Symptoms in the Opposite or Uninjured Leg

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Prepared by:

Dr. Ian J. Harrington

Orthopaedic Surgeon

Dr. Ian J. Harrington graduated from the University of Toronto as a Professional Engineer in 1958. He obtained his medical degree from the University of Western Ontario in 1965. He did post-graduate training in orthopedics at the University of Toronto. He was granted his fellowship in orthopedic surgery in 1971. Dr. Harrington received an M.S. (Surgery) from the University of Toronto in 1972 and a M.Sc. from the University of Strathclyde, Scotland, in 1973. He joined the University of Toronto faculty in 1973 and holds the rank of Associate Professor in the Department of Surgery. His clinical and research interests are in orthopedics and biomechanics. He has published widely in those areas. He practiced at the Toronto East General Hospital as Chief of Staff from 1982 to 1987, as Chief of the Division of Orthopaedic Surgery from 1990 to 2000 and as Chief of Surgery from 1993 to 2001. Dr. Harrington also serves as the Designated Amputee and Prosthetic Device Consultant for the Ontario Ministry of Health/TEGH Amputee Clinic since 1990. Dr. Harrington is involved with the Tribunal as an assessor since 2000.

This medical discussion paper will be useful to those seeking general information about the medical issue involved. It is intended to provide a broad and general overview of a medical topic that is frequently considered in Tribunal appeals.

Each medical discussion paper is written by a recognized expert in the field, who has been recommended by the Tribunal's medical counsellors. Each author is asked to present a balanced view of the current medical knowledge on the topic. Discussion papers are not peer reviewed. They are written to be understood by lay individuals.

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SYMPTOMS IN THE OPPOSITE OR UNINJURED LEG

I. Introduction

Lay people and many doctors as well, believe that pain or disability in one leg can stress the other one and produce symptoms in it. It is often claimed that an injury causing disability of one leg initiated or aggravated a disabling condition in the opposite normal or previously asymptomatic lower extremity. It may be reasoned that the injury to one leg caused the patient to "favour" it and that this in turn unduly stressed the normal leg because it has had to bear more weight, causing or accelerating arthritis in one of its joints (usually the knee). It is assumed that when a person says he favours his leg, he means that he limps, sometimes requiring him to use crutches in order to protect the injured limb. The mechanics of limping are poorly documented in the orthopaedic literature and there is no clear scientific basis for such reasoning. In particular, few references have been found to the effect of the limp on the other leg. The evidence available indicates that an injury in one extremity rarely causes a major problem in the opposite or uninjured extremity except when damage to the leg results in a major displacement of the centre of gravity of the body while walking, significant shortening of the injured limb and the abnormal gait pattern has been present for an extended period of time.

To understand limping and its effect on the opposite leg, it is important to understand normal gait.

II. Normal Gait

Normal gait (level walking) is divided into stance (60%) and swing phase (40%). Stance is when the leg is on the ground.[14] Swing is when the leg is advancing through the air in preparation for its next stance phase (Fig. 1). The major proportion of force transmitted by a lower extremity occurs during the stance phase of gait, due to the subject's body weight and acceleration forces generated by the walking process, acting at the centre of gravity of the body's mass (Fig 2). During the swing phase of gait, acceleration forces only are transmitted by the leg.
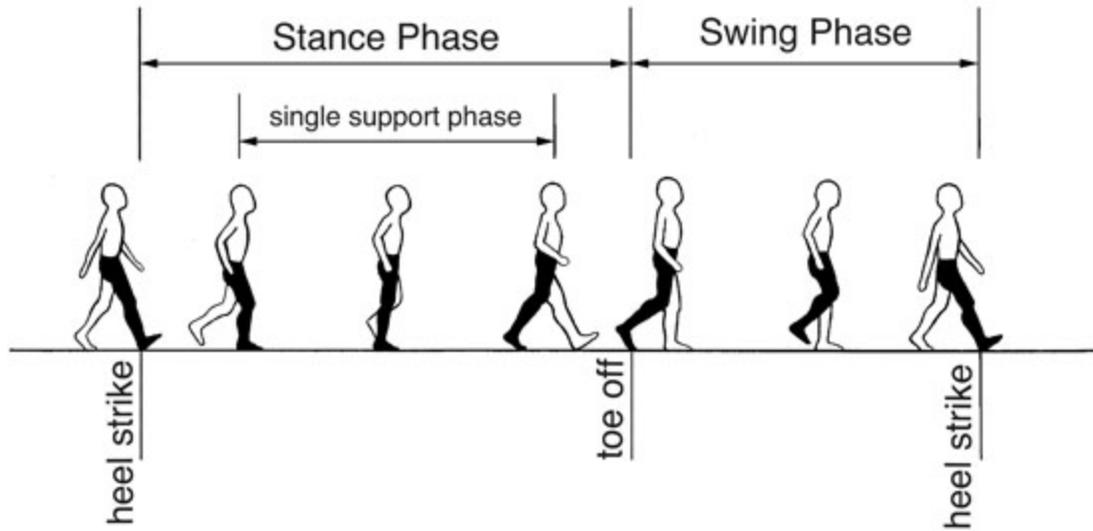
Figure 1 - Stance Phase and Swing Phase

Dynamic Analysis

centre of gravity
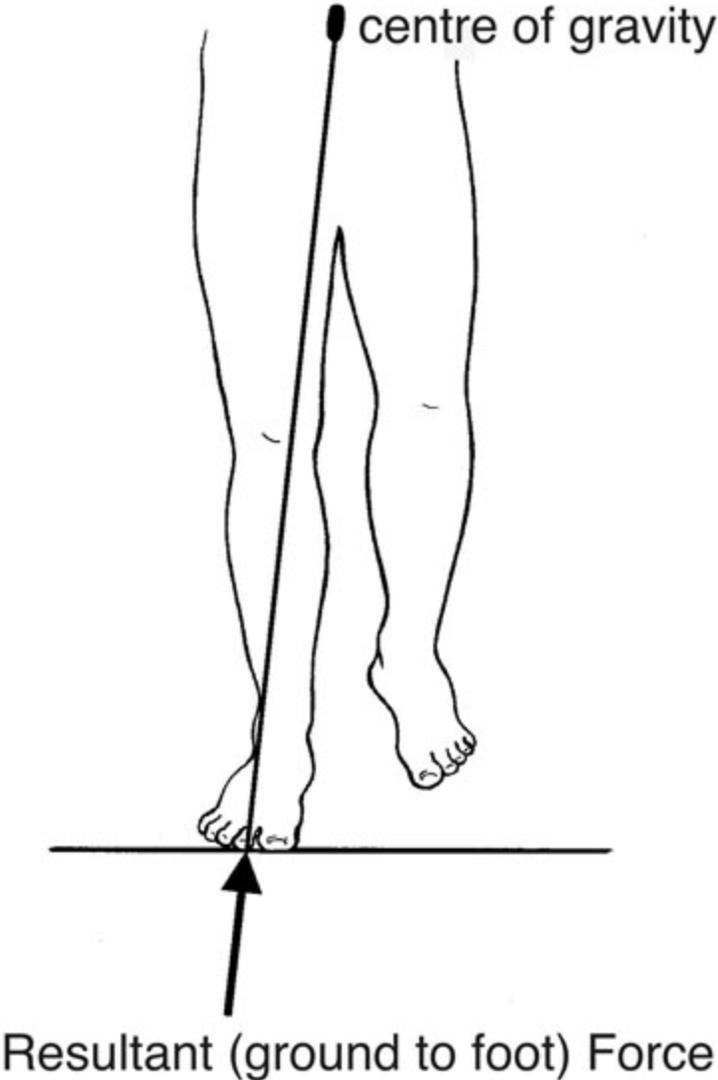
Resultant (ground to foot) Force

Figure 2 - Dynamic analysis

An individual's walking speed provides an index of functional status. The age related decline in gait speed, for example, is the result of a decrease in step or stride length.[6,14] Decreased speed and stride length allow increased double support time and thus improve bipedal balance, i.e. a safer and more stable gait pattern. Gait alteration such as diminished stride length, increased double limb support, reductions in limb ranges of motion, stepping variability and reductions in floor clearance are common in patients with a variety of diseases such as hemiplegia/hemiparesis, knee and hip osteoarthritis, diabetic neuropathy, Parkinson's disease and following injury to a lower extremity. These gait alterations increase with increasing severity of disease and degree of lower extremity injury. Joint and leg pain, muscle paralysis or a major difference in leg lengths, for example, may lead to many of these gait alterations including uneven forward progression, lateral lurching and asymmetry of gait characterized by limping. The awkward, unnatural gait pattern coupled with an inordinate amount of work required for walking causes a significant increase in energy consumption which in turn can place increased stress on the cardiovascular system.[3]

III. Types of Limp

There are three basic limps - antalgic (anti-pain), paralytic and short legged.

Limping is an abnormal gait, which can be caused by pain, muscular dysfunction, or deformity, including leg length discrepancy. Limping is never normal and the causes should be established.[4]

The most common types of limping are:

1. Antalgic limp

This is a common limp caused by pain. An individual with a painful lower extremity attempts to take less weight on the affected limb and shortens the duration of the stance phase on that side, whereas the normal leg comes forward more quickly, i.e. it has a shortened swing phase.[14] Weight bearing on the normal side tends to be prolonged. This produces a characteristic gait with uneven strides of different duration. This type of limp often occurs with normal muscle power and is due to the tendency of the body to protect a painful bone or joint.

2. Paralytic Limp

In the paralytic type, one or more muscles are weakened by neuromuscular disease e.g. poliomyelitis, muscular dystrophy, and cerebral palsy or from injury to motor nerves innervating a muscle or as a result of direct damage of muscle tissue [11,17]. If

muscle power is diminished and unable to balance body weight, the individual must adopt an unnatural walking pattern, whereby the trunk and upper body are positioned over the affected limb producing a characteristic lurch or limp.

3. Limping and limb length discrepancy

In the short leg limp there is usually no alteration in the rhythm of gait, however, because one leg is shorter than the other, there is a tendency for the body to dip towards the short leg in its stance phase. Patients who have a significant limb length discrepancy demonstrate an altered gait pattern or limp.[1] In the short leg limp, there is a dip when the short leg is in the stance phase, which is scarcely noticeable unless the shortening is marked (5 cm. or more).

IV. Biomechanics of Pathological Gait

Bilateral symmetry in ambulation is one of the fundamental properties that is often used by clinicians to evaluate gait disorders. Motion of the body's centre of gravity is a summary indicator of the mechanics of human pathological gait.[5] Musculo-skeletal disorders, including injury to a lower extremity disturb normal movements of the body segments during gait and these abnormal movements influence the motion of the body's centre of gravity. A compensatory type of gait occurs where movement of the centre of gravity is such that there is an accommodation in gait pattern to minimize muscle effort by the affected leg and the pain in it. The main compensatory mechanism that occurs in "abnormal gait" is the Trendelenburg lurch [1, 11, 12, 17, 18] (Fig 3).
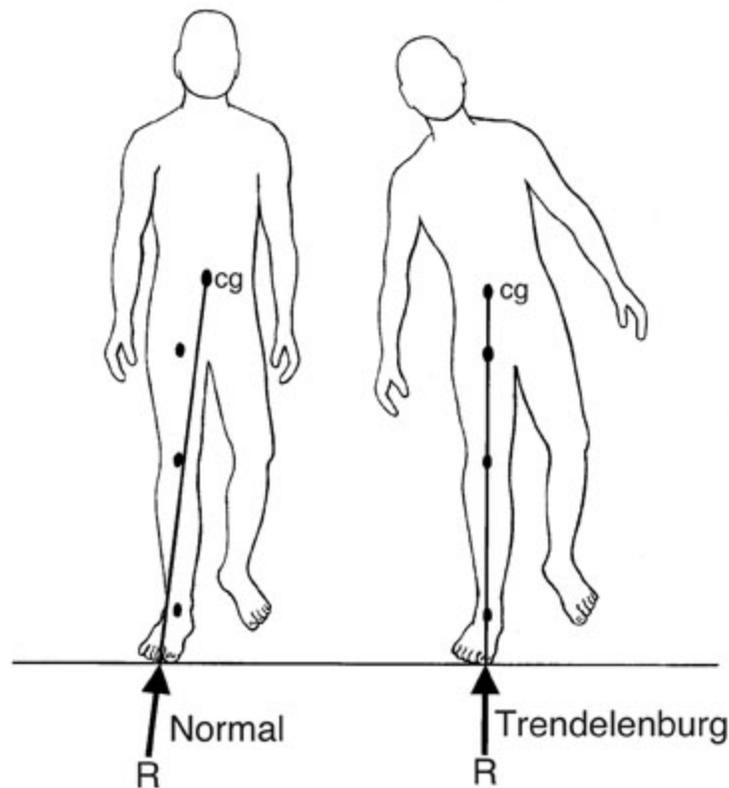
Figure 3 - Centre of Gravity Shift

i) Trendelenburg lurch (gait pattern)

During normal gait, the centre of gravity of the body mass moves in a smooth, sinusoidal (wave-like) pattern in the vertical and horizontal planes, i.e. up and down, and side to side.. Gait is even and the upper segments of the body are maintained in an erect position with very little side-to-side movement of the head, arms, trunk and thorax. When weight is borne on an injured, painful or paralyzed limb, the pelvis, trunk, thorax, head and neck rotate towards it [6]. The upper extremity on the side of the damaged leg also tends to swing away from the body. The net effect is that there is a shift of the centre of gravity of the body's mass directly over the damaged leg "a dynamic functional adaptation of gait". This is an involuntary compensatory mechanism that results in a reduction of lower extremity muscle force required to stabilize the injured or paralyzed leg [1,17,18]. By this mechanism, less muscular force is required to balance the body mass. The overall effect is a reduction in load transmitted by the muscles, bone, and joints of the injured limb and therefore, less pain.

ii) Walking speed

Another mechanism for minimizing load transmission is to reduce gait speed. Older, less fit individuals, particularly those with a painful extremity, adopt similar compensatory gait mechanisms to reduce overall load transmission.[6]

Joint force in the lower extremities is directly proportional to body weight, stride length, cadence, walking speed, and height [15,16] (Fig. 4). This means that a short, light individual walking slowly with a reduced stride length will transmit significantly less force in both lower extremities during level walking than a tall, heavy individual with a long stride length who walks quickly. Increased stride length, for example, increases the leverage of the lower extremity muscles used to propel the body forwards, thereby increasing muscular force and joint torque generating maximum load in each leg. With slow gait and shortened stride length, as would occur with an injured lower limb or in an unfit individual, acceleration forces are diminished or reduced almost entirely so that in most instances, the maximum force that can be transmitted by either leg is very close to a static situation, i.e. body weight.

Magnitude of Joint force is related to
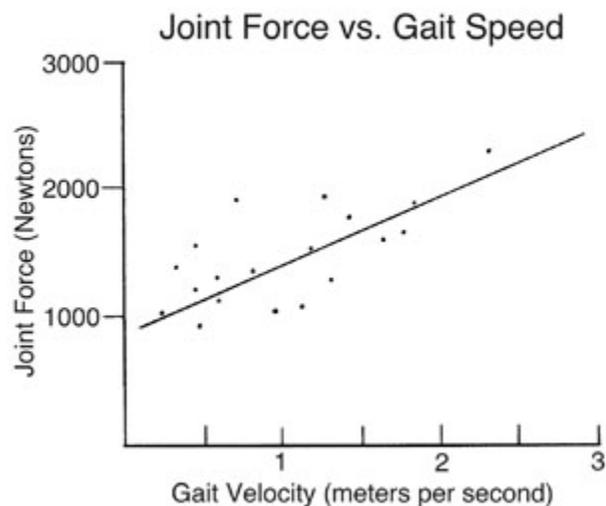
- Body weight

- Stride length

- Gait velocity

Joint Force vs. Gait Speed

Figure 4 - Magnitude of joint force is related to body weight, stride length, gait velocity

iii) Normal and abnormal lower extremity joint profiles

There are three distinct peaks of force transmission during the stance phase of gait, each corresponding to the contraction of major muscle groups in the lower extremity, e.g. hip muscles, hamstrings, quadriceps and gastrocnemius muscles etc. The force peaks occur at heel strike and during the early and late stages of the stance phase. Transmission of force is least during the mid part of gait and approximates the individual's body weight, [7,13,15] (Fig. 5).
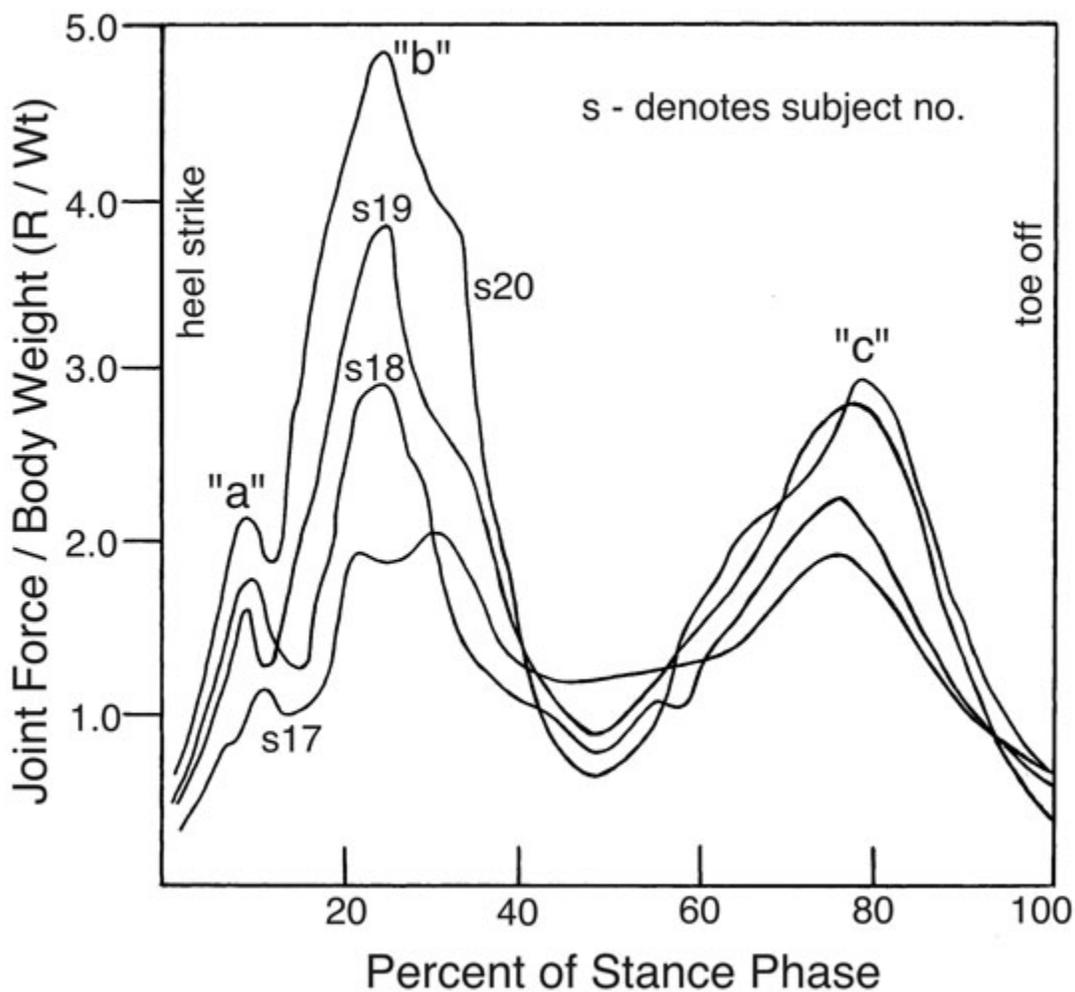
Figure 5 - Knee Joint Force - Normal Subjects

Joint force curves for individuals with abnormal gait are quite different from normal joint curves, i.e. there are blunted peaks of force transmission and the total load transmitted by the injured or weakened limb is near body weight throughout the stance phase of gait [7,8,9] (Fig. 6). The forces transmitted by the uninjured leg in persons with an abnormal walking pattern have normal joint force peaks and the magnitude of force transmission is always greater compared to the injured leg but not necessarily of greater magnitude than one would anticipate for normal individuals without injury. There are no studies to date that clearly demonstrate that force transmitted by the opposite uninjured lower extremity is greater than load transmission in normal subjects.
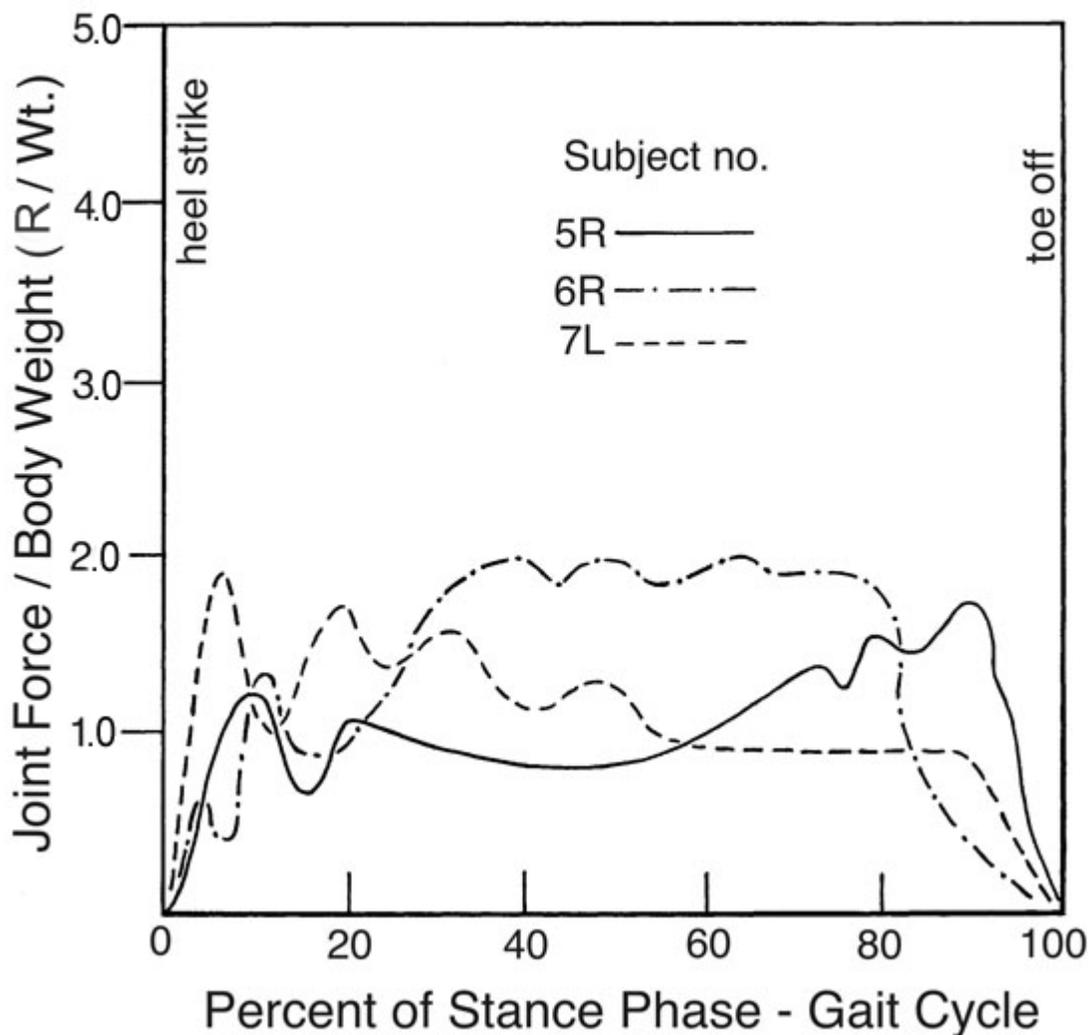

Figure 6 - Knee Joint Bearing Force in Paralytic Limbs

V. Stress Borne by the Normal Leg

When an individual stands on both legs, half of the body weight is supported by each lower extremity. For example, if a person weighs 200 lbs. load distribution is such that each lower extremity supports 100 lbs. If that person sustains an injury to one leg, i.e. someone steps on that person's foot or kicks that individual in the shin, there will automatically be a shift in weight to the opposite leg because the injured limb is painful. For a 200 lbs. individual, this would mean that the uninjured limb supports full body weight, i.e. 200 lbs. while the injured limb takes no weight. At first glance, this would tend to support the patient's claim that injuring one leg has caused more weight to be transmitted by the opposite normal leg, possibly causing damage to it. Most activities, however, are not static in nature. Walking is a dynamic activity which generates dynamic forces acting on the lower limb segments, directly proportional to the Newtonian force equation where force is equal to mass times acceleration. Each lower limb segment has its own mass, which is accelerated and decelerated intermittently during walking. The total force transmitted by a lower extremity is equal to the sum of the static force generated from the individual's body weight and the dynamic forces that are produced as the body mass, including the thigh, shank, foot, and ankle, is accelerated and decelerated during walking. This means that the maximum forces transmitted by both lower extremities during normal walking will be greater than body weight. For a 200 lb. individual, maximum force transmitted in each leg, depending on level of activity, can range from three to six times body weight, e.g. 600 to 1200 lbs (Fig. 7).
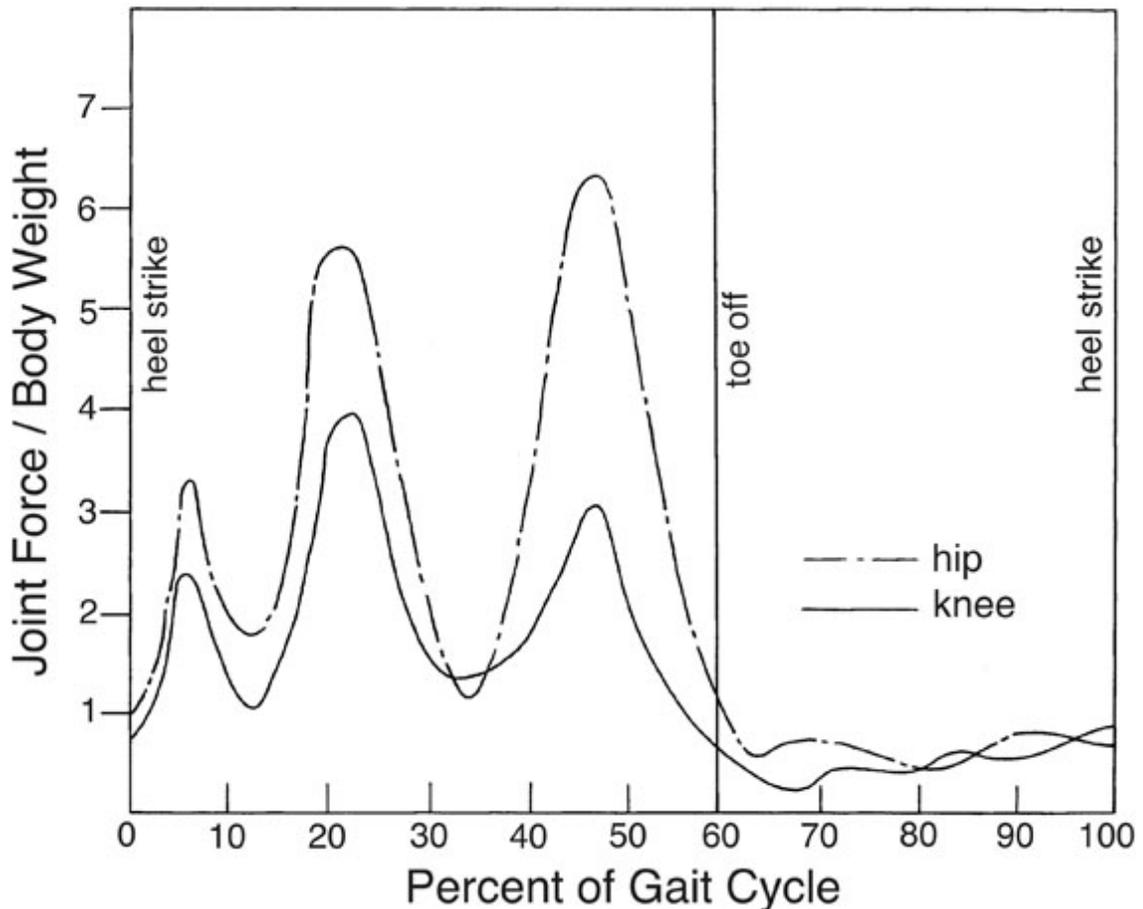
Figure 7 - Hip and Knee Joint Force Profiles

(i) Patients with limb paralysis often have rather marked displacements of the centre of gravity, in both the saggital (vertical) and frontal (side-to-side) directions so that when weight is borne on the injured leg, the pelvis, trunk, thorax, and upper extremity rotate towards it, i.e. the Trendelenburg lurch [12]. At heel strike, when the normal limb begins its weight-bearing phase, the pelvis is tilted away from the normal leg, therefore the abductor muscles at the hip are elongated and may have to work harder to pull the pelvis into a horizontal position, as the stance phase in the normal side progresses. Increased force in the abductor musculature, results in increased force transmission across the hip joint. Because the pelvis is tilted away from the normal limb, the femoral head is not as well covered by the hip socket as it is when the pelvis is maintained at a horizontal level during normal gait, therefore, force transmission across the hip would then be concentrated over a smaller joint bearing area, thereby increasing joint pressure e.g. pounds per square inch (PSI) [1] - Fig. 8.

Mechanics of Limping

$$T \times a = W \times b$$
$$a > a_1$$

T = the Tension force in the hip abductor muscles
a = lever arm from the centre of hip rotation to the abductor muscle of hip
b = the lever arm from the hip centre to the line of action of W
w = individual's body weight
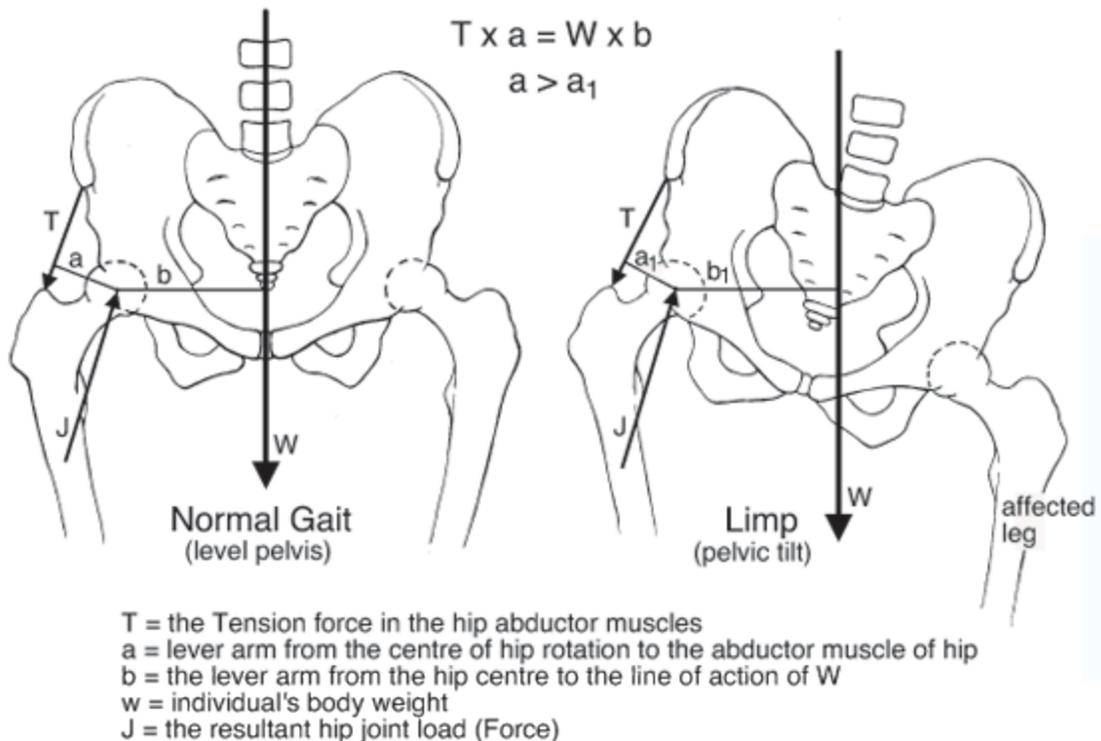J = the resultant hip joint load (Force)

Figure 8 - Mechanics of Limping

In paralytic gait, it takes the patient longer during the swing phase to position the injured leg for its next stance phase. This altered rhythm means that the normal leg spends more time in its stance phase so that the time spent transmitting force across the normal lower extremity joints (hips, knees, feet and ankles) would tend to be prolonged. This could have a detrimental effect in the long term because the joint force is applied over an extended time period, however, it would likely take many years to have a significant effect. Any condition or injury causing severe muscle damage or paralysis of a lower extremity often results in major horizontal or vertical displacements of the centre of gravity of the body mass that could, in theory, generate increased force transmission by the normal leg.

(ii) With an antalgic gait, the stance phase of the painful leg is reduced because the patient is getting off the affected limb as quickly as possible. This means that the swing phase of the normal leg is rushed as the patient hurries to ready it before its next stance phase - this increases the magnitude of acceleration forces on the limb segments of the normal leg as it swings forward striking the ground more quickly because of the hastened action. The leg's momentum (mass times velocity) is, therefore, increased. The increased impact at heel strike theoretically could increase stress in the normal leg and typically occurs at the beginning of the stance phase of gait.

(iii) As a rule, shortening of the leg does not cause symptoms. About 5% of normal people have shortening of up to four or five centimetres of which they are entirely unaware except possibly as a problem when getting clothing to fit properly, e.g. maintaining equal trouser leg lengths.

Exceptions would occur for those individuals who have a significant leg length discrepancy, i.e. greater than four or five centimetres, which would likely put extra stress on the opposite leg, particularly the hip [1]. Severe shortening produces a typical dip during gait on the short side but the rhythm of gait is unchanged. In severe shortening, the altered alignment of the pelvis elongates the abductor muscles of the normal hip and shortens their lever arm so that greater muscle force is required to level the pelvis while walking, which in turn generates increased hip joint load, (Fig. 8). The constant dipping and levelling of the pelvis with this type of gait could cause greater force to be transmitted by the normal limb, which over an extended period of time may create wear and tear problems for the individual's good hip and knee. The hip joint is especially vulnerable because dipping of the pelvis towards the short leg results in decreased area of coverage of the femoral head by the acetabulum, causing greater compression stress on the hip articular cartilage surfaces. It is unlikely, however, that a short leg gait would have any effect on the shorter limb since joint force would be reduced there as a result of the compensatory mechanisms previously described, i.e. a shift of the centre of gravity of the body's mass over the shortened leg. Dipping of the pelvis towards the short side also provides increased coverage of the femoral head by the acetabulum, thereby reducing articular stress.

(iv) Clinical observations. In the days when limping from poliomyelitis was common, complaints in the opposite leg attributable to limping were unknown. In fact, the commonest complaint related to limping was backache, not pain in the normal leg [2].

The ultimate disability a leg can suffer is amputation. Despite modern technology, no artificial leg comes close to restoring normal gait. Amputees do not seem to develop unusual arthritis in the opposite leg that can be attributed to the amputation. MJ Burke et al (Annals of Rheumatic Disease, 1978), however, has reported from a study of above knee amputee patients that there was a slight but not significant increase in osteoarthritis of the hip of the normal leg compared to the hip of the amputated side [2]. Burke reported that his findings were in keeping with those of Hungerford and Cokin (1974) who in a survey of above knee World War II single leg amputees, reported an increase in knee arthritis on the normal side, whereas osteoporosis of the resected femur was present on the amputated side.

Almost all above knee amputees walking with an artificial leg have a significant Trendelenburg lurch when they walk, so that for the reasons previously stated under (Section V, patients with limb paralysis) force transmitted by the amputated leg would be reduced due to shifting the centre of gravity of the body over the amputee limb, whereas there could be an increase in force transmission, particularly at the hip of the normal leg because of the constant dipping and levelling of the pelvis that occurs with a severe Trendelenburg lurch, (Fig. 8).

VI. Does Limping Increase the Weight Borne by the Normal Leg?

The answer is probably no. While there is no convincing evidence from gait studies or other investigators that greater force than normal is transmitted by the opposite uninjured leg, theoretical biomechanical considerations suggest that force borne by the normal leg could possibly be increased under the following conditions (please refer to Section IV - Biomechanics of Abnormal gait.

1. Major displacements of the centre of gravity of the body's mass in both the vertical and horizontal planes during gait - e.g. severe Trendelenburg lurch.

2. Significant leg length discrepancy greater than four to five centimetres.

3. The alteration of the gait pattern occurring over a prolonged period of time.

- **Diagnosis**

The diagnosis of problems related to the opposite and uninjured leg is made basically from a good history describing the severity of the injury sustained and whether or not this has resulted in a significant limp over an extended period of time. There are no diagnostic tests, apart from clinical examination and X-rays of the injured extremity that will provide important information. Gait studies to determine if there is a significant increase in force transmission by the uninjured leg would be of value but this type of assessment is often impractical in a clinical setting. X-rays taken of both lower extremities prior to injury would be very helpful in determining whether there was any pre-existing abnormal condition affecting the uninjured leg but this information, for obvious reasons, is rarely available. Even X-rays of the opposite normal limb taken at the time of injury are rarely available.

Since force transmission by an individual's lower extremity is directly proportional to stride length, body weight, and height, it follows that an individual's body habitus at the time of injury is an important predictor for the subsequent development of arthritis involving the normal extremity. The patient's weight is especially important. It is well documented that the incidence of osteoarthritis increases for both male and female subjects with obesity [10].

In order to make a decision as to whether limping is or was affecting the normal leg, it is important to know:

a) Whether limping was or is present. Unfortunately, most medical records do not document this well and it may be necessary to communicate with the original physician for more information.

b) Is the limp mild or severe? A mild limp is unlikely to cause any significant effect on the opposite leg. If the worker's injury has caused a pronounced limp, most times this would occur from an injury that resulted in severe paralysis of a lower extremity, e.g. from major nerve or muscle damage. This type of patient usually has a significant Trendelenburg lurch, which for reasons described in Section IV could cause increased force transmission, particularly at the hip and perhaps the knee of the normal leg.

c) What was the duration of the limp? If the limp has been present for only a few weeks or months - up to a year - it likely would not have any significant effect on the opposite leg. An injury to a lower extremity that resulted in a mild to moderate limp over a short period of time is unlikely to have any major impact on the opposite normal limb.

d). What sort of limp was it? A short leg limp probably does not affect the opposite leg unless leg length discrepancy is severe, e.g. 4 to 5 cm. and has been present over an extended period of time. Limping from any cause that results in significant displacements of the centre of gravity of the body mass causing a severe Trendelenburg lurch could affect the normal limb over the long term.

VII. Cast, Cane, and Crutches

Does the use of crutches increase the strain on the opposite leg?

The answer is no. Crutches are used either to completely unload the injured extremity or to partially unload it. In the case of completely unloading the extremity, the injured leg dangles in the air in permanent swing phase and progression is made by means of the normal leg alternating with the crutches, which substitute

completely for the injured leg's stance phase. The only change to the weight borne by the normal leg during its stance phase is the additional two or three pounds of the crutches themselves - less than the weight of a briefcase or a newborn child and not enough to cause strain.

In the case of crutches being used to partially unload the injured extremity, the injured leg is on the ground during its stance phase at the same time as the crutches. The body weight that the injured leg cannot bear is borne by the arms through the crutches; however, as in the case above, there is no change in the weight borne by the normal leg during its stance phase except the two to three pounds addition of the crutches themselves. It should also be noted that the use of crutches to lessen the weight taken by the injured leg causes no change in the rhythm of gait.

Does the use of a plaster increase the stress on the opposite normal leg?

The answer is no. The mechanics are the same as in the preceding section with the normal leg taking no additional weight except that of the plaster; in the case of a long leg plaster (i.e. thigh to toes) about an extra three pounds, as above, not enough to cause stress. Patients consistently overestimate the weight of such plaster casts, guessing them to be in the 25 to 30 pound range.

Summary and Conclusions

There is no clear evidence to suggest that an injury to one lower extremity would have any significant impact on the opposite uninjured limb unless the injury resulted in major muscle or nerve damage causing partial or complete paralysis of the damaged leg, and/or shortening of the injured lower extremity resulting in a limb length discrepancy of more than four or five centimetres so that the individual's gait pattern has been altered to the extent that clinically there is an obvious lurching type gait (a significant limp). In order for this type of gait to have impact on the opposite or uninjured leg, it is likely that the abnormal gait or limp would need to be present over an extended period of time - years. A temporary abnormality in gait, e.g. a limp over a relatively short period of time of weeks or months is unlikely to have any effect on the opposite leg. The use of a cast, cane, and crutches is also unlikely to have any major impact on the stress borne by the uninjured limb. Increased body weight (obesity) does, however, have a detrimental effect on both lower extremities and magnifies all of the previously described risk factors.

VIII. Some Case Examples

- **Aggravation of pre-existing osteoarthritis of left knee related to additional strain secondary to surgery for a compensable right knee condition of pre-existing extensive osteoarthritis of medial compartment.**

A Case Example under this category could involve a worker who previously underwent surgery for an injury to the right knee, which had gone on to develop osteoarthritis of the medial compartment of that knee. The worker claims that the surgery resulted in a strain of the opposite knee aggravating pre-existing degenerative change present in the left knee.

Unless the surgery carried out on the right knee resulted in a significant limp over a long period of time - greater than a few months - it is unlikely there would be an aggravation of the pre-existing arthritis of the left knee due to the mechanism previously described, i.e. a minimal Trendelenburg lurch and decreased walking speed as a result of surgical treatment and pain is likely to result in less than normal load transmission by the opposite left knee.

- **Plantar fasciitis of the left foot related to an altered gait pattern secondary to compensable right ankle soft tissue injury.**

In this situation a worker may complain that as a result of injuring the right ankle, e.g. sprain or fracture, the worker went on to develop plantar fasciitis of the left foot due to favouring the right leg and as a result, more weight was taken on the left leg and foot.

In general terms, a soft tissue injury to an individual's right ankle would result in protected weight bearing on that side and a reduction in walking speed so that there would tend to be decreased force transmission overall throughout the right and left lower extremities (antalgic gait). This type of walking pattern is unlikely to cause increased force to be applied to the left leg or foot.

- **Osteoarthritis of the left knee related to increased weight bearing demands secondary to compensable right knee condition of torn meniscus and post-traumatic osteoarthritis.**

An example of this situation would be a worker who underwent surgery for a torn meniscus of the right knee and went on to develop post-traumatic osteoarthritis of the same knee and then months or years later, complained of pain involving the opposite left knee which the worker attributed to osteoarthritis precipitated by taking greater weight on the unoperated knee, i.e. left knee joint.

Post-traumatic osteoarthritis of the knee is common following meniscectomy, particularly if a complete medial meniscectomy was carried out. Osteoarthritis often develops fifteen to twenty years following meniscectomy and is usually localized to the medial compartment. It is not uncommon for a worker to undergo surgery for a torn meniscus of one knee then claim months or years later that pain and degenerative arthritis has developed in the opposite knee, related to taking more weight on that side because of protecting the operated knee during walking. Unless there are major complications that have caused a significant alteration to the individual's gait pattern, e.g. resulted in a major post surgical limp occurring over a prolonged period of time, it is unlikely there would be any detrimental effect on the opposite uninjured knee. There is no evidence either clinically or from gait studies to suggest, that greater weight is borne by the unoperated leg following meniscectomy of the opposite limb.

- **Localized pain of the left knee related to overuse secondary to compensable right knee condition of injury and post-traumatic osteoarthritis.**

In this situation, a worker has developed osteoarthritis of the right knee secondary to an injury that occurred a number of years previous and then develops pain in the opposite left knee and attributes symptoms to overuse, i.e. taking more weight on the left side because of favouring the right leg.

The same rationale applies to this situation as the previous, i.e. unless the right knee condition with post-traumatic osteoarthritis results in a significant limp over an extended period of time, it is unlikely that greater force would be transmitted by the normal knee. Walking speed for this type of condition is also likely to be reduced so that overall force transmission by both lower extremities will be less than normal.

- **Pain and degenerative arthritic changes in the left knee related to overuse secondary to compensable right knee condition of torn medial meniscus, subsequent surgery, and permanent impairment.**

In this situation, it would depend on the nature of the permanent impairment affecting the right knee, i.e. did it cause a significant flexion contracture or knee deformity etc. that caused the patient to walk with a significant limp resulting in a Trendelenburg lurch? If the patient's walking pattern was essentially normal throughout, then it is unlikely that a greater stress would be transmitted by the normal knee resulting in arthritic change there.

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Legend

Fig. 1. Normal gait showing that the stance phase of gait accounts for 60% of the gait cycle and the swing phase 40%.

Fig. 2. The direction and magnitude of the resultant ground to foot force is directed towards the body's mass centre of gravity during normal and abnormal gait.

Fig. 3. Trendelenburg lurch or gait - a dynamic functional adaptation of gait showing a shift of the centre of gravity of the body's mass directly over the damaged leg due to weakness of the lower extremity musculature. The net result is a significant decrease in force transmitted by the injured or paralyzed limb.

Fig. 4. The magnitude of joint force is directly related to the subject's body weight, stride length and gait velocity. A heavy set individual walking at a fast pace with a long stride length will transmit a greater force through his lower extremities than a lighter person walking slowly with a shortened stride.

Fig. 5. Knee joint force profiles for normal subjects. There are three distinct peaks of force transmission due to hamstring, quadriceps and gastroc nemeus muscle contraction during the stance phase of gait.

Fig. 6. Joint force profiles for paralytic (polio) lower extremities in subjects with a moderate to severe Trendelenburg lurch. The joint force profiles tend to be flat - there are no peaks and the magnitude of force transmitted by the injured limb is on average, much less than the normal lower extremity.

Fig. 7. Joint force profiles for the hip and knee, illustrating typical magnitudes of force transmission. The maximum forces transmitted are multiples of body weight. Force transmission by the hip in normal individuals is greater than the force transmitted at knee level.

Fig. 8. In severe shortening of a limb or in any subject with a severe Trendelenburg lurch, the pelvis dips towards the affected side which results in less coverage of the femoral head (ball) by the acetabulum (socket). Dipping of the pelvis also causes elongation of the abductor muscles of the hip (T) and shortening of the lever arm (A) to the centre of rotation of the hip joint which results in greater force transmission to the hip (J) when the abductor muscles contract to level the pelvis. Greater than normal hip abductor muscle force is required to level the pelvis in order to support body weight (W). The net result is a greater hip joint force (J) acting over a smaller area of the femoral head due to incomplete coverage, thereby increasing the compression stresses applied to the hip joint cartilage (PSI).