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ANTERIOR COMPARTMENT PRESSURES IN NORDIC SKIERS

by

SUSAN KATHLEEN LAWSON

A THESIS

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The undersigned certify that they have read, and recommend to the FACULTY OF GRADUATE STUDIES AND RESEARCH, for acceptance, a thesis entitled ANTERIOR COMPARTMENT PRESSURES IN NORDIC SKIERS submitted by SUSAN KATHLEEN LAWSON in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

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Date. May 2, 1989

ABSTRACT

The purpose of the study was to compare the total increase (from rest to post-exercise) in the anterior compartment pressure between skating ski trials and classical ski trials, all other variables being constant. Intracompartmental pressures were recorded in the tibialis anterior muscle of ten subjects. A local anesthetic was administered, followed by the measurement of the resting pressure of the subject's right leg. After 10-12 minutes of cross country skiing using a "skating" technique on a designated course, an "immediate" post-exercise pressure was recorded 15 seconds after the termination of exercise. Subjects all completed two trials on different days: in one trial, subjects skated on skating skis and for the other trial, classical skis were used for the skating technique. The results of the study showed that, although the average pressure increase was higher for the classical ski trials (18.0 mmHg) than for the skating ski trials (17.3 mmHg), the difference was not significant (alpha level=.05). This finding would indicate that cross country skiers who skate on a classical ski as opposed to a skating ski which is ten centimeters shorter will not see a significantly greater increase in their anterior compartment pressure. Thus, it appears that the type of ski utilized is not a factor in contributing to chronic compartment syndrome.

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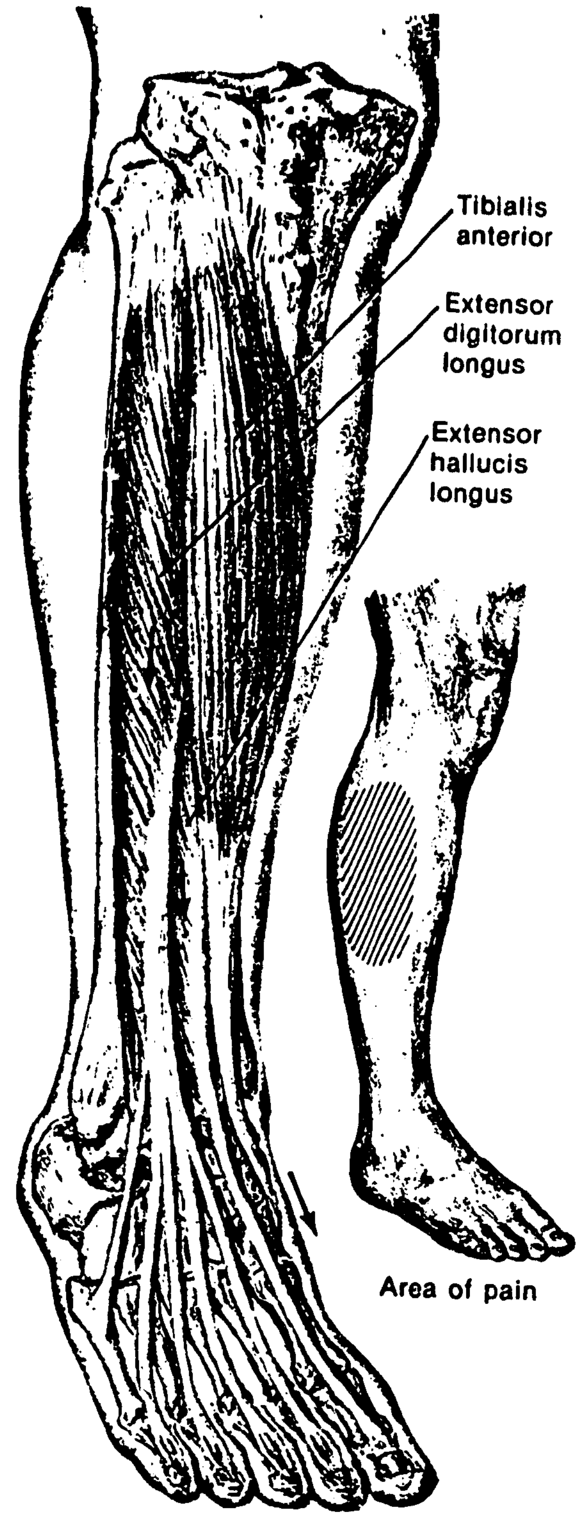
Chapter I
INTRODUCTION

A. Introduction to Chronic Compartment Syndrome

The chronic, exertional or exercise-induced compartment syndrome has been recognised in recent years as a cause of lower leg pain. It is possible that the first complete description of the chronic compartment syndrome (CCS) was that so graphically outlined in Captain Scott's diary during his 1912 Antarctic expedition (Huxley, 1977). Captain Lawrence "Titus" Oates, a sailor on that fateful treck, developed the syndrome and subsequently sacrificed his own life in an effort to allow his comrades to press on unincumbered. The CCS is therefore frequently referred to as the Titus Oates Syndrome. The first clearly outlined description in the medical literature was by Mavor in 1956. He also discussed the surgical management (Mavor, 1956). During the 1960's and early 1970's, CCS received little attention, but thereafter reports of the disorder increased significantly as did the development of techniques for measuring compartment pressure. Laboratory documentation of the diagnosis and pathophysiology of CCS has therefore become well established (Wiley, 1987).

Classically, the lower leg is divided into four muscle compartments: the anterior, lateral, deep posterior and superficial posterior. Davey et al. (1984) found evidence of a tibialis posterior muscle compartment within the deep posterior compartment and Detmer et al. (1985) believe there are seven functional compartments, with the superficial posterior compartment divided into three separate compartments. In effect, these authors are classifying the individual muscle sheaths as separate compartments. For the purpose of the present study, only the anterior compartment was considered. The muscles involved in an anterior compartment syndrome include: tibialis anterior, extensor digitorum longus, and extensor hallicus longus (Figure I.1) The various muscle groups in the lower leg, along with the appropriate nerves, arteries and veins, make up the major contents of these compartments. Each compartment is surrounded by an "envelope" of fascia and bone and in the anterior compartment, this envelope includes the anterior ridge of the tibia and the anterior intermuscular septum. When an individual exercises, the intramuscular pressure within each of these envelopes increases as blood flows to the muscle, with resultant muscle swelling. If the fascia is too tense to accomodate the increasing volume and the intramuscular pressure becomes too high, the result can be a painful cramping in the leg. The high intramuscular pressure can impair circulation and nerve conduction causing both neurological and muscular symptoms (Gertsch, 1987). Awbrey et al. (1988) described CCS as a condition which occurs when tissue pressure within a closed fascial space exceeds the



Brody, 1980

Figure I.1 Anterior Compartment Muscles

critical closing pressure of the local microcirculation.

There may be a certain physical predisposition in those individuals who experience CCS. The exact pathophysiological weakness or underlying mechanism which causes this intolerable increase in the compartment pressure in certain individuals is unknown (Lloyd-Smith, personal communica ion). Possibilities include: an abnormally tight or hypertrophied fascia, an unusually small compartment volume, an increase in extracellular fluid or excessive muscle swelling. Awbrey et al. (1988) felt that there was an inadequacy of musculofascial compartment size. The role of muscle hypertrophy in the development of CCS has not been established (Wiley et al., 1987). If muscle hypertrophy were a significant factor, one would expect to see more weight lifters and body builders with the disorder.

A patient with CCS typically complains of lower leg pain and muscle tightness that occurs with physical exertion (Wiley, 1987). The pain is described as either an aching or a cramping pain. The involved compartment determines quite clearly the anatomic location of the discomfort. There may be pain on passive stretching of the involved muscle(s). The leg may also be shiny, red or swollen. Impaired muscle function may be evident. In anterior compartment syndrome, there may be weakness of the foot dorsiflexors: tibialis anterior, extensor digitorum longus and extensor hallicus longus. Sensation testing may reveal abnormalities of the involved sensory nerve which runs through the compartment.

In anterior compartment syndrome, a dysesthesia or numbness may be evident in the first web space or along the lateral border of the ankle and foot, caused by compression of the deep peroneal nerve (Logan, 1983).

The effort needed to produce symptoms tends to be quite consistent for one patient; the symptoms frequently come on at a regular and predictable time during the activity. However, interpatient symptoms vary greatly, according to the degree of involvement in the compartment. For some people, walking for five minutes can bring on the symptoms. In most patients, the minimum time to the onset of pain after beginning to exercise is ten minutes and the maximum is thirty minutes (Detmer, 1985). As the syndrome progresses, the symptoms begin after shorter durations of exercise. The symptoms are often relieved by rest or by a decrease in intensity of exercise, but usually return with the resumption of exercise. If exercise is continued, symptoms become more severe until exercise becomes either extremely painful or impossible.

Patients with CCS have been treated with a variety of conservative treatments, including prescription of anti-inflammatory drugs, changes in training programs and techniques, therapeutic modalities, strengthening, taping, and orthotics. In many cases, the results of these non-operative approaches have not been good (Martens et al., 1984, Rorabeck et al., 1983, Wallentsten, 1983). In these particular cases, a fasciotomy is performed. The fasciotomy technique of Rorabeck et al (1983) is initiated by making two vertical skin incisions midway between the fibula and the crest of the tibia. The fascia between these two incisions is undermined proximally and distally. The anterior compartment is decompressed by retracting the skin anteriorly and cutting the fascia one centimeter in front of the anterior intermuscular septum. The most favorable results have come from a surgical release or fasciotomy of the involved compartment. However, the search for non-operative treatments still continues (Norman, Lloyd-Smith, Sheier, Wiley, personal communications).

Signs and symptoms alone cannot form the basis for a definite diagnosis. A presumptive diagnosis of CCS can be made on clinical grounds, but confirmation of that diagnosis requires measurement of intracompartmental pressure. The clinical presentation of CCS is known to mimic other disorders such as stress fractures, shin splints, periostitis of the tibia, intermittent claudication, and peroneal nerve compression. Intracompartmental pressure measurements provide the diagnostic differentiation of CCS from these other entities with similar symptoms (Awbrey et al., 1988, Styf, 1988). In order to make a definite diagnosis, it is recommended that patients with exercise pain in the leg initially be treated conservatively (Wiley, 1987). If there are no improvements, and symptoms have persisted for at least six months, then intracompartmental pressures should be measured.

Many different pressure measurements techniques have been considered for diagnosis. The three most common are: the pre-exercise pressure (or resting pressure), exercise pressure, and post-exercise pressure (Gertsch et al., 1987, Logan, 1983, McDermott et al., 1982, Rorabeck et al., 1988, Styf et al., 1987, Wiley et al., 1987). After measuring compartment pressures before, during and after the particular exercise which brings about the characteristic symptoms, these pressures can be compared to "normal" pressures. There are no universally accepted or agreed upon "normal" measurements, however a minimum to maximum range can be constructed from the standards of Allen and Barnes(1986), Detmer et al.(1985), Gertsch et al.(1987), Logan (1983), McDermott et al.(1983), Rorabeck et al.(1983), Styf et al.(1987) and Wiley et al.(1987). A normal resting pressure ranges from 2-15 mmHg and an exercise pressure can be anywhere from 30-80 mmHg (Figure I.2). Rorabeck et al. (1988) found in their study an increased intramuscular pressure at rest in symptomatic CCS patients (18.1 mmHg) when compared to normal controls (10.9 mmHg). Some pressure measurements are more useful than others when making a diagnosis. For example, many patients may have an elevated resting compartment pressure, but that is not enough to confirm diagnosis (McDermott et al., 1982, Rorabeck et al., 1988). Muburak et al. (1976) stated that measurement of pressure during exercise is quite variable and is the least reproducible of the three primary exercise measurements. If,

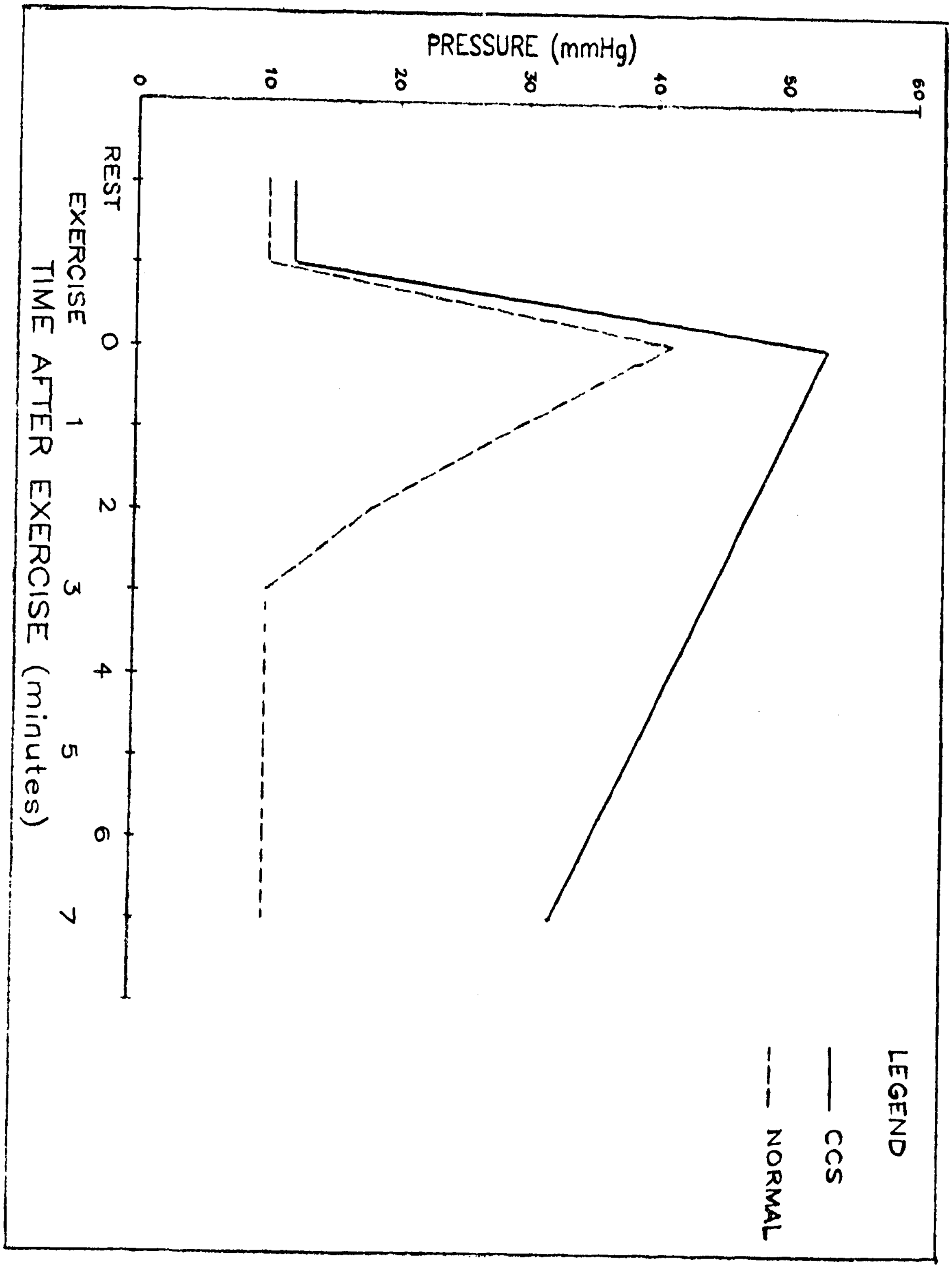


Figure I.2 Compiled Average Compartment Pressures however, a patient has a persistent elevation of pressure after exercise, then this pressure would be a finding of diagnostic significance. In CCS, pressures which are normally elevated with exercise typically fail to return to normal for at least ten minutes (Allen and Barnes, 1986, Gertsch et al., 1987, Rorabeck et al., 1983, Styf and Korner, 1987, Wiley et al., 1987). Most authors agreed that the most reliable pressure measurement in patients with suspected CCS was a pressure taken immediately after exercise. In addition to being elevated, this pressure measurement showed delayed return to normal resting values after exercise (Rorabeck et al., 1988). Most emphasis in the diagnosis has been placed on the time it takes for the post exercise pressure to return to normal. Although all the aforementioned authors concurred that pressure in an affected compartment took longer to return to its resting level, there was no agreement as to the precise criteria of pressure and time: a normal compartment returned to its resting level in 1-3 minutes (Figure I.2). Thus, a post-exercise pressure was of more value diagnostically if monitored for 10-15 minutes after exercise. Pain usually disappeared when the compartment pressure returned to its normal pre-exercise level.

For a particular type of movement, a corresponding group of muscles will be involved. Affected compartments will therefore differ from sport to sport (Gertsch, 1987). In the cross country skating technique, the muscles of the anterior compartment are involved. The primary function of these muscles is dorsiflexion of the ankle (Fig. I.1).

B. Introduction to Nordic "Skating"

Competitive nordic or cross country skiing has undergone a revolution. During the 1984-85 winter season, a new technique in cross country ski racing evolved called the Siitonen Step, free style or skating technique. This style of skiing was developed by Bill Koch, an American cross country ski racer, who found that it was faster than the classical or diagonal stride technique. The efficiency of this method was so great that it was generally adopted in competition and has, since 1985, almost completely replaced the classical step in most international races (Gertsch et al., 1987). There are now two separate races in the Olympics and World Cup races: classical and freestyle (skating). In skating, the skier pushes off from his rear ski in a motion derived from down hill skiing. These lateral pushes on the skis result in a skating movement when performed from side to side (Figure I.3). At the end of each skating stride, the musculature of the anterior compartment has to dorsiflex the foot to lift the ski and maintain a contraction until the next stride. Gertsch et al. (1987) were surprised that CCS was not more common in skiers after three seasons of the Siitonen technique.

Fischer, 1988

Figure I.3 Cross Country "Skating" Technique

The incidence of compartment syndrome in elite cross country skiers was far higher when the transition was first made to skating. In 1985, a year after skating was introduced, three Canadian national team members and one provincial team member were diagnosed as having CCS (Lloyd-Smith, Reid, personal communications). The U.S. national team also reported problems with the anterior compartment of the leg from the repetitive lifting up of the foot to skate (Dorsen, 1986). With the advent of skating, these elite racers rushed into the skating technique "full force" and virtually ignored the diagonal stride technique (Lloyd-Smith, personal communication). Since their anterior leg muscles were not accustomed to the action of skating, the muscles probably became overloaded.

In a study by Orava in 1985 of 194 overuse injuries in cross country skiers, 85.6% of the injuries were seen in competitive skiers. Almost 15% of the injuries were seen in "top athletes" representing the national or international levels. About 70% of the injuries hampered the training and competitive performances. It was stated in this study that anterior leg muscle pains were commonly seen in the skiers. The year that this study took place (1985) indicates that skating may have contributed to these overuse injuries.

Another important factor is that these competitive skiers initially skated on their classical skis which are not designed for skating. Skating skis, which are lighter and shorter, were not yet available when skiers started to skate. As Dr. Reid (personal communication) suggested, "skiers have developed the style before the equipment was adapted". Now, with the evolution of skating skis, the equipment has been adjusted to suit the style. Thus, since elite level competitors now skate on skating skis, the problem of CCS for them has decreased significantly (Lloyd-Smith, Norman, Reid, Wiley, personal communications). There was, however, still a concern for recreational competitors who did not have two pairs of skis and continued to skate on their classical skis. It is for this reason that these skiers were the focus of the present study.

C. Statement of the Problem

The purpose of this study was to determine the differences in the anterior compartment pressure of cross country skiers using the skating technique of skiing, and two different types of skis: the classical ski and the skating ski.

D. Limitations

The present study was limited by:

1. The reliability and accuracy of the pressure measurement and of the measuring equipment.
2. The inconsistencies between the subjects' exercise

intensities.

3. Any variations in weather or snow conditions between trials.
4. Inconsistencies between subjects in the exact amount of time after exercise that pressure was measured.
5. The fact that all subjects skated on the same length of skis, irrespective of their height and weight.
6. The varying amounts of the subject's activity prior to testing between the two trials.
7. The fact that an invasive technique of measuring was used and, therefore, it was decided that to perform reliability tests on people was inappropriate.

E. Delimitations

This study was delimited to:

1. Ten skiers who were familiar with the skating technique in cross country skiing. All subjects were tested on skating skis and classical skis.
2. The analysis of compartment pressure at rest and immediately (15 sec) after ten minutes of cross country skiing at a preset intensity.
3. The pressure measurement of the anterior compartment of the right leg only in all ten subjects.

F. Significance of The Study

If the different types of skis had a significant effect on the anterior compartment pressures, this finding may have implications for compartment syndrome. If it was found that a certain type of ski caused a comparatively high increase in the intramuscular pressure of the anterior compartment of the leg, perhaps that particular type of ski should be avoided. By using the ski which evoked the lowest compartment pressure, perhaps the classical symptoms of CCS could be prevented or alleviated in cross country skiers. If no significant pressure differences between the two ski types were noted immediately after the exercise trials, then one could assume that one type of ski was not significantly more effective in decreasing the incidence of anterior compartment problems. Wiley et al. (1987) believed that an initiating injury, trauma or overuse may precede CCS. He suggested that early, aggressive, non-operative management might prevent the cycle that promotes chronic compartment syndrome.

Chapter II

REVIEW OF LITERATURE

A. Possible Causes of CCS in Nordic Skiers

There is an uncertainty as to the underlying cause of CCS in cross country skiers. However, besides overuse, two of the more common proposed etiologic factors are the equipment and technique used in skiing (Lloyd-Smith, Norman, Wiley, personal communications).

The new "skating boots" may help to decrease lower leg pain from skating. Greater ankle support is offered by these boots since they extend higher up the leg than the regular classical ski boots. With these boots, movement at the subtalar joint, specifically, inversion and eversion of the ankle, is controlled and reduced, thereby reducing the work of the anterior compartment muscles. When the skiers on the Canadian national and the provincial teams first noticed the CCS symptoms, skating boots were not yet on the market.

As mentioned in the last chapter, the type of ski that the skier skates on may affect leg problems. Skating skis are lighter and shorter than classical skis and are designed for skating. Robert Norman, a biomechanist at the University of Waterloo who works closely with the Canadian national cross country ski team, expects compartment problems to be more prevalent in those skiers who skate on classical skis, as all racers did before skating skis were available. Since, in classical skis, the length from the ski binding to the tip is longer, decreasing the mechanical leverage, more muscular effort from the anterior compartment is required to skate. If the length of the ski were irrelevent, one would expect to see a larger percentage of hockey players or speed skaters with CCS. Dr. Gordon Cameron, the team physician for the Edmonton Oilers hockey team, has only seen one case of CCS in a hockey player and confirms that it is not a problem for hockey players. Even though the biomechanics may be the same for skating in hockey and in skiing, the lever arm of the hockey skate is almost non-existent compared to that of a ski since the skate does not extend beyond the toes. There is not an exaggerated effort in hockey to lift the skate to clear the ice, as there is in skiing. In addition, hockey players skate for very short shifts and are then able to rest. Thus, it is speculated that the tibialis anterior muscles of hockey players are not as prone to overuse or as constantly stressed as they are in cross country skaters.

The location of the binding on the ski is another important aspect in equipment. If the binding is located too far back on the ski, the front of the ski becomes longer and heavier and presumably the skier has to work harder and use more tibialis anterior effort to dorsiflex the ankle to lift the ski tip clear of the snow. If the binding is moved forward on the ski, weight is taken off the tip. This "unweighting" makes it easier to lift the ski by dorsiflexion. Norman (personal communication) has done a pilot study in this area. He measured electromyographical (EMG) activity of the tibialis anterior muscle in different binding positions: normal (at the balance point of the ski), 2.5 centimeters forward from the normal position, and five centimeters forward from normal. Results showed that the farther back the binding position, the higher the EMG activity of the tibialis anterior muscle.

The foot position during skating is another major area of emphasis in technique analysis. The position of the foot is known to influence the pressure in the anterior compartment (Nkele, 1988). The amount of dorsiflexion throughout the skate cycle varies among skiers. If skiers keep their foot in constant dorsiflexion and do not extend the ankle, or plantarflex, after the pushoff, then the tibialis anterior is under continual muscular tension. Wiley, Lloyd-Smith, and Reid (personal communications) felt that those skiers who did not follow through or plantarflex after pushoff, allowing tibialis anterior to relax, had a greater chance of suffering from the effects of CCS.

B. Factors Affecting Compartment Pressure

Several relationships between compartment pressure and exercise factors have been studied. Kirby and McDermott (1983) found that anterior compartment pressures were significantly influenced by running style in the majority of subjects studied. During a comparison of rearfoot to forefoot landing styles, some individuals experienced increases in anterior compartment pressure when they ran with an accentuated rearfoot landing style. The authors made two suggestions to such individuals based on their study. First, individuals whose intramuscular pressures rise during rearfoot landing should avoid this running style, perhaps by shortening their stride. Second, anterior compartment pressures might be lowered when rearfoot landing by the use of cushioned heels. This modification should shorten the torque arm, decreasing the plantarflexion moment resulting from ground reaction forces during early foot contact. If less muscle firing is required to resist the plantarflexion torque, presumably less pressure should result. No studies have confirmed this finding, however.

In a study by Logan et al. (1983), a relationship between anterior compartment pressure and walking speed was demonstrated. Compartment pressures were found to be proportional to walking speed, indicating a possible reason for recurrent compartment syndrome sufferers being able to continue to exercise at a reduced pace after the onset of compartment syndrome symptoms.

Nkele et al. (1988) studied the effect of exercise and of the positions of the lower extremity and trunk on the pressures in the anterior compartment. When the leg was actively rotated externally so that the foot was in a horizontal position while the subject was sitting with legs outstretched, there was an average increase in compartment pressure of 1.8 mmHg for thirty subjects. When the trunk was raised from the supine position to 60 degrees from the horizontal, there was an average increase in pressure of similar magnitude (1.7 mmHg). Since the positioning of the lower extremity and the trunk does appear to effect resting compartmental pressures, it is necessary to standardize the positioning of the patient or subject during the study of compartment pressures.

C. Compartment Pressure Measuring Techniques

Of the clinical investigative tools used to evaluate cases of suspected CCS, the most direct is the measurement of the compartment pressure (Kirby and McDermott, 1983). It has been noted by Muburak et al. (1978) that changes in compartmental pressure precede the clinical signs and symptoms of CCS. Thus, it follows that compartmental pressure measurement can be extremely helpful in detecting and possibly preventing a CCS.

Several measuring techniques are currently in clinical use. The needle manometer technique which has been advocated by Whitesides (1975), uses the injection of saline through intravenous tubing and an 18 gauge needle to equibrilate the pressure of the muscle compartment. Matson et al. (1976)

suggest the use of a needle using a continuous infusion technique to measure pressures. Murburak et al. (1976) have recommended the use of a wick catheter. All of these devices and techniques have potential problems (Rorabeck et al., 1981). The slit catheter, which was designed and developed at the University of Western Ontario by Rorabeck et al. in 1981, greatly simplifies the measurement of compartment pressures. Rorabeck has shown the slit catheter to be at least as accurate as a wick catheter and more accurate than a needle manometer technique in the measurement of compartmental pressures. The slit catheter has some theoretical and practical advantages over the other two commonly used techniques. The catheter itself eliminates the potential problem of muscle blocking the end of the barrel as happens occasionally when a needle is used. In addition, the slit catheter is manufactured with no detachable pieces or parts. This type of manufacture eliminates the potential danger of some or all of the wick portion of the catheter breaking off and being left in situ after withdrawal of the catheter.

In order to make an early and objective diagnosis, and therefore to optimize treatment, a system is needed to measure intracompartmental pressure which is fast, readily available, accurate and easy to use. The Stryker Intra-Compartmental pressure monitor system is a new hand-held digital device designed to provide high accuracy, safety, sterility, portability and easy and rapid assembly and use. *

The entire device can be easily held and utilized in one hand. It allows the physician to monitor the compartment pressure with repeated or continuous measurements. A patient with suspected CCS can be monitored continuously during the course of an exercise stress test with the indwelling slit catheter. The device allows transducer re-use, thereby minimizing cost and calibration problems.

Awbrey et al. (1988) found this pressure monitor to be accurate, convenient, versatile, reliable and less time-consuming than Whiteside's needle manometer method. His study revealed that the digital monitor was accurate to +0.8mmHg (standard deviation) of actual pressure; there were no readings more than 1 mmHg from the actual pressure. The time of assembly and actual compartment pressure measurement was over three times as long for the needle manometer technique compared to the hand-held monitor. This hand-held monitor was more than twice as precise at reproducing pressure results than the needle manometer. This Stryker device represents a significant advance in the diagnostic assessment and management of patients suffering from CCS.

* Stryker Corporation, Kalamazoo, Michigan, 49001.

Chapter III

METHODS AND PROCEDURES

A. Subjects

The ten subjects used in the study were volunteers who responded to letters which requested subjects and described the study. There were two females and eight males with ages ranging from 22-39 years (average age = 28.5 years). All subjects were normal, asymptomatic, had no complaints of leg pain, and had never experienced CCS or its symptoms before. All subjects were competitive or recreational cross country skiers and must have previously skated in a race or loppet on classical or skating skis. Subjects all read and signed an informed consent form (Appendix A).

B. Pilot Study

A preliminary pilot study was conducted to accomplish the following:

1. Finding the minimum length of time subjects need to ski to show obvious increases in compartment pressure and to see significant differences between types of skis. Resting pressures were measured for this test.
2. Testing the efficiency of monitoring heart rate to

control intensity of skiing and ability of subjects to ski at the given intensity. The portable heart rate monitor used in the research study was used in this pilot study. See Testing Apparatus for further detail.

3. Becoming experienced and confident at using all the measuring and testing apparatus.

C. Testing State Standardization

Each subject attended both treatment tests (using a different type of ski for each test trial).

All subjects skied at a certain intensity range measured in beats per minute (bpm) according to their training heart rate. The range was calculated by subtracting the subjects' age from 220, taking eighty percent of that figure, and adding 5 bpm's in both directions.

Example:

Intensity range for a 25 year old would be:

0.8 x (220 - 25) = 156 + and - 5

= 151 to 161 bpm

It was understood that this was not an accurate assessment of training heart rate but rather a rough estimate. However, it was not important that subjects work at their exact training heart rate range, only that they worked hard enough to elicit their peak exercise compartment pressure, and that their intensities for both trials be consistent. Half the subjects skated on skating skis for their first trial and the other half used classical skis.

Two pairs of skis were used in the testing: one for each trial. Both pairs were Fischer RCS Graphite and were supplied by the experimenter. The skating skis were 190 cm in length and the classical skis were 200 cm, since a general rule of thumb for skiers is that their classical skis should be ten centimeters longer than their skating skis. An attempt was made to eliminate possible effects that different brand names and models of skis might have on compartment pressures. Also by having all subjects tested on the same pair of skis for each trial, the load that each subject had to lift was exactly the same. All subjects skied in skating boots to control for the effects that boots may have on intramuscular pressures. The bindings used by all subjects for both trials were Salomon skate bindings. They were mounted in the same place for all subjects - in the "normal" position. The "balance point" of a ski can be determined by balancing the ski on one finger. Typically, bindings are mounted 1/4 of an inch forward from this point. In this experiment, that point (1/4 in forward from the balance point) will be considered the "normal" position.

D. Testing Apparatus

While skating, each subject wore an "Exersentry" portable electronic heart rate monitor. The monitor was strapped to the chest next to the bare skin. The subject's training heart rate range (see Testing State Standardization) was entered into the monitor and it was programmed to 'beep' if the subject strayed from that range during the skating test. The beep was slow if the subject fell below the preset range and it was faster if the subject was working above the range. This range was to ensure that subjects consistently worked at the same intensity for both trials.

The Stryker Intra-Compartmental Pressure Monitor System was used to measure compartment pressures. This electronic monitor was a self-contained, battery-operated unit which provided an immediate digital displayed reading of compartment pressure. It measured 5"x 3"x 1" weighing 150 gm and consisted of a pressure transducer, solid-state miniaturized electronic circuitry, 9 volt battery, electronic calibration (Appendix C), and digital LCD readout. For routine compartment pressure measurement, the device housed a sterile prepackaged 3cc syringe containing normal saline, a transducer diaphragm chamber with a one-way valve and an 18 gauge needle (Figure III.1). In addition, for continuous monitoring, a polyethylene indwelling slit catheter set with a disposable tubing in a breakaway 14 gauge needle would be utilized.

Figure III.1 Stryker Compartment Pressure Monitor

E. Treatment Test Procedure

The subjects engaged in a warm up of similar nature and duration for each test trial. The heart rate monitor was programmed and attached to the subject with firm but comfortable straps. The monitor was positioned so that if it beeped, the subject was able to hear it and adjust his/her speed accordingly. All pressure measurements and anesthetizing were performed by the same physician. The resting anterior compartment pressure was taken indoors with the subject in a supine position and the foot in the neutral position (90 degrees of flexion). The area of the leg where the measuring needle was to be inserted was cleaned with rubbing alcohol and then frozen with a local anesthetic (xylocaine). The needle was then inserted into the muscle belly of the tibialis anterior muscle of the subject's right leg. The angle of insertion of the needle was not consistent for all subjects. The pressure in the compartment forced back the saline and was recorded and displayed on the digital screen of the pressure monitor. The subject then went outside and skated around a designated loop, approximately 400-500 metres. A stop watch was started when the subject began and he/she skated for 10-12 minutes, ending back at the starting position. An immediate post-exercise pressure was taken - 15 seconds after termination of skiing, again with the subject supine and with the right foot in the neutral position. Additional measurements at 30 seconds, 1 minute, 2 minutes, 3 minutes, and 4 minutes were recorded until the subject's pressure returned to its original resting pressure. This testing procedure was completed for all subjects in each of the two trials.

Chapter IV

RESULTS AND DISCUSSION

A dependent or correlated t-test was calculated between the pressure increase measured for the classical ski and skating ski trials. The t was found to be insignificant (t=.67, df=9, p .05). The mean increase in compartment pressure was only very slightly larger for the classical ski trials (Mean Increase = 18.0 mmHg, S.D.= 6.41) as compared to the skating ski trials (Mean Increase = 17.3 mmHg, S.D.= 6.02 mmHg). These results indicated that skating on classical skis did not increase the anterior compartment pressure significantly more than when skating on skating skis.

The average skating ski trial pressures for the ten subjects were 11.5 mmHg at rest and 28.8 mmHg after exercise, while classical ski trials produced an average resting pressure of 10.7 mmHg and 28.7 mmHg after exercise (Figure IV.1).

There was a large inter-subject variability seen in both resting and post-exercise pressures and also in both ski trials. Pressures at rest for skating ski trials ranged from 8-25 mmHg and from 8-19 mmHg for classical ski trials (Appendix B). One reason for such a variance in pressure could be related to the position of the ankle when taking pressure measurements. Styf (1988) found in his study, as did the present researcher, that the subject's ankle was

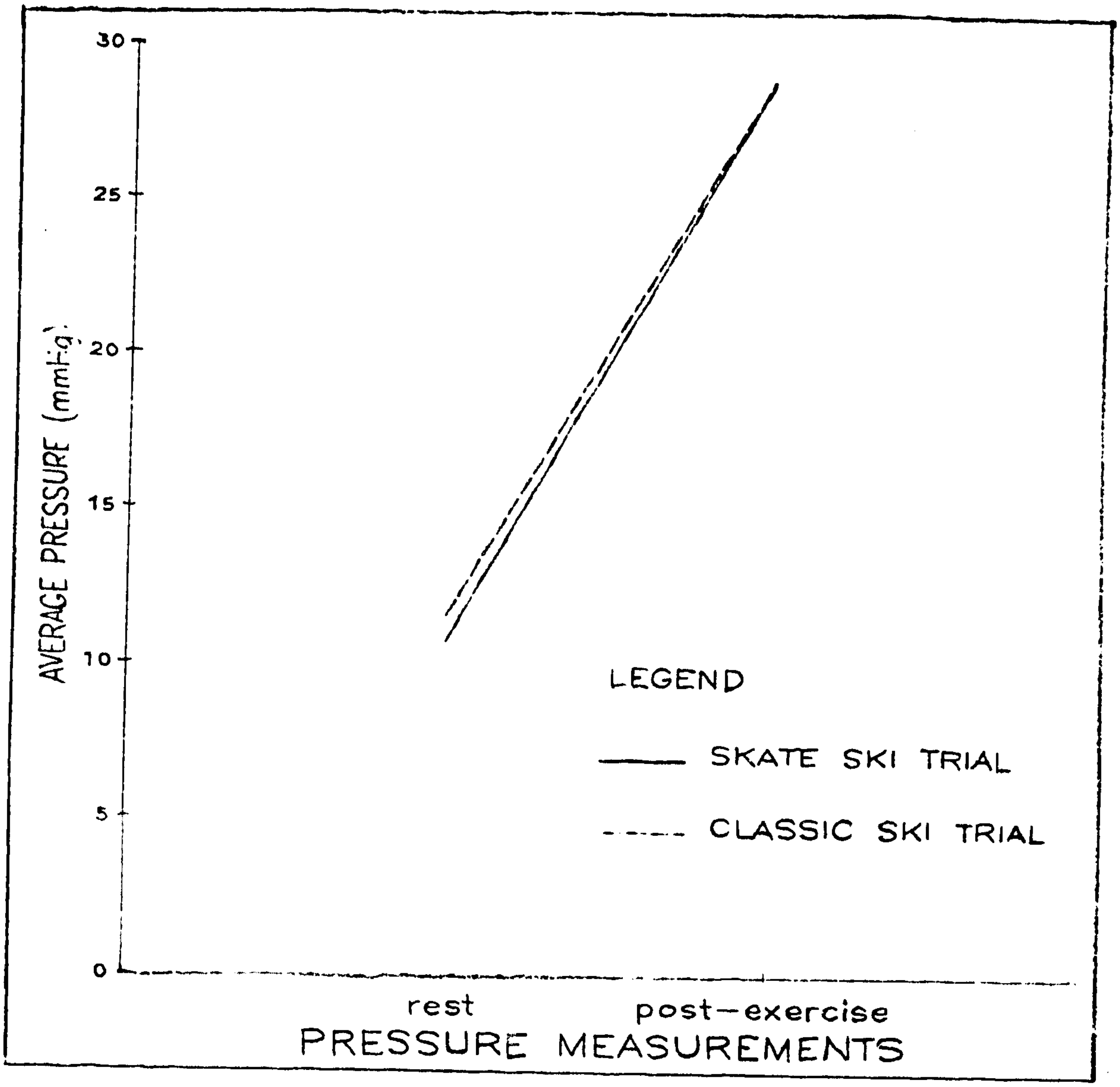


Figure IV.1 Comparison of Pressure Increases by Trial allowed to rest in the neutral position, but valid attempts were not made to control the position precisely. This lack of control may have accounted for some of the variance. Post-exercise pressure recordings also showed large variances between subjects. After the skating ski trials, pressures ranged from 20-51 mmHg and after using classical skis, the pressures were found to be between 17 and 51 mmHg. Intramuscular pressure generated during exercise depended to a certain extent on the force of contraction of the tibialis anterior muscle (Styf, 1988). Each of the ten subjects' muscles undoubtedly contracted to a different degree. The measured pressure also varied with the depth of the catheter placement. In the present study, a substantial difference in pressure was noted when the catheter was placed at a different angle to the leg, or when its insertion depth changed. Styf (1988) was in agreement with the present researcher when he stated that neither of these variables could be controlled completely.

The height of the ten subjects was not uniform and, consequently, the skis used in the experiment were not necessarily the recommended length for all subjects. When a skier stands with their arms outstretched over their head, their classical skis, standing on end, should reach their wrist. The suggested length recommendation for skating skis is recognized as being ten centimeters shorter than classical skis (Fischer, 1989). This factor did not seem to affect the results of the present study. The shortest skier, subject number 2, would be recommended to skate on 185 cm skating skis, making the experimental skating skis five centimeters too long. This particular subject's pressure increase on skating skis was 18.0 mmHg which was only slightly above the average pressure of 17.3 mmHg. Likewise, the classic ski pressure increase was 19.0 mmHg, compared to the average of 18.0 mmHg. Neither of these differences were significant. In relation, the tallest skier in the study, subject number 3, found the experimental classical skis to be fifteen centimeters shorter than his recommended ski length. His pressure increase on the classical ski trial did not reflect this discrepancy as it was actually larger than the average pressure increase for classical skis. If ski length variability played a part in affecting results, one would expect to see that shorter skiers would have a greater than average pressure increase since they were working harder to lift a comparatively longer ski. Similarily, a taller skier would be expected to attain a smaller than average pressure increase since they were using less muscular effort to lift the same ski. Since the shortest and tallest skiers in the study did not demonstrate this principle, the inconsistency in work load for each subject did not affect the results of this study.

According to the results of the present study, one must deduce that factors other than ski type play a role in affecting compartment pressures while cross country skating. The sudden and complete change in skiing techniques from classical to skating, which many skiers have recently undergone, is one such factor. When changing from one technique to another, the skiers and skier's muscles are not used to the new activity. Dr. James Stray-Gunderson, a medical advisor with the U.S. Ski Team, added that if one has a fit, well-developed cardiovascular system and switched exercises, one may developoveruse injuries (Higdon, 1987). The reasoning behind this was that ones "... musculoskeletal system is not used to the new motion".

Chapter V

CONCLUSION

Based on the results obtained in this study and within the limitations of this research, there is no significant difference in the compartment pressure increase when cross country "skating" which can be attributed to the use of a classical or skating ski. Thus, according to this study, skating on longer and heavier classical skis can be eliminated as a possible single factor in causing or aggravating a chronic anterior compartment syndrome. The implication of these observations were that cross country skiers who were concerned about the increase in their anterior compartment pressure while skating, need not worry about the type of ski that they were using.

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APPENDIX A: Sample Informed Consent Form

Informed Consent for Compartment Pressure Study

I ....

agree to participate in a research project conducted by Sue Lawson for the purpose of measuring muscle compartment pressures in the front of the lower leg following cross country skiing in the skating technique. The skin over the anterior compartment of the lower leg will be frozen using needle. There may be a slight stinging sensation when local freezing anesthetic is first introduced after which there should only be a dull sensation when the needle is inserted. This is similar to the freezing at a dentist. Following, a larger needle will be inserted so that the pressure measuring device can be secured in the muscle.

This procedure has been used as a standard diagnostic test for years and there have been no reported complications. Theoretically, complications include: bruising and tenderness following the experiment, small scar from the needle, risk of infection, and risk of allergy to the local anesthetic (xylocaine). A physician will, however, be administering the needles and will be present during the whole experiment. Needles will be disposed of after each subject. I agree to follow the instructions and procedures to the best of my ability. I understand that minimal discomfort will be experienced during this test. I understand that I can withdraw from this test at any point in time. I will have the opportunity to question and discuss the exact procedures to be followed and review the results following the completion of all testing. I have read this form and understand the test and I consent to participate. I understand that the data will be used for research purposes and will not allow personal identification.

Date ....

Name ....

Signature ....

Witness ....

APPENDIX B: Experimental Data

Experimental Data

PRESSURE MEASUREMENTS (in mmHg)

Subjects	Skate Ski Rest	Skate Ski Post-Exercise	Skate Ski Increase	Classic Ski Rest	Classic Ski Post-Exercise	Classic Ski Increase
1.	18	51	33	19	51	32
2.	9	27	18	7	25	18
3.	11	25	14	11	30	19
4.	9	33	14	12	25	13
5.	25	45	20	10	33	23
6.	8	26	18	8	27	19
7.	10	24	14	8	17	9
8.	9	24	15	7	26	19
9.	8	23	15	8	20	12
10.	8	20	12	14	30	16
$\bar{x}$	11.5	28.8	17.3	10.7	28.7	18.0
sd	3.89	9.45	6.02	5.60	10.39	6.41

APPENDIX C: Monitor Calibration Technique

Monitor Calibration Technique

The following steps should be taken to calibrate the Stryker pressure monitor:

1. Assemble monitor.
2. Make sure all junctions fit well.
3. Close lid and make sure diaphragm is seated.
4. Push plunger in and allow fluid to go through system.
5. Hold monitor at a 30 degree angle with needle pointing down.
6. Push "zero" button.
7. Make sure the reading on the screen is zero.