion and recommendations.
Chapter Two

2.1 Literature Review

Prostate cancer is now the commonest cancer in men, accounting for almost 25 percent of all new male cancer diagnoses and is the second most common cause of cancer related death in men. There has been a huge rise in the recorded incidence of prostate cancer with the use of prostate-specific antigen (PSA) and surgery for benign prostatic hypertrophy (BPH), but this is not reflected in increased mortality rates. There are almost 32 000 new cases and 10 000 deaths from prostate cancer a year in the UK. However, most men die with their prostate cancer rather than from it and management must balance the potential toxicity of active treatment, with the chances of benefit in a disease with a long natural history. Advances in diagnosis and screening policies with the use of PSA have led to a stage migration so that prostate cancer is now detected at earlier stages with better prognostic features. The most common type of prostate cancer is adenocarcinoma (95 percent). Tumors’ are graded using the Gleason scoring system which evaluates architectural details of individual cancer glands and describes five distinct growth patterns from Gleason 1 (well differentiated) to Gleason 5 (poorly differentiated). The two commonest growth patterns seen are summated to give a final Gleason score (GS) ranging from 2 (1-1) to 10 (5-5). There are other rarer types of prostate carcinoma such as ductal, intralobular acinar, small cell and clear cell. This chapter focuses on the treatment of the common adenocarcinoma. There is less evidence to guide treatment of other pathological subtypes. Prostate cancer is staged using the AJCC and TNM staging. Tumors are stratified by T stage, GS and PSA into three prognostic groups of low, intermediate and high risk:

- Low risk: T1–T2a and PSA _10 ng/mL and GS 6
Intermediate risk: T2b or PSA 10–20 ng/mL or GS 7

High risk: T2c–T4 or PSA _20 ng/mL or GS 8–10.

The risk is higher in an intermediate risk patient who has GS 4-3 than with GS 3-4. Patients can be offered appropriate treatment options by a multidisciplinary team, according to stage of disease, prognostic risk group and estimated survival taking into account performance status and co morbidity. EBRT, interstitial brachytherapy and surgery are options for the curative treatment of localized prostate cancer with equivalent outcomes but different side effects. The options for treatment of low, intermediate and high risk prostate cancer are listed in Box 28.1. Factors that influence the choice include PS, other medical illnesses, likelihood of progression to symptomatic disease, life expectancy, morbidity of treatment (particularly on sexual function) and patient preference (Barrett et al,2009).

<table>
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<th>Table 2-1. Treatment options for localized prostate cancer</th>
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<td>■ Prostate iodine-125 brachytherapy</td>
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<tr>
<td>■ Radical prostatectomy (open/laparoscopic/robotic)</td>
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<td>■ Radical prostatectomy (open/laparoscopic/robotic)</td>
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<td>■ Radical EBRT with 6 months HT (_WPRT)</td>
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<td>■ Radical EBRT with 2–3 years HT (_WPRT)</td>
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<td>■ Hormone therapy alone</td>
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<td>■ Watchful waiting</td>
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HT, hormone therapy; WPRT, whole pelvis radiotherapy.

In general patients should have a life expectancy of greater than 10 years before Radical treatment is recommended. Men younger than 75 with other major illnesses such as ischemic heart disease and diabetes may not live 10 years and
men over 75 with no other illnesses may live into their nineties. There is evidence that radical radiotherapy in fit men over 75 is very well tolerated and just as effective. It is the role of the multidisciplinary team to identify patients who will benefit from radical treatment and counsel the patient on the different options available. Radical treatments with surgery, EBRT or brachytherapy have similar outcomes and the patient should be informed of the different side effects of each treatment. Factors that influence the final choice for an individual patient include lower urinary tract symptoms, sexual function, likelihood of infertility, and risks of anaesthesia and surgery. The benefits and risks of surgery, EBRT and brachytherapy are shown in table 2.1. The results of radiotherapy are assessed by monitoring the PSA, DRE and symptoms and signs of metastases. A PSA nadir of _2 within 2 years is associated with long term control. Biochemical failure is defined by a rise in PSA by 2.0ng/mL above the nadir level following radiotherapy, according to the international RTOG-ASTRO (Barrett et al, 2009). Published nomograms are very useful for assessing potential benefits from treatment. The Memorial Sloane Kettering pretreatment monogram gives a 5-year progression-free probability following radical EBRT from 70-90 per cent for low risk to 50-70 percent for intermediate risk and 20-50 per cent for high risk prostate cancer (Barrett et al, 2009).

2.2. Radiation therapy for prostate cancer:
Radiation therapy uses high-energy rays or particles to kill cancer cells. Radiation may be used:

- As the initial treatment for low-grade cancer that is still confined within the prostate gland. Cure rates for men with these types of cancers are about the same as those for men getting radical prostatectomy.
• As part of the first treatment (along with hormone therapy) for cancers that have grown outside of the prostate gland and into nearby tissues.
• If the cancer is not completely removed or comes back (recurs) in the area of the prostate after surgery.
  • If the cancer is advanced, to reduce the size of the tumor and to provide relief from present and possible future symptoms.

Two main types of radiation therapy can be used: external beam radiation and brachytherapy (internal radiation). Both appear to be good methods of treating prostate cancer, although there is more long-term information about the results of treatment with external beam radiation. (Another type of radiation therapy, in which a medicine containing radiation is injected into the body, is described in the section "Preventing and treating prostate cancer spread to the bone.")

2.2.1. External beam radiation therapy (EBRT)

In EBRT, beams of radiation are focused on the prostate gland from a machine outside the body. This type of radiation can be used to try to cure earlier stage cancers, or to help relieve symptoms such as bone pain if the cancer has spread to a specific area of bone. To reduce the risk of side effects, doctors carefully figure out the exact dose of radiation needed and aim the beams as accurately as they can to hit the carefully outlined target. Before treatments start, imaging tests such as MRIs, CT scans, or plain x-rays of the pelvis are done to find the exact location of your prostate gland. The radiation team may then make some ink marks on your skin that they will use later as a guide to focus the radiation in the right area. Each treatment is much like getting an x-ray. The radiation is stronger than that used for an x-ray, but the procedure is painless. Each treatment lasts only a few minutes,
although the setup time — getting you into place for treatment takes longer. EBRT for prostate cancer is most often given using techniques that let doctors give higher doses of radiation to the prostate gland while reducing the radiation exposure to nearby healthy tissues.

2.2.2. Three-dimensional conformal radiation therapy (3D-CRT)

3D-CRT uses special computers to precisely map the location of your prostate. Radiation beams are then shaped and aimed at the prostate from several directions, which makes it less likely to damage normal tissues. You will most likely be fitted with a plastic mold resembling a body cast to keep you in the same position each day so that the radiation can be aimed more accurately. This method seems to be at least as effective as standard radiation therapy with lower side effects. (Milano et al, 2005).

2.2.3. Intensity modulated radiation therapy (IMRT)

IMRT is an advanced form of 3D therapy. It uses a computer-driven machine that actually moves around the patient as it delivers radiation. In addition to shaping the beams and aiming them at the prostate from several angles, the intensity (strength) of the beams can be adjusted to minimize the dose reaching the most sensitive normal tissues. This lets doctors deliver an even higher dose to the cancer areas. This is the most common method of giving external beam radiation for prostate cancer. Some newer radiation machines have imaging scanners built into them. This advance, known as image guided radiation therapy (IGRT), lets the doctor take pictures of the prostate and make minor adjustments in aiming just before giving the radiation. This may help deliver the radiation even more precisely, which may result in fewer side effects, although more research is needed to prove
this. A variation of IMRT is called volumetric modulated arc therapy. It uses a machine that delivers the radiation quickly as it rotates once around the body. This allows each treatment to be given over just a few minutes. Although this can be more convenient for the patient, it hasn’t yet been shown to be more effective than regular IMRT. Another approach is to place tiny implants into the prostate that send out radio waves to tell the radiation therapy machines where to aim. This lets the machine compensate for movement (like during breathing) and may allow less radiation to go to normal tissues. In theory, this could lower side effects. So far, though, no study has shown side effects to be lower with this approach than with other forms of IMRT. The machines that use this are known as Calypso (Milano et al, 2005).

2.2.4. Stereotactic body radiation therapy (SBRT)

This technique uses advanced image guided techniques to deliver large doses of radiation to a certain precise area, such as the prostate. Because there are large doses of radiation in each dose, the entire course of treatment is given over just a few days. SBRT is often known by the names of the machines that deliver the radiation, such as Gamma Knife, X-Knife, Cyber Knife, and Clinac. The main advantage of SBRT over IMRT is that the treatment takes less time (days instead of weeks). Side effects, though, are not better. In fact, one study showed that some side effects were actually worse with SBRT as compared with IMRT in men treated for prostate cancer.

2.2.5. Proton beam radiation therapy

Proton beam therapy focuses beams of protons instead of x-rays on the cancer. Protons are positive parts of atoms. Unlike x-rays, which release energy both
before and after they hit their target, protons cause little damage to tissues they pass through and release their energy only after traveling a certain distance. This means that proton beam radiation can, in theory, deliver more radiation to the prostate while doing less damage to nearby normal tissues. Proton beam radiation can be aimed with similar techniques to 3D-CRT and IMRT. Although early results are promising, so far studies have not shown that proton beam therapy is better in the long-run than other types of external beam radiation. Right now, proton beam therapy is not widely available. The machines needed to make protons are very expensive, and they aren’t available in many centers in the United States. Proton beam radiation might not be covered by all insurance companies at this time. Any numbers below used to describe the possible side effects relate to standard external radiation therapy, which is now used much less often than in the past. The risks of the newer treatment methods described above are likely to be lower.

2.3. Problems of respiratory motion detection during radiotherapy:

If respiratory motion is not accounted for, as is the case when conventional radiotherapy techniques are applied in thoracic and abdominal sites, it causes artifacts during image acquisition. These artifacts cause distortion of the target volume and incorrect positional and volumetric information. These motion artifacts occur because different parts of the object move in and out of the computed tomography (CT) slice window during image acquisition. Artifacts can be generated within a slice, since CT reconstruction algorithms assume that the imaged anatomy is invariant during data acquisition (Chen et al 2004).

Motion artifacts are commonly seen with thoracic CT images. An example of the difference between a respiratory-gated and a non-gated CT scan for a patient and a sinusoidally moving sphere is shown in Figures 1 and figure 2, respectively.
Artifacts from CT scans manifest themselves as target/normal tissue delineation errors and adversely affect dose-calculation accuracy. It is important to note that respiratory motion can generate artifacts for all imaging modalities, including positron emission tomography (PET) scanning which is becoming a standard-of-care imaging technique for NSCLC (Caldwell et al 2003).

If not accounted for, tumor motion will further blur the PET image, leading to difficulties in clearly delineating boundaries as well as failure to detect small mobile volumes that are potentially cancerous (Nehmeh et al 2003).

![Figure 2-1. Coronal views of CT scans of the same patient taken during free breathing (FB) (a) and with respiratory-gated scanning exhale (b) (Keall et al 2002)](image)

During treatment planning, margins need to be large enough to ensure coverage of the target for most of the treatment delivery. Generally, for CT-planned lung cancer treatments, the GTV is outlined, and a margin is added to include the suspected microscopic spread (which when added to the GTV creates the CTV). Thus, using International Commission on Radiation Units and Measurements (ICRU) report 62 nomenclature, to obtain the planning target volume (PTV) from
the CTV involves the addition of the margins to account for intrafraction motion (due to respiration), interfraction motion, and setup error (Giraud et al 2000).

Accounting for respiratory motion by adding treatment margins to cover the limits of motion of the tumor is suboptimal, because this increases the radiation field size and consequently the volume of healthy tissues exposed to high doses. This increased treatment volume increases the likelihood of treatment-related complications (Stevens et al 2001).

However, if the margins are not sufficiently large, part of the CTV will not receive adequate dose coverage. Because of the artifacts observed in CT images in which respiratory motion has not been accounted for, the magnitude of margin to allow for respiratory motion is difficult to quantify, particularly for individual patients in whom a wide range of tumor motion is observed (Seppenwoolde et al 2002).

Figure 2-2. Coronal views of CT scan of a static sphere (a) and a sinusoidally moving sphere (b) (2-cm range of motion and a 4-second period). (Vedam et al 2003)
Radiation delivery in the presence of intrafraction organ motion causes an averaging or blurring of the static dose distribution over the path of the motion. This displacement results in a deviation between the intended and delivered dose distributions. Assuming a static beam, the total positional error affecting the dose is the composite vector of internal (e.g., tumor-bone) and external (bone-treatment room) displacements. Thus, for conventional (non-IMRT) treatments, in which the dose gradient in the center of each field can be assumed to be fairly small, the effect is manifested by a blurring of the dose distribution by the anatomy moving near the beam edges, in effect increasing the beam penumbra. This effect is thought to be exacerbated during IMRT delivery, causing motion artifacts in dose distribution due to the interplay between motion of the leaves of a multileaf collimator (MLC) and the component of target motion perpendicular to the beam (Malone et al 2000).

2.4. Magnitude and measurement of respiratory motion:

2.4.1. The mechanics of breathing:

The primary function of the lung is to facilitate gas (O₂ and CO₂) exchange between blood and air, thus maintaining normal levels of gas pressure (partial pressure of oxygen, PO₂, and partial pressure of carbon dioxide, PCO₂), in the arterial blood. Respiration is an “involuntary” action; i.e., a person would continue to breathe despite being unconscious. However, within limits, individuals are capable of controlling the frequency and displacement magnitude of their respiration as well as breath-holds. Unlike cardiac motion, the respiratory motion is not rhythmic. The periodic cycle of respiration is regulated through chemoreceptors by the levels of CO₂, O₂, and pH in the arterial blood. Of these, the most important is PCO₂. Reducing PCO₂, as occurs with hyperventilation, is a very
effective means for reducing the urge to breathe, or sustaining a breath-hold. Under normal conditions, the O₂ and blood pH stimuli play a small role in ventilation control (Oetzel et al 2005).

Anatomically, the lungs are held within the thoracic cavity, encased by the liquid-filled intrapleural space. Inhalation requires active participation of respiration muscles. During the inhalation part of quiet breathing, the increasing volume of the thoracic cavity draws air into the cavity. The most important muscle of inhalation is the diaphragm. As the diaphragm is contracted, it descends and the abdomen is forced inferiorly and interiorly, increasing the superior–inferior (SI) dimension of the chest cavity. The intercostals muscles connect adjacent ribs and also participate in normal inhalation. They contract during inhalation, pulling the ribs superiorly and interiorly, thereby increasing both the lateral and anterior–posterior (AP) diameters of the thorax, as shown in Figure 2-3. Exhalation is passive for quiet breathing. The lung and chest walls are elastic and return passively to their pre-inhalation positions at exhale. Other ventilation muscles are involved only during active exhalation. The tendency of the lung to recoil to its deflated volume is opposed by the tendency of the chest cage to bow out. The lung volume at the end of exhale, termed “functional residual capacity,” is at equilibrium or in the most relaxed state. Typically, the time taken to breathe in is longer than the time taken to breathe out. Transpulmonary pressure, the pressure difference between respired gas at the mouth and the pleural pressure around the lungs, is reduced during inhalation and is recovered during exhalation. During normal breathing, the deflating lung volume is larger than the inflating volume at the same transpulmonary pressure. This is called hysteresis, attributable to the complex respiratory pressure volume relationship of the lung and chest wall (Weiss et al 2003).
Breathing pattern characterization measurements have been distinguished by posture (upright, prone, supine, lateral decubitus), breathing type (chest or abdominal), and depth of respiration (shallow, normal, deep). For example, when the change in abdominal circumference was more than 10 mm greater than the change in chest circumference, Davies et al. (1994) classified the breath as abdominal. During normal quiet respiration, the lung volume typically changes by 10% to 25%; at deep inhale, the increase in lung volume is approximately three to four times that of normal breathing. For radiotherapeutic purposes, data measured in the upright posture are relevant only in limited situations (e.g., total body irradiation with the patient standing); therefore, we include only data taken from prone, supine, and lateral positions (Peters, 1996).
2.4.2. Mathematics of breathing

Patients breath asymmetrically and a much-used representation, determined from x-ray fluoroscopy, is that from Lujan et al (2003), a form of which is

\[ z(t) = z_0 + b \cos^{2n}(\pi t/\tau + \pi/2) \]

For motion in a \( z \)-direction where \( t = \) time, \( z_0 = \) exhale position, \( b = \) peak-to-peak amplitude, \( \tau = \) breathing period and \( 2n = \) shape parameter. As \( 2n \) increases, more time is spent at end expiration. A value of \( 2n = 6 \) has often been used but extensive data fitting by George et al (2005) showed \( 2n = 4 \) modeled better but even considered \( \cos \) to be adequate. If a static dose distribution is convolved with such a function it gives an approximate indication of the motion degradation. Sadly, real breathing can be more erratic with changes in amplitude, period and shape and occasional wild excursions during the breathing cycle (Seppenwoolde et al 2002, Nottrup et al 2005). This must be remembered when reading studies and motion-correction techniques based on this equation.

2.4.3. Measuring respiratory motion

The lungs, esophagus, liver, pancreas, breast, prostate, and kidneys, among other organs, are known to move with breathing. The degradation of image quality due to this motion and subsequent effects on radiotherapy dose planning and delivery have prompted medical physicists and clinicians to study the motion using a variety of imaging modalities. The survey is not exhaustive, but is intended to provide guidelines for accommodating the motion during treatment (Vedam et al 2003).

In many cases, the object being measured is the tumor or host organ itself, while in other cases it is an artificial marker implanted in or near the tumor. In some cases, the object is a surrogate organ such as the diaphragm. Patients’ breathing
patterns can vary in magnitude, period, and regularity during imaging and treatment sessions, as demonstrated in Figure 2-4 (George et al 2005).

Systematic changes in the respiratory baseline also occur. Motion also varies markedly between patients, indicating that an individual approach to respiratory management is advised. Audiovisual biofeedback has been demonstrated to improve Respiratory reproducibility (Kini et al 2003).

Figure 2-4. Variations in respiratory patterns from the same patient taken a few minutes apart. The three curves in each plot correspond to infrared reflected measured patient surface in the SI, AP, and ML directions, with each component arithtrity normalized. In (a) the motion pattern is relatively reproducible in shape, displacement magnitude, and pattern. In (b) the three trace is so irregular that it is difficult to distinguish any respiratory pattern.
Organ motion has been detected via ultrasound, CT (Giraud et al 2001) magnetic resonance (MR) (Korin et al 1992), and fluoroscopy (Shimizu et al 2001), (Kubo and Hill, 2002), (Engelsman et al 2001) and Stevens et al (2001) made double-exposure radiographs at deep inhale and deep exhale to establish the full range of lung tumor motion. Weiss et al. (1992) and Harauz and Bronskill (1999) measured liver and diaphragm motion with a gamma camera following administration of $^{99}$Tc-sulphur colloid. Table 1 identifies the published observations by organ site and imaging modality.

Hanley et al, (1999), Ross et al, (1990), Grills et al (2003) and Sixel et al (2003) performed respiratory motion studies have tracked the movement of the tumor, the host organ, radiographic fiducial markers imbedded at the tumor site which studied by Ozhasoglu and Murphy (2002) and Murphy et al (2000), radioactive tracers targeting the tumor and surrogate organs, such as the diaphragm, which are assumed to correlate with the tumor. (Minohara et al 2000)

A single fluoroscopic study can provide detailed two-dimensional (2-D) information on organ motion trajectories and timing/phase shift relationships among different moving structures, but two simultaneous projections (e.g., angiography) are necessary for a complete three-dimensional (3-D) reconstruction of real-time tumor motion. These statements assume that either the anatomy or a suitable surrogate, such as an implanted fiducial marker, can be visualized. A single 2-D projection may lack the information or achieve the sufficient contrast required to recognize out-of-plane motion, rotation, or deformation of the tumor during breathing. Two CT studies acquired at inhale and exhale breath-hold may retrospectively define the full range of tumor motion in three dimensions, but do not provide trajectory or time-profile details for the motion. This method relies on the geometric relationship between organs during breath-hold being similar to that
during free breathing (FB). Vedam et al (2003) and Low et (2003) studied four-dimensional (4-D) or respiratory correlated CT using single-slice, multislice, or cone-beam acquisition can provide 3-D data on tumor position at several points along the breathing cycle with a somewhat reduced spatial resolution, as compared with conventional CT, thus providing a compromise between the good time resolution of a fluoroscopic study and the detailed 3-D information of a CT scan (Sunke et al 2003). Multiple fiducial markers can provide a valuable indicator of tumor rotations and deformation during respiration, which is an issue that has not yet received sufficient attention in discussions of respiratory motion compensation (Taguchi, 2003).

2.4.4. Respiratory Motion observations:

Most of the published reports are based on cohorts of 10 to 30 subjects. For the tumor sites, each set of them has been condensed into a mean displacement and a full range of observed displacements. These data are summarized in (lung) and (abdomen). There are significant differences in organ motion during quiet (shallow) and deep breathing. Therefore, some of the observers have distinguished their measurements by breathing mode. Generally, abdominal organ motion is in the SI direction, with no more than a 2-mm displacement in the AP and lateral directions. However, in some individuals, the kidneys show more complex patterns.68 Lung tumor motions generally show a much greater variation in the trajectory of motion (Harauz and Bronskill, 1999).

Stevens et al. (2001) found that out of 22 lung tumor patients, 10 subjects showed no tumor motion in the SI direction. Of the remaining 12 subjects, the average SI displacement was anywhere from 3 to 22 mm (mean 8 +/- 4 mm). They found no correlation between the occurrences or magnitude of tumor motion and tumor size,
location, or pulmonary function, suggesting that tumor motion should be assessed individually.

Barnes et al. (2001) found the average motion of tumors in the lower lung lobe to be significantly greater than that in the middle lobe, upper lobe, or mediastinal tumors (18.5-mm vs. 7.5-mm average SI displacement). This observation has generally been corroborated by other observations, although the individual ranges of motion are such that some individuals will show less motion in the SI direction than others will show in the AP and left–right directions.

At the time of writing, the most detailed lung tumor-motion data reported in the literature comes from the measurements of Seppenwoolde et al. (2002) who measured 3-D trajectories for 20 patients via dual real-time fluoroscopic imaging of a fiducial marker implanted in or near the tumor. They observed hysteresis in the trajectories of half the patients, amounting to a 1- to 5-mm separation of the trajectories during inhalation and exhalation, with 4 out of 20 patients exceeding a 2-mm separation. This indicates that in cases where high accuracy is required in dose alignment, a real-time tracking or gating process based on surrogate breathing signals should not only correlate with the tumor’s motion along each axis with the breathing signal, but should have knowledge of the respiratory phase, because the phase difference is what leads to the hysteresis effect. In Figure 2-5, motion trajectories during radiotherapy of lung tumors, measured using implanted gold markers, are depicted. The amount of motion ranges from a 1-mm displacement to more than a 2-cm displacement. Furthermore, it can be seen that the motion is nonlinear for about half of the fiducial markers. The majority of the fiducial markers (78% in this study) move with less than a 1-cm range of motion. Similar results, based on portal imaging studies, have been reported. (Erridge et al 2003)
A review of the respiratory motion literature leads to the following conclusion: there are no general patterns of respiratory behavior that can be assumed for a particular patient prior to observation and treatment. The many individual characteristics of breathing quiet versus deep, chest versus abdominal, healthy versus compromised, etc. and the many motion variations associated with tumor location and pathology lead to distinct individual patterns in displacement, direction, and phase of tumor motion. Therefore, the respiratory motion pattern for each individual patient should ideally be assessed prior to treatment. Furthermore, the respiratory compensation procedures and algorithms should be adaptable to each patient’s particular breathing behavior (Koch et al 2004).

In many cases, it is difficult or impossible to observe the tumor directly during treatment delivery with fluoroscopic or portal images, prompting researchers to observe surrogate internal structures, such as the diaphragm, which would be expected to have a close relationship with the tumor motion for abdominal organs and lower-lobe lung tumors, in which the mechanical coupling between tumor and diaphragm will be the strongest. However, this practice has not yet been
adequately validated with data that directly correlates tumor motion with diaphragm motion, and there are known instances where it will lead to errors. For example, Iwasawa et al. (2000) reported observations of diaphragm motion in patients with emphysema. They noticed instances in which the diaphragm moved paradoxically, both as a single structure and with respect to the ventral rib cage. Because the population of lung cancer patients presenting for radiotherapy contains many patients with compromised pulmonary function, concerns are raised about the use of the diaphragm as a surrogate indicator of lung tumor motion even in the lower lobes, where the tumor, diaphragm, and external surface motions are assumed to be the most closely coupled. Other observers notice that diaphragm motion is not necessarily related to the motion of other organs and structures in either displacement or phase. (Ford et al 2002)

If a surrogate structure, such as the chest wall or diaphragm, is used to signal tumor position for the purpose of beam gating or tracking, without observing the tumor directly during treatment, there will be uncertainties in the displacement and phase relationship between the surrogate and the tumor or other anatomy. (Ahn et al 2004) A summary of such studies is given in Table 4. It needs to be stressed that both surface markers and spirometers provide signals that are surrogates of tumor motion (Liu et al 2004).

Liu et al (2004) applications should be validated by the users performing fluoroscopic and CT imaging studies. In a gating approach to motion compensation, the displacement correlation does not need to be known explicitly, because one is not trying to predict the absolute tumor position from the surrogate motion signal. The surrogate breathing signal only needs to indicate the phase of the breathing motion. However, it cannot be assumed a priori that the phase of the organ motion matches the phase of the surrogate motion, nor can it be assumed that
the phase relationship is stationary. In fact, nonzero phase differences are evidence of either instability and nonstationary time behavior or multiple driving forces in complex oscillatory mechanical systems. These will be especially significant in the lung, where the mechanical coupling between the tumor and the surrogate structure is often weak, resulting in complex relationships between the two, and the breathing forces from the chest and/or the diaphragm. It should also be mentioned that implanted fiducial markers are also a surrogate for tumor motion, and their accuracy in depicting true tumor motion has yet to be studied (Senan et al 2001).

Ultrasound and MR real-time imaging procedures are being developed and their application to volumetrically monitor respiratory motion is appealing (Senan et al 2004).

2.4.5. Methods of determination location of tumors:

2.4.5.1. Ultrasound location of tumors

The main commercial apparatus for ultrasound location of tumors is the NOMOS beam acquisition and targeting device (the BAT) which has been used mostly to give a pre-treatment interfraction measurement of the prostate. The contour of the prostate is then extracted (not always easily) and correlated with the contour from the treatment-planning CT slice. Misregistration then gives the docking translations required. Clearly this can only be correct for rigid-body shifts. Sometimes one reads that it can make intrafraction measurements (Huang et al 2002) but this is a misnomer and refers to a comparison of before- and after treatment fraction. There have been many published studies including those by Lattanzi et al (2000), Beyer et al (2000), Willoughby et al (2000), Trichter and Ennis (2001), Falco et al (2001), Chandra et al (2001, 2003), Morr et al (2000, 2002), Héon et al (2002) and Little et al (2003). Most of these studies reported on large numbers of patients and gave the mean and standard deviation of motion in
three orthogonal coordinate directions. However, of much more importance is the general observation of outliers, occasions on which the target was grossly mispositioned. There is some discussion of operator training, interoperator comparisons and operator self-comparison. Interestingly, Van den Heuvel et al (2003) and Langen et al (2003) find the BAT of no use for predicting the motion as assessed from implanted markers (figure 2-6).

Figure 2-6. Cartoon schematic showing the several ways to measure the motion of a tumor.
Others have built their own equipment. Bouchet et al (2000) attached light-emitting diodes to an ultrasound probe to record its in-room location for registration with 3D data. Sawada et al (2002, 2004) have a CT scanner, ultrasound scanner and linac together in the same room. At CT scanning, ultrasound measurements are also made and then, using further ultrasound data recorded during treatment and correlated to the first set, the linac is gated if the target drifts away from the expected location. Artignan et al (2002, 2004) showed that the pressure applied by the ultrasound probe actually displaced the prostate by 3 mm for every 1 cm of applied ‘pressure’. Conversely, using MR images, McNeeley et al (2003) disputed this, finding only 1 mm prostate movement due to transducer pressure.

2.5. Methods to account for respiratory motion in Radiotherapy:
The methods that have been developed to reduce the impact of respiratory motion in radiotherapy can be broadly separated into five major categories: motion-encompassing methods, respiratory-gating techniques, breath-hold techniques, forced shallow-breathing techniques, and respiration-synchronized techniques. These methods are discussed in detail in this section. A summary of published intra- and interfractional variations for the different methods (Lujan et al 1999).

2.5.1. Motion-encompassing methods
Most radiotherapy facilities do not currently have methods that explicitly account for respiratory motion, the problems of which were outlined in section III. In the current section, it is given the imaging and treatment-planning guidelines for tumor sites affected by respiratory motion. Since respiratory induced tumor motion will be present during radiation delivery, it is important to estimate the mean position and range of motion during CT imaging. The three techniques possible for CT imaging that can include the entire range of tumor motion for respiration (at the
time of CT acquisition) are slow CT, inhale and exhale breath-hold CT, and four-dimensional (4-D) or respiration-correlated CT. These are listed in order of increasing workload. For these techniques, it is important to understand that the breathing patterns and, hence, tumor motion will change between simulation sessions and treatment sessions. Furthermore, the radiation dose to the patient from these imaging procedures can be greater than standard CT simulation procedures by a factor of 2 to 15 if no efforts are made to reduce CT dose (Beckham et al 2002).

2.6. Measurement of prostate motion during radiotherapy:

2.6.1. Image guided radiation therapy (IGRT):

It is currently one of the most active research fields in medical physics. The recent development of high precision dose delivery techniques with high energy photon and hadron beams can only be fully exploited if we confidently know the shape and location of radiation targets and the organs at risk at the time of the treatment. Most of the time, anatomical images of the patient were only acquired for the purpose of diagnosis and treatment planning usually days before the treatment planning process, i.e., the patient anatomy was assumed to be static in time. As a result, all time dependent variations of relevant anatomical structures, like shifts and deformations of tissues in time, for instance also caused by the radiation treatment, were not accounted for and therefore are a significant source of potential treatment errors that geometrical uncertainties caused by patient setup, dose delivery and organ motion of the radiation target can be reliably accounted for by appropriate CTV to PTV safety margins. Usually, no specific measures are taken for the respective geometrical misalignments of organs at risk and radiosensitive anatomical structures. Unfortunately, the magnitude of these assumptions could only be estimated and hardly be verified by quantitative
measurements. Furthermore, it is well known, that other long term trends like tissue responses to radiation or weight loss of a patient will modify the irradiation geometry from the one employed for treatment planning. All these effects accumulated, therefore can lead to a considerable uncertainty whether the optimized planned treatment was actually delivered to a patient. To resolve this problem of radiation therapy additional x-ray imaging of the patient in treatment position, either directly prior or during treatment, was developed in the last decade. These imaging devices provide quantitative data of the actual irradiation geometry which forms the basis for image-guided radiation therapy (IGRT). IGRT aims to detect and correct for all time dependent changes of the irradiation geometry encountered during a course of radiotherapy. Specifically, the following sources of geometrical irradiation errors can potentially be addressed by IGRT:

- Patient and radiation target setup errors.
- Inter- and intra-fraction organ motion.
- Short term organ deformations.
- Long term anatomical changes (weight-loss or -gain, tissue swelling).

Depending on the anticipated rate of anatomical changes, as for instance caused by different types of organ motion, various levels of adaptive radiation therapy can be imagined. For inter-fraction errors like patient setup errors, on-line and off-line protocols of ART can be performed. A first level of ART can be achieved by the acquisition of several CT scans of the patient in treatment position prior to the beginning of the treatment. A statistical analysis of these imaging

2.6.2. Delineation errors:

Basically, delineation errors are a misplacement of the delineated contour with respect to the true position of the target volume or tumor. The problem is that it is often very hard to know where that true position is. In many cases, the use of
multiple modalities will improve accuracy but the real ‘gold truth’ can only be found through pathology. Because delineation is performed only once per patient, any errors introduced in this stage will be systematic. Multi-observer studies can be used to quantify the delineation error 4–6 (Lawrence B. Marks et al 2010). (Figure 2-7).

![Figure 2-7. An example of delineation uncertainty. On the left, delineations of the prostate on a CT scan by two observers are shown. The second observer clearly delineated a smaller volume. On the right the same two observers performed the same delineation on MR, revealing an even larger modality (MR versus CT) difference.](image)

**2.6.3. Organs motion:**

Organ motion is most commonly defined as motion of the target volume, or tumor, relative to the bony anatomy (Figure 2-8). Organ motion is always present and therefore happens both during the scanning and the treatment phase. An example of a systematic organ motion error could be a shifted prostate due to rectum filling at the time of scanning. To quantify organ motion, a repeat study on a group of patients can be performed.
Figure 2-8. Organ motion. Depicted are two 3-D views of the bladder, taken 1 h apart. The total movement of the cranial bladder wall was 7 cm, which shows that in some cases organ motion will be very difficult to determine a priori (Barrett et al, 2009).

2.6.4. Setup errors:

Setup errors are displacements of the patient’s bony anatomy with respect to the treatment room coordinate system, usually indicated by lasers. These errors also occur both during the treatment preparation phase (i.e. scanning) and during treatment delivery. By monitoring setup errors by, for example, portal imaging it is possible to quantify them.

The applicability of respiratory gating in radiotherapy was first studied in Japan in the late 1980s and early 1990s. Initial studies monitored respiratory motion using some form of an external marker that generated the required respiratory signal. Gating was successfully applied by adopting such an approach on a phantom and on patients with tumors close to the diaphragm. Early clinical studies using respiratory gating as a treatment delivery approach on patients reported successful implementation with treatment times up to a maximum of twice the time required for conventional radiation delivery. More recently, Minohara et al. (2010) have reported on gated heavy ion-beam treatment and Hara et al. (2010) have reported on stereotactic single high-dose irradiation of lung tumors under respiratory gating. In the United States, early research into this
approach began around the mid-1990s. Kubo et al. (2011) evaluated different external respiratory signals (by employing thermistors, thermocouples, strain gauge methods, and a pneumotachograph) to monitor respiratory motion and concluded that temperature and strain gauge methods produce the most desirable signals in terms of reproducibility, accuracy, and dynamic response. Subsequent studies further investigated the requirements for applying respiratory gating as a routine clinical tool, among them, the clinical efficacy of respiratory gating desired beam characteristics, potential for gating in combination with IMRT (gated IMRT), determination of optimal parameters and potential radiotherapy improvements.
Chapter three
Material and Methods

3.1. Materials:

3.1.1. Sampling:

The study was conducted at different hospitals in Sudan (Radiation and Isotopes center of Khartoum (RICK) and Antalya clinic center for the specific purpose of acquiring data for this study. The study conducted from May 2014 to December 2014.

Data were taken for only a single day for these patients. This analysis included all patients’ images to measure the significant difference between the prostate motion inspiration scoring and expiration scoring.

3.1.2. Computed Tomography (CT) Machines:

A CT of the chest was performed on a 16-slice CT scanner. Axial images were taken: 5 mm x 5 mm and 3 mm x 3 mm for soft tissue, 31 kernel 400 window/401 levels. CT scans were performed using different CT machines as a Somatom AS. Star, Somatom Sensation and Medic (Siemens Medical Solutions Inc., Knoxville, TN, USA, Philips) containing a 16-slice CT scanner. Unenhanced CT scans for attenuation correction were performed in a cranio-caudal direction from the skull base to lower thighs. Scanning parameters were as follows: 10 mAs, 100-120 kV, online tube current modulation, 1.5 mm slice collimation, 0.5–0.75 s rotation time, and reconstruction of 1, 3, 5 and 10 mm slices.

• Mat Lab (R2009) image processing program
Methods of Data Collection:

3.2.1. Image Registration Technique:

For patients treated using external beam radiotherapy machines (linear accelerator and Co-60), the procedure based on the acquisition of CT scan sequences, followed by an automatic detection of the movement using cross-correlations with matched filters by using image registration technique. Image registration is the process of aligning two or more images of the same scene. Typically, one image, called the base (inspiration) image or reference (expiration) image, was considered the reference to which the other images, called input images, were compared. The objective of image registration was to bring the input image into alignment with the base image by applying a spatial transformation to the input image. The differences between the input image and the output image might have occurred as a result of terrain relief and other changes in perspective when imaging the same scene from different viewpoints. Lens and other internal sensor distortions, or differences between sensors and sensor types, could also cause distortion. A spatial transformation maps locations in one image to new locations in another image. Determining the parameters of the spatial transformation needed to bring the images into alignment were keys to the image registration process. Image registration was often used as a preliminary step in other image processing applications. For example, it could use image registration to align images created by different medical diagnostic modalities (MRI and SPECT). After registration, researcher would be able to see if a tumor is visible in an MRI or SPECT image or not.
3.2.2. **Point Mapping using Mat Lab program:**

The Image Processing Toolbox software of Mat Lab program provides tools to support point mapping to determine the parameters of the transformation required to bring an image into alignment with another image. In point mapping, researcher picked points in a pair of images (inspiration and Expiration images) that identify the same feature or landmark in the images. Then, a spatial mapping was inferred from the positions of these control points. Researcher might need to perform several iterations of this process, experimenting with different types of transformations, before researcher achieved a satisfactory result. In some cases, researcher might perform successive registrations, removing gross global distortions first, and then removing smaller local distortions in subsequent passes. Figure (3-5) provides a graphic illustration of this process.

![Figure 3-5. A graphic illustration of image registration process.](image-url)
If researcher needed to perform the same kind of registration for many images, researcher had automated the process by putting all the steps in a script. Researcher could create a script that launches the Control Point Selection Tool with an input and a base image. The script could then use the control points selected to create a TFORM structure and pass the TFORM and the input image to the imtransform function, outputting the registered image. Researcher specifies the 'Wait' option when researcher calls cpselect to launch the Control Point Selection Tool. With the 'Wait' option, (cpselect) blocks the MATLAB command line until control points have been selected and returns the sets of control points selected in the input image and the base image as a return values. If researcher did not use the 'Wait' option, (cpselect) returns control immediately and the script would continue without allowing time for control point selection. In addition, without the 'Wait' option, (cpselect) did not return the control points as return values.

**Steps of image registration process**

**Step 1: Read the Images**

The base image was *inspire1*, the inspiration position. It was a panchromatic (grayscale) image, supplied by the scanning patients using CT scanning which had been orthorectified to remove camera, perspective, and relief distortions (via a specialized image transformation process). The exspire1 was also medical registered the columns and rows of the digital *inspire1* image were aligned to the axes of the Massachusetts State Plane coordinate system. In the *exspire1*, each pixel center corresponded to a definite chest organ location. The image to be registered was *exspire1*, a digital CT scan radiograph and was a visible-color RGB image. The medical image was geometrically uncorrected: it included for example camera perspective, terrain and building relief, internal (lens) distortions, and it did not have any particular alignment or registration with respect to the human body.

**Step 2: Choose Control Points in the Images**
The toolbox provided an interactive tool, called the Control Point Selection Tool, which researcher could use to pick pairs of corresponding control points in both images. When the researcher selected the control points in *inspire* the computer select the same points in *expire* images.

**Step 3: Save the Control Point Pairs to the MATLAB Workspace**

**Organ: prostate (as sample)**

input_points = (inspiration Phase by pixel x, y)

235.5102  180.7870  
213.7709  201.7767  
190.5322  236.2599  

Base_points = (expiration phase by pixel x, y)

229.5132  185.2848  
207.7738  206.2745  
191.2818  235.5102  

3.1.3. **Data Storage Method:**

- Data in correspondence with the thesis procedures stored safely in personal (PC) and pass-worded computer.
- Patient questionnaire kept safely and responsibly.

3.1.4. **Ethical Issue:**

- Permission of Radiotherapy department and patients arise at the area of the study must be taken to use the patients’ data.
- No patients’ details were disclosed.
Chapter Four

The Results

Total geometrical error is built up of many smaller errors, which are presented by systemic and the random deviations can be predicted and use for correction strategy. Systematic errors introduced by target volume delineation, organ motion, and set-up errors should be reduced by clear delineation protocols, multimodality imaging, correct CT scan procedures, and by the application of electronic portal imaging with decision rules (protocols). The results showed the radiation oncologist to take suitable countermeasures in case of significant errors (body contour was equally (9.19±1.77 mm) and for prostate was (4.22±1.07 mm). In addition, the uses of the image registration technique for automatic position control. When imaging axially, inspiration and expiration phase displacement corresponds to chest organs positions motion were measured. This was measurements and the resulting relative organs position of body contour and prostate were shown in table 4-1, figure 4-1, figure 4-2 and figure 4-3 respectively showed the breathing wave form of different patients and Cross-correlation between inspiration and expiration phase. The thresholds were set for treatment at end expiration at the beginning of the session; however, the breathing wave form was irregular during the session, resulting in beam enable signals at unintended points in the breathing cycle arrows Figure.4-2 (b), Figure 4-3 showed a breathing wave form for the same patient in (expiration phase).
Table 4-1. Mean and standard deviation of errors in body contour reading and prostate reading during inspiration and expiration phases.

<table>
<thead>
<tr>
<th></th>
<th>Inspiration Phase</th>
<th>Expiration Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-reading</td>
<td>12.6 ± 1.6</td>
<td>10.5 ± 0.92</td>
</tr>
<tr>
<td>Y-reading</td>
<td>8.52 ± 2.01</td>
<td>10.4 ± 3.32</td>
</tr>
</tbody>
</table>

There is a difference in average between the body contour position regarding (X-reading) to the inspiration phase which is equal to 12.6 ± 1.6 and 10.5 ± 0.92. This difference was significant at p= .05 using t-test with t= 3.91 and p=0.0008. As well as there is a difference in average between the body contour positions regarding to (Y-reading) the inspiration phase which is equal to 9.03 ± 2.52 and 11.3 ± 1.90. This difference was significant at p= .05 using t-test with t= -2.45 and p< 0.001 (p=0.023).

Figure 4-1. Showed the breathing waves for inspiration Phase and expiration phase for body contour.
There is a difference in average between the lung position regarding to (X-reading) of the inspiration phase which is equal to $6.16 \pm 2.01$ and $12.6 \pm 1.12$. This difference was significant at $p=0.05$ using t-test with $t=-9.74$ and $p=0.001$. As well as here is a difference in average between the lung position regarding to (Y-reading) of the inspiration phase which is equal to $12.6 \pm 1.12$ and $12.7 \pm 1.12$. This difference was not significant at $p=0.05$ using t-test with $t=0.162$ and $p=0.87$.

*Figure 4-2. Showed the breathing waves for inspiration Phase and expiration phase for prostate.*
Figure 4-2. Showed the displacement in the body contour and displacement of the prostate

\[ y = 0.889x - 0.295 \]

prostate displacement (mm) = 0.889 (body contour displacement) - 0.295
Chapter Five  

Discussion, Conclusion and Recommendations  

5.1. Discussion:  

Organ motion in Radiotherapy induces an error in the received dose by the tumour, the outcome of the Laser positioning system confirms its potential as tool for patient repositioning and automatic or manual detection of errors caused by breathing or other unpredictable movements. The laser alignment system feedback on the patient's position given by the system provides operator with appropriate visual indices and allows them to take suitable countermeasures in case of significant failures. In addition, the use of system output may be used for automatic control is envisaged. The maintenance of technical condition related errors within known and acceptable limits must be ensured by regular applying of Quality Assurance (QA) procedures for all equipment involved in radiotherapy procedures chain. Total geometrical error is built up of many smaller errors which are presented by systemic and the random deviations can be predicted and use for correction strategy. Systematic errors introduced by target volume delineation, organ motion, and set-up errors should be reduced by clear delineation protocols, multimodality imaging, correct CT scan procedures, and by the application of electronic portal imaging with decision rules (protocols). The mobility of chest
structure example lung ranged from 2.13 mm up to 12.2 mm with an average of 3.14 mm this movement was appertained between the inspiration and expiration for right and left lung in x, z direction and there are significant difference in the location of the chest structure using t-test at p =0.05 (table 4-1 and table 4-2). Tsukuda et al (2007), Curtin et al (2005), Kauczor and Plathow (2008) studied impaired respiratory mechanics and Respiratory motions of the diaphragm and chest wall (D/CW) using CT and MR imaging in healthy subjects.
5.2. Conclusion:

- In conclusion, individualized assessment of tumor mobility can improve the accuracy of target definition in patients who are undergoing SRT for stage I and stage II patients and Translational errors can thereby be reduced to 1 mm and rotational errors to 1 mm and Systemic error can be corrected and Patient motions, such as respiratory and muscular motion, can cause significant artifacts during 3DCT imaging.
5.3. **Recommendations:**

The recommendations of this study are:

- Radiotherapy facility should use the respiratory management devices with collaboration with record-and-verify systems to ensure that the relevant parameters for a patient’s treatment are included in the patient’s electronic file.

- The distortion of the planning CT due to respiratory motion-induced artifacts is an important source of systematic error these artifacts are found to varying degrees in free-breathing, slow, gated, and 4D CT scans.

- Further studies were recommended with more patients and using more than one breathing measurement technique.
References: