Review of Literature
2: REVIEW OF LITERATURE

2.1: Pregnancy

Pregnancy is the common name for gestation in humans. A multiple pregnancy involves more than one embryo or fetus in a single pregnancy, such as with twins. Childbirth usually occurs about 38 weeks after conception; in women who have a menstrual cycle length of four weeks, this is approximately 40 weeks from the start of the last normal menstrual period (LNMP). Human pregnancy is the most studied of all mammalian pregnancies. Conception can be achieved through sexual intercourse or assisted reproductive technology.

An embryo is the developing offspring during the first 8 weeks following conception, and subsequently the term fetus is used until birth. Duration of human pregnancy is somewhat arbitrarily divided into three trimester periods, as a means to simplify reference to the different stages of prenatal development by different methods by medical/legal societies. The first trimester carries the highest risk of miscarriage. During the second trimester, the development of the fetus can be more easily monitored and diagnosed. The third trimester is marked by further growth of the fetus and the development of fetal fat stores. The point of fetal viability, or the point in time at which fetal life outside of the uterus is possible, usually coincides with the early third trimester, and is typically associated with high degrees of morbidity and mortality.

2.1.1: Terminologies regarding pregnancy

One scientific term for the state of pregnancy is gravidity (adjective "gravid"), Latin for "heavy" and a pregnant female is sometimes referred to as a gravida. Similarly, the term parity (abbreviated as "para") is used for the number of times a female has given birth, counting twins and other multiple births as one pregnancy, and usually including stillbirths. Medically, a woman who has never been pregnant is referred to as a nulligravida, a woman who is (or has been only) pregnant for the first time as a primigravida and a woman in subsequent pregnancies as a multigravida or multiparous. Hence, during a second pregnancy a woman would be described as gravida 2, para 1 and upon live delivery as gravida 2, para 2. An in-progress pregnancy, as well as abortions, miscarriages, or stillbirths account for parity values being less than the gravida number. In the case of twins, triplets etc., gravida number
and parity value are increased by one only. Women who have never carried a pregnancy achieving more than 20 weeks of gestation age are referred to as nulliparous (11).

2.1.2: Physiology of pregnancy

2.1.2.1: INITIATION

The most commonly used event to mark the initiation of pregnancy is the first day of the woman's last normal menstrual period, and the resulting fetal age is called the gestational age (12), (13), (14). This choice is a result of a lack of a convenient way to discern the point in time when the actual creation of the baby naturally happens. In case of in vitro fertilization, gestational age is calculated by days from oocyte retrieval + 14 days (15).

Still, already at the initiation of the preceding menstrual period the female body goes through changes to prepare for an upcoming conception, including a rise in follicle stimulating hormone that stimulates folliculogenesis and subsequently oogenesis in order to give rise to a mature egg cell, which is the female gamete. Fertilization is the event where the egg cell fuses with the male gamete, spermatozoon. In lay terms, it is more commonly known as "conception." After the point of fertilization, the fused product of the female and male gamete is referred to as a zygote or fertilized egg. The fusion of male and female gametes usually occurs following the act of sexual intercourse, resulting in spontaneous pregnancy. It can also occur by assisted reproductive technology such as artificial insemination and in vitro fertilization, and may be undertaken as a voluntary choice or due to infertility.

The event of fertilization is sometimes used as a mark of the initiation of pregnancy, with the derived age being termed fertilization age, and is an alternative to gestational age. Fertilization usually occurs about two weeks before her next expected menstrual period, and if either date is unknown in an individual case it is a frequent practice to add 14 days to the fertilization age to get the gestational age and vice versa.

2.1.2.2: DIAGNOSIS

The beginning of pregnancy may be detected either based on symptoms by the pregnant woman herself, or by using medical tests with or without the assistance of a medical professional. These tests are based on detection of hCG in maternal urine (16).
2.1.2.3: PHYSICAL SIGNS

Most pregnant women experience a number of symptoms \(^{(17)}\), which can signify pregnancy. The symptoms can include nausea and vomiting, excessive tiredness and fatigue, cravings for certain foods that are not normally sought out, and frequent urination particularly during the night.

A number of early medical signs are associated with pregnancy \(^{(18)}\). These signs typically appear, if at all, within the first few weeks after conception. Although not all of these signs are universally present, nor are all of them diagnostic by themselves, taken together they make a presumptive diagnosis of pregnancy. These signs include the presence of human chorionic gonadotropin (hCG) in the blood and urine, missed menstrual period, implantation bleeding that occurs at implantation of the embryo in the uterus during the third or fourth week after last menstrual period, increased basal body temperature sustained for over 2 weeks after ovulation, Chadwick's sign (darkening of the cervix, vagina, and vulva), Goodell's sign (softening of the vaginal portion of the cervix), Hegar's sign (softening of the uterus isthmus), and pigmentation of linea alba – Linea nigra, (darkening of the skin in a midline of the abdomen, caused by hyperpigmentation resulting from hormonal changes, usually appearing around the middle of pregnancy) \(^{(18)}\). Breast tenderness is common during the first trimester, and is more common in women who are pregnant at a young age \(^{(19)}\). Shortly after conception, the nipples and areolas begin to darken due to a temporary increase in hormones. This process continues throughout the pregnancy.

2.1.2.4: BIOMARKERS

Pregnancy detection can be accomplished using one or more various pregnancy tests, which detect hormones generated by the newly formed placenta, serving as biomarkers of pregnancy. Blood and urine tests can detect pregnancy 12 days after implantation \(^{(20)}\). Blood pregnancy tests are more sensitive than urine tests (giving fewer false negatives) \(^{(21)}\). Home pregnancy tests are urine tests, and normally detect a pregnancy 12 to 15 days after fertilization. A quantitative blood test can determine approximately the date the embryo was conceived. Testing 48 hours apart can provide useful information regarding how the pregnancy is doing. A single test of
progesterone levels can also help determine how likely a fetus will survive in those with a threatened miscarriage (bleeding in early pregnancy)\textsuperscript{(22)}.

\textbf{2.1.2.5: ULTRASOUND}

Obstetric ultrasonography can detect some congenital diseases at an early stage, estimate the due date as well as detecting multiple pregnancy\textsuperscript{(23)}. The resultant estimated due date of the fetus is slightly more accurate than methods based on last menstrual period\textsuperscript{(24)}.

\textbf{2.1.3: Maternal physiological changes in pregnancy}

Maternal physiological changes in pregnancy are the normal adaptations that a woman undergoes during pregnancy to better accommodate the embryo or fetus. They are physiological changes, that is, they are entirely normal, and include cardiovascular, hematologic, metabolic, renal and respiratory changes that become very important in the event of complications. The body must change its physiological and homeostatic mechanisms in pregnancy to ensure the fetus is provided for. Increases in blood sugar, breathing and cardiac output are all required. Levels of progesterone and estrogens rise continually throughout pregnancy, suppressing the hypothalamic axis and subsequently the menstrual cycle. The woman and the placenta also produce many hormones.

The body must change its physiological and homeostatic mechanisms in pregnancy to ensure the fetus grows properly and receives adequate nutrition. Increases in blood sugar, breathing and cardiac output are all required.

\textbf{2.1.3.1: HORMONAL CHANGES}

Pregnant women experience adjustments in their endocrine system.

Levels of progesterone and estrogens rise continually throughout pregnancy, suppressing the hypothalamic axis and subsequently the menstrual cycle. Estrogen is mainly produced by the placenta and is associated with fetal well-being. Women also experience increased human chorionic gonadotropin (β-hCG); which is produced by the placenta. This maintains progesterone production by the corpus luteum. The increased progesterone production, first by corpus luteum and later by the placenta, mainly functions to relax smooth muscle.

Prolactin levels increase due to maternal pituitary gland enlargement by 50%. This mediates a change in the structure of the mammary gland from ductal to lobular-
alveolar. Parathyroid hormone is increased which leads to increases of calcium uptake in the gut and reabsorption by the kidney. Adrenal hormones such as cortisol and aldosterone also increase.

Human placental lactogen (hPL) is produced by the placenta and stimulates lipolysis and fatty acid metabolism by the woman, conserving blood glucose for use by the fetus. It can also decrease maternal tissue sensitivity to insulin, resulting in gestational diabetes\(^{(25)}\).

2.1.3.2: WEIGHT GAIN DURING PREGNANCY

Current recommendations for weight gain during pregnancy are an average of 25 to 27 lbs\(^{(26),(27)}\) with a distribution as shown below.

\[\text{Table 1: weight gain during pregnancy}\]\(^{(12)}\)

<table>
<thead>
<tr>
<th></th>
<th>Total weight gain (Ranges) for single fetus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetus</td>
<td>3.36-3.88 kg 7.5-8.0 lb</td>
</tr>
<tr>
<td>Placenta</td>
<td>0.48-0.72 kg 1.0-1.5 lb</td>
</tr>
<tr>
<td>Amniotic fluid</td>
<td>0.72-0.97 kg 1.5-2.5 lb</td>
</tr>
<tr>
<td>Uterus and breasts</td>
<td>2.42-2.66 kg 50-5.5 lb</td>
</tr>
<tr>
<td>Blood and fluid</td>
<td>1.94-3.99 kg 4.0-7.0 lb</td>
</tr>
<tr>
<td>Muscle and fat</td>
<td>0.48-2.91 kg 1.0-6.0 lb</td>
</tr>
<tr>
<td>Total</td>
<td>9.7-14.55 kg 20.0-30.0 lb</td>
</tr>
</tbody>
</table>

2.1.3.3: CHANGES IN ORGAN SYSTEMS

2.1.3.3.1: Uterus and Related Connective Tissue

The uterus increases from a prepregnant size of 5 by 10 cm (2 by 4 inches) to 25 by 36 cm (10 by 14 inches). It increases five to six times in size, 3000 to 4000 times in capacity, and 20 times in weight by the end of pregnancy. By the end of pregnancy, each muscle cell in the uterus has increased approximately 10 times over its pre-pregnancy length\(^{(28)}\). Once the uterus expands upward and leaves the pelvis, it becomes an abdominal rather than a pelvic organ.

Ligaments connected to the pelvic organs are more fibroelastic than ligaments supporting joint structures. The fascial tissues, which surround and enclose the organs
in a continuous sheet, also include a significant amount of smooth muscle fibers. The round, broad, and uterosacral ligaments in particular provide suspensory support for the uterus

2.1.3.3.2: Reproductive system

Amenorrhoea is one of the first signs of pregnancy for most women, although it is not uncommon to experience a slight bleed, for 1–2 days, at the time at which menstruation would be expected if conception had not occurred. Within a few days of conception the cervix, if viewed with a speculum, will be seen to have changed in colour from pink to a bluish shade. From a firmly closed structure, which increases in depth early in pregnancy, the cervix changes by a gradual but accelerating process, which in the final weeks involves the softening, greater distensibility, effacement and eventually dilation (collectively called ripening) of the cervix.

The growing uterus rises out of the pelvis to become an abdominal organ at about 12 weeks’ gestation, increasingly displacing the intestines and comes in direct contact with the abdominal wall as pregnancy proceeds. The uterus increases in size dramatically, as does its blood supply.

The muscle fibers of the uterus increase in activity, and coordinated contraction of the uterus can be detected by the woman by about 20 weeks’ gestation. Bursts of irregular, short, usually painless contractions become progressively more evident and systematic. They are called Braxton Hicks contractions; they facilitate the blood flow through the placental site and play a part in the development of the lower uterine segment.

2.1.3.3.3: Urinary System

The kidneys increase in length by 1 cm. The ureters enter the bladder at a perpendicular angle because of uterine enlargement. This may result in a reflux of urine out of the bladder and back into the ureter; therefore, during pregnancy there is an increased chance of developing urinary tract infections because of urinary stasis. There is an increased urinary output, and small changes in tubular resorption caused by the pregnancy may result in excretion of significant amounts of sugar and protein. Diabetes may be first diagnosed in pregnancy because pregnancy is one of the factors that may precipitate its onset in women genetically predisposed to the condition. This usually regresses after delivery (gestational diabetes).
2.1.3.3.4: Pulmonary System

Hormone changes affect pulmonary secretions and rib cage position.

Edema and tissue congestion of the upper respiratory tract begin early in pregnancy because of hormonal changes. Hormonally stimulated upper respiratory hypersecretion also occurs.

Changes in rib position are hormonally stimulated and occur prior to uterine enlargement. The subcostal angle progressively increases; the ribs flare up and out. The anteroposterior and transverse chest diameters each increase by 2 cm (1 inch). Total chest circumference increases by 5 to 7 cm (2 to 3 inches) and does not always return to the pre-pregnant state.

The diaphragm is elevated by 4 cm (1.5 inch); this is a passive change caused by the change in rib position.

Respiration rate is unchanged, but depth of respiration increases.

Tidal volume and minute ventilation increase, but total lung capacity is unchanged or slightly decreased.

There is a 15% to 20% increase in oxygen consumption; a natural state of hyperventilation exists throughout pregnancy to meet the oxygen demands of pregnancy.

The work of breathing increases because of hyperventilation; dyspnea is present with mild exercise as early as 20 weeks into the pregnancy.

2.1.3.3.5: Cardiovascular System

Blood volume progressively increases 35% to 50% (1.5 to 2 liters) throughout pregnancy and returns to normal by 6 to 8 weeks after delivery.

Plasma increase is greater than red blood cell increase, leading to the “physiologic anemia” of pregnancy, which is not a true anemia but is representative of the greater increase of plasma volume. The increase in plasma volume occurs as a result of hormonal stimulation to meet the oxygen demands of pregnancy.

Venous pressure in the lower extremities increases during standing as a result of increased uterine size and increased venous distensibility. This may result into lower limb edema, varicosities and distension in the veins.

Pressure in the inferior vena cava rises in late pregnancy, especially in the supine position, because of compression by the uterus just below the diaphragm. In
some women, the decline in venous return and resulting decrease in cardiac output may lead to symptomatic supine hypotensive syndrome. The aorta is partially occluded in the supine position.

Blood pressure decreases early in the first trimester. There is a slight decrease of systolic pressure and a greater decrease of diastolic pressure. Blood pressure reaches its lowest level approximately midway through pregnancy, and then rises gradually from mid-pregnancy to reach the pre-pregnant level approximately 6 weeks after delivery. Although cardiac output increases, blood pressure decreases because of venous distensibility.

Heart size increases, and the heart is elevated because of the movement of the diaphragm.

Heart rhythm disturbances are more common during pregnancy.

Heart rate usually increases 10 to 20 beats per minute by full term and returns to normal levels within 6 weeks after delivery.

Cardiac output increases 30% to 60% during pregnancy and is most significantly increased when a woman is in the left side-lying position, in which the uterus places the least pressure on the aorta.

2.1.3.3.6: Musculoskeletal System

The abdominal muscles, particularly both sides of the rectus, are stretched to the point of their elastic limit by the end of pregnancy. This greatly decreases the muscles’ ability to generate a strong contraction, and thus decreases their efficiency of contraction.

The pelvic floor muscles, in their anti-gravity position, must withstand the total change in weight; the pelvic floor drops as much as 2.5 cm (1 inch) as a result of pregnancy.

The hormonal influence on the ligaments is profound, producing a systemic decrease in ligamentous tensile strength. This change is primarily a result of an increase in relaxin and progesterone levels.

The thoracolumbar fascia is put in a position of extreme length, which diminishes its ability to stabilize the trunk effectively.

Joint hypermobility occurs as a result of ligamentous laxity and may predispose the patient to injury, especially in the weight-bearing joints of the back, pelvis, and lower extremities.
2.1.3.3.7: Thermoregulatory System

During pregnancy, basal metabolic rate and heat production increase.

An additional intake of 300 calories per day is needed to meet the basic metabolic needs of pregnancy.

In pregnant women, normal fasting blood glucose levels are lower than in nonpregnant women.

2.1.4: Changes in Posture

During pregnancy it is usually necessary for a woman to adapt her posture to compensate for her changing center of gravity. How a woman does this will be individual and will depend on many factors, including muscle strength, joint range, fatigue and role models \(^{(13)}\).

The center of gravity shifts upward and forward because of the enlargement of the uterus and breasts. This requires postural compensations to maintain balance and stability \(^{(12)}\).

The lumbar and cervical lordoses increase to compensate for the shift in the center of gravity, and the knees hyperextend, probably because of the change in the center of gravity.

The shoulder girdle and upper back become rounded with scapular protraction and upper extremity internal rotation because of breast enlargement; this postural tendency persists with postpartum positioning for infant care. Tightness of the pectoralis muscles and weakness of the scapular stabilizers may be preexisting to or perpetuated by the pregnancy postural change.

The suboccipital muscles respond in an effort to maintain appropriate eye level (optical righting reflex), and to moderate forward head posture along with the change in shoulder alignment.

Weight shifts toward the heels to bring the center of gravity to a more posterior position \(^{(29)}\)\(^{(30)}\). This contributes to the “waddling” gait that is typically seen in pregnancy.

Changes in posture do not automatically correct after childbirth, and the pregnant posture may become habitual.

In addition, many child-care activities contribute to persistent postural faults and asymmetry.
2.1.5: Changes in Balance

With the increased weight and redistribution of body mass there are compensations to maintain balance.

The pregnant woman usually walks with a wider base of support and increased external rotation at the hips. This change in stance along with growth of the baby makes some activities such as walking, stooping, stair climbing, lifting, reaching, and other activities of daily living (ADLs) progressively more challenging.

Activities requiring fine balance and rapid changes in direction, such as aerobic dancing and bicycle riding, may become inadvisable, especially during the third trimester.

2.2: Symptoms and discomforts during pregnancy

Symptoms and discomforts of pregnancy are those presentations and conditions that result from pregnancy but do not significantly interfere with activities of daily living or pose any significant threat to the health of the mother or baby, in contrast to pregnancy complications. Still, there is often no clear separation between symptoms versus discomforts versus complications, and in some cases the same basic feature can manifest as either a discomfort or a complication depending on the severity. For example, mild nausea may merely be a discomfort (morning sickness), but if severe and with vomiting causing water-electrolyte imbalance it can be classified as a pregnancy complication (hyperemesis gravidarum).
2.2.1: Nausea (morning sickness)

Morning sickness occurs in about seventy percent of all pregnant women, and typically improves after the first trimester \(^{31},^{32},^{33}\). Although described as "morning sickness", women can experience this nausea during afternoon, evening, and throughout the entire day.

2.2.2: Low back pain during pregnancy

Low back pain is one of the major musculoskeletal symptom during pregnancy usually caused by weight gain, altered mechanical alignment of lumbar spine, shift of center of gravity anteriorly, muscular dysfunction and effects of ligament relaxing hormone (relaxin) \(^{34},^{35},^{36},^{37},^{38},^{39},^{40}\). Pain may be present at low lumbar spine, sacro-iliac joint or around hip region.

Presence of low back pain may influence gait pattern as a strategy to control pain during walking \(^{41}\).

Various proposed causes of pregnancy related low back pain are described in Table 2.

Table 2: factors related to development of low back pain and sacroiliac pain during pregnancy

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Proposed causative factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low back pain</td>
<td>Weight gain during pregnancy (^{42})</td>
</tr>
<tr>
<td></td>
<td>Rapid postural changes (^{43})</td>
</tr>
<tr>
<td></td>
<td>Vascular effects (^{43})</td>
</tr>
<tr>
<td></td>
<td>Previous back pain experienced during menstruation (^{44})</td>
</tr>
<tr>
<td></td>
<td>Back pain in previous pregnancies (^{42})</td>
</tr>
<tr>
<td></td>
<td>Repetitive lifting/bending</td>
</tr>
<tr>
<td>Sacroiliac pain</td>
<td>Pelvic insufficiency due to hormonal changes (^{42})</td>
</tr>
</tbody>
</table>

2.2.3: Pelvic girdle pain

Pelvic girdle pain is complex and multi-factorial and likely to be represented by a series of sub-groups with different underlying pain drivers from peripheral or central nervous system, altered laxity/stiffness of muscles, laxity to injury of tendinous/ligamentous structures to 'mal-adaptive' body mechanics. Musculo-Skeletal Mechanics involved in gait and weight bearing activities can be mild to grossly
impaired. PGP can begin peri or postpartum. There is pain, instability or dysfunction in the symphysis pubis and/or sacroiliac joints.

2.2.4: Carpal tunnel syndrome

Carpal tunnel syndrome (CTS) is a frequent complication of pregnancy. The true prevalence is unknown, but has been reported to be as high as 62%. CTS commonly presents during the third trimester, but can occur during the first trimester (45), (46), (47), (48), (49).

2.2.5: Leg cramps

Leg cramps (spasms in the calves) can be very painful, and possibly affect more than 30% of all pregnant women (50). Leg cramps usually occur at night, lasting from seconds to minutes (51). Although a variety of interventions such as compression stockings, salt, calcium and magnesium are sometimes used, it is not known whether any are both effective at reducing leg cramps and safe for the fetus (51).

2.2.6: Constipation

Constipation is believed to be caused by decreased bowel mobility secondary to elevated progesterone (normal in pregnancy), which can lead to greater absorption of water, but it can also be caused or worsened by iron supplementation (52), (53).

2.2.7: Edema

Edema during pregnancy occurs due to changes in factors governing renal sodium and water handling along with fall in interstitial fluid colloid osmotic pressure and a rise in capillary hydrostatic pressure (54).

2.2.8: Urinary incontinence

Prevalence of incontinence during pregnancy varies widely, with figures ranging from 4 – 53% (55).

2.2.9: Varicose veins

Hormone induced lowered venous tone combined with uterine compression of venous returns causes over-distension of superficial and deep veins and valvular incompetence, resulting in varicose veins (56).
2.2.10: Diastasis recti or abdominal separation

Diastasis recti is a condition in which the rectus abdominis muscle separates in the midline at the linea alba (57).

2.2.11: Striae gravidarum

Striae gravidarum (pregnancy-related stretch marks) occur in 50% to 90% of women (58). The cause of striae gravidarum remains unknown but clearly relates to changes in the structures that provide the skin with its tensile strength and elasticity. Mechanical stretching of the skin in association with hormonal factors has been implicated in the pathogenesis. It has been postulated that some hormones, like estrogen, relaxin, and adrenocortical hormones, decrease the adhesiveness between collagen fibers and increase ground substance, which results in the formation of striae in areas of stretching (59).

2.2.12: Round ligament pain

Round Ligament pain is the pain experienced when the ligaments positioned under the uterus stretch and expand to support the woman's growing uterus.

2.3: Gait Analysis (General)

Gait analysis is the systematic study of animal locomotion, more specific as a study of human motion, using the eye and the brain of observers, augmented by instrumentation for measuring body movements, body mechanics, and the activity of the muscles (60). Gait analysis is used to assess, plan, and treat individuals with conditions affecting their ability to walk. Quantitative gait analysis is a useful objective tool for gait assessment.

Purpose of Gait analysis according to O’ Sullivan is as follows (61):

1. To assist with understanding the gait characteristics of a particular disorder. This includes:
   a. Obtaining accurate descriptions of gait patterns and gait variables typical of different conditions
   b. Identifying and describing gait deviations present, or typically present in specific disorders.
   c. Determining balance, endurance, energy expenditure, and safety
d. Determining the functional ambulation capabilities of the patient in relation to functional ambulation demands of the home, community, and work environments
e. Predicting a patient’s future status

2. To assist with movement diagnosis by:
   a. Identifying and describing gait deviations and describing the differences between a patient’s performance and the parameters of normal gait.
   b. Analyzing gait deviations and identifying the mechanisms responsible for producing them
   c. Examining balance, endurance, energy expenditure and safety and determining their gait on gait

3. To inform selection of intervention(s) by guiding the therapist in:
   a. Proposing appropriate treatment of impairments that may improve gait performance.
   b. Determining the need for adaptive, assistive, orthotic, prosthetic or supportive devices or equipment

4. To evaluate the effectiveness of treatment and guide the therapist in:
   a. Determining how interventions such as therapeutic exercise, endurance activities, developmental activities, strengthening or stretching, electrical stimulation, balance training, surgical procedures and medication will affect gait.
   b. Determining the effectiveness and fit of devices or equipment selected in providing joint protection and support, correcting deviations and dysfunctions, reducing energy expenditure, and promoting safe locomotive function.

2.3.1: Methods of studying gait

The pioneers of scientific gait analysis were Aristotle in De Motu Animalium (On the Gait of Animals)\(^{(62)}\) and much later in 1680, Giovanni Alfonso Borelli also called De Motu Animalium (I et II). Aristotle (-384 – -322) is regarded to have written the first ever book on biomechanics, “On the Movement of Animals”, in which he sees animal bodies as mechanical systems. The father of modern biomechanics, Giovanni Alfonso Borelli (1608 – 1679), heavily influenced by the
work of Galileo Galilei (1564 – 1642), was the first to understand the musculoskeletal system as a set of levers that magnified motion rather than force (63). In the 1890s, the German anatomist Christian Wilhelm Braune and Otto Fischer published a series of papers on the biomechanics of human gait under loaded and unloaded conditions (64).

With the development of photography and cinematography, it became possible to capture image sequences that reveal details of human and animal locomotion that were not noticeable by watching the movement with the naked eye. Eadweard Muybridge and Étienne-Jules Marey were pioneers of these developments in the early 1900s (65).

2.3.1.1: PHOTOGRAPHIC TECHNIQUES

Chronophotography is the most basic method for the recording of movement. Strobe lighting at known frequency has been used in the past to aid in the analysis of gait on single photographic images (66), (67), (68).

![Chronophotography](image)

*Figure 3 Chronophotography* (65)

2.3.1.2: VIDEOGRAPHY

Cine film or video recordings using footage from single or multiple cameras can be used to measure joint angles and velocities. This method has been aided by the
development of analysis software that greatly simplifies the analysis process and allows for analysis in three dimensions rather than two dimensions only.

The types of gait analysis in use today can be classified under two broad categories: kinematic and kinetic. Kinematic gait analysis is used to describe movement patterns without regard to the forces involved in producing the movement. A kinematic gait analysis consists of movement of the body as a whole and/or body segments in relation to each other during gait. Kinetic gait analysis is used to determine forces involved in gait. In some instances both kinematic and kinetic gait variables may be examined in one analysis. In addition to examining kinematic and kinetic gait variables, physiologic variables such as heart rate, oxygen consumption, and energy cost may be considered.

2.3.1.3: MOTION ANALYSIS SYSTEMS

Passive marker systems, using reflective markers (typically reflective balls), allows for very accurate measurement of movements using multiple cameras (typically five to twelve cameras), simultaneously. The cameras utilize high-powered strobes (typically red, near infrared or infrared) with matching filters to record the reflection from the markers placed on the body. Markers are located at palpable anatomical landmarks. Based on the angle and time delay between the original and reflected signal, triangulation of the marker in space is possible. Software is used to create three dimensional trajectories from these markers which are subsequently given identification labels. A computer model is then used to compute joint angles from the relative marker positions of the labeled trajectories\(^{(69)}\). These are also used for motion capture in the motion picture industry\(^{(70)}\).

Active marker systems are similar to the passive marker system but use "active" markers. These markers are triggered by the incoming infra-red signal and respond by sending out a corresponding signal of their own. This signal is then used to triangulate the location of the marker. The advantage of this system over the passive one is that individual markers work at predefined frequencies and therefore, have their own "identity"\(^{(71)}\).

Inertial (cameraless) systems based on MEMS (Micro-Electro-Mechanical Systems) inertial sensors, biomechanical models, and sensor fusion algorithms. These full-body or partial body systems can be used indoors and outdoors regardless of lighting conditions\(^{(72)}\).
A typical modern gait lab has several to many cameras (video and/or infrared) placed around a walkway or treadmill, which are linked to a computer. The patient has single markers applied to anatomical landmarks, such as palpable bony landmarks (e.g., the iliac spines of the pelvis, the malleoli of the ankle, and the condyles of the knee), or clusters of markers applied to the middle of body segments. The patient walks down the walkway or the treadmill and the computer calculates the trajectory of each marker in three dimensions. A model is applied to compute the underlying motion of the bones. This gives a full breakdown of the motion at each joint.

In addition, to calculate movement kinetics, most laboratories have floor-mounted load transducers, also known as force platforms, which measure the ground reaction forces and moments, including magnitude, direction, and location (called center of pressure). The spatial distribution of forces can also be measured using pedobarographic equipment. Adding this to the known dynamics of each body segment, enables the solution of equations based on the Newton–Euler equations of motion permitting computations of the net forces and the net moments of force about each joint at every stage of the gait cycle. The computational method for this is known as inverse dynamics.
Figure 4: Motion Capture System generated stick diagrams along with force vectors using marker system\textsuperscript{(73),(74)}
This use of kinetics, however, does not result in information for individual muscles but muscle groups, such as the extensor or flexors of the limb. To detect the activity and contribution of individual muscles to movement, it is necessary to investigate the electrical activity of muscles. Many labs also use surface electrodes attached to the skin to detect the electrical activity or electromyogram (EMG) of, for example, a muscles of the leg. In this way it is possible to investigate the activation times of muscles and, to some degree, the magnitude of their activation—thereby assessing their contribution to gait. Deviations from normal kinematic, kinetic, or EMG patterns are used to diagnose specific pathologies, predict the outcome of treatments, or determine the effectiveness of training programs.

Recently gait analysis has undergone technological advancements. However footprint data still can provide a simple and inexpensive and reliable method for measuring a gait\(^{(75),(76)}\).

Thus during pregnancy, a woman changes obviously in body weight, body shape, and endocrine system. Those changes make the posture and gait pattern of the pregnant women different from those of the non-pregnant women.

### 2.4: Gait during pregnancy

#### 2.4.1: Distance and time variables

The overall speed of walking is reduced in pregnancy with prominent changes during third trimester\(^{(41),(77),(78),(79),(80),(81),(82)}\). According to some authors the speed does not change during pregnancy.\(^{(83)}\) Walking velocity may be affected by history of fall\(^{(84)}\). Cadence may decrease\(^{(80)}\) or remain normal\(^{(83)}\).

Step length and stride length reduces\(^{(80),(81),(85)}\) or may remain normal\(^{(83),(86)}\) during pregnancy.

Base of gait increases significantly during third trimester of pregnancy\(^{(80),(86),(87)}\).

Stance time increases\(^{(88)}\) although Branco et al\(^{(81)}\) did not find significant change.

Foot progression angle does not show any deviation from normal pattern\(^{(83)}\).

#### 2.4.2: Kinematic changes

Anterior pelvic tilt increases during pregnancy. The same change is also evident during walking along with increased maximum hip flexion\(^{(77),(83),(78)}\).
Although some authors did not find any difference in hip flexion angle during walking (80), (81).

Stance phase hip adduction may increase (83) or may remain unchanged (80), (81).
Knee flexion may increase during midstance (77) or remain unchanged (80), (81).
Ankle dorsiflexion may reduce (77), (78) or remain unchanged (80), (81).
Trunk tilt and trunk obliquity and trunk rotation angles during walking remain similar to that of nonpregnant women (83), (82).

2.4.3: Kinetic changes

Tsan Hsun et al (89) suggested the following kinetic changes during gait in pregnancy. They attributed these changes to sacroiliac pain during pregnancy.

- Increase of hip extension moment
- Decreased knee extension moment
- Decreased ankle planter flexion moment
- Increased knee adduction moment

2.4.4: Metabolic cost

Although resting metabolic rate increases overall metabolic cost of walking is reduced due to adaptations made in walking during pregnancy (79).

2.5: Evaluation of gait during pregnancy in India

Currently no data is available on gait analysis during pregnancy in India. Evaluation of gait may help to find adaptations made by pregnant women to compensate for physiological changes acquired during pregnancy. Although it may be assumed that the adaptations may be similar to those found in other countries, a separate evaluation on Indian subjects may help us to confirm this hypothetical idea. However as basic anthropometric characteristics and lifestyle changes from one residual zone to other, it may have an impact on adaptive strategies assumed by their residents and so we may also assume that gait adaptations may be different in Indian pregnant women. This may be the first study analyzing gait of pregnant women in the area of Jamnagar city in the state of Gujarat, India.