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Biomechanical Comparison of Ankle Ligament Reconstructive Techniques

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Biomechanical Comparison of Ankle Ligament Reconstructive Techniques

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Main findings

- Through testing ankle kinematics in unloaded, unconstrained conditions, only the soft tissues guide the motion and thereby isolate the effects of altering ligament conditions.
- The injury and reconstructions are most sensitive to applied in-eversion moment as opposed to plantar-dorsiflexion moment.
- Based on the ROM data analysis, the Brostrom repair and gracilis reconstruction appear to behave similarly to intact motion.
- Qualitatively, the intact patterns of motion appear preserved by both methods. However, failure of some Brostrom repairs compared to the absence of gracilis failures at the loads tested suggests that the gracilis-graft reconstruction is initially a stronger repair.
- The largest disadvantage of such an *in vitro* study is the inability to predict the effects of biological healing response of the reconstructed tissue on joint kinematics.
- The study demonstrates that the range of motion in the ankle is near normal after gracilis reconstruction. As many of the older non anatomic reconstructions with poor outcomes have restricted ankle and subtalar motion, restoration of motion is an important concept in the anatomic reconstructions.
- The study supports the early mobilization of patients after anatomic gracilis reconstructions of the ankle. This can reduce the rate of chronic pain and decrease the recovery time.

Executive Summary

Ankle sprains are one of the most common injuries and is among the most common of all injuries seen by physicians ^{1 2}. Although most patients can be managed successfully with a rehabilitation program and the use of a brace, ongoing instability of the ankle develops in approximately 20% of patients and many patients, particularly those working on their feet, eventually require surgical treatment ³⁻¹². Operations for ankle instability need to maintain the range of motion of the joints while still restoring ankle stability. The operation should be as strong as possible to allow early weight bearing and early return to work.

We have developed a reconstruction of the lateral ligaments for instability using a knee (hamstrings - gracilis) tendon. Most centres presently repair the old ligaments (called a Brostrom repair). The repair relies on the quality of the old ligaments to stabilize the ankle. Often the damaged ligaments tear and cannot hold sutures well. The surgeon therefore augments the repair with local tissue and will protect the patient after operating with a cast, delaying rehabilitation. Despite this, failure rates are still acceptable. Older reconstructions (such as the Evans and Watson Jones) sacrifice the active muscles pushing the ankle out and stabilizing it. These repairs also do not follow the normal anatomy and therefore restrict joint motion, causing a feeling of instability without the ankle giving way. Finally, the restriction of motion is thought to cause long term arthritis.

This study was designed to assess the biomechanics of the gracilis repair using testing on cadaveric limbs. As previous models for ankle instability did not suit our study, we designed a testing protocol using the Division of Orthopaedic Engineering Research's extensive experience on spine models. This model of testing may become a new standard for ankle instability studies.

Once the model had been tested, we then performed a study on seven specimens. The range of motion and stability of the ankle was measured for the intact lateral ligaments, after they had been cut, after a Brostrom repair and a gracilis (Hamstring) reconstruction.

We found that the ankles had 50% more motion in the lateral ligaments after their division. The repair and reconstruction resulted in a normal range of ankle motion, but that the repair had a slightly higher degree of instability. The repair also failed in two of the seven ankles.

This study therefore supports the use of a gracilis (hamstring) reconstruction, and supports the use of early physiotherapy. Clinical studies will be required to confirm the outcome of these earlier rehabilitation protocols. However, on the basis of this study we have adopted earlier recovery protocols. The patients with hamstrings reconstructions start walking at 5 days in a removable walker boot, and start stationary cycling at 2 weeks. Balance training starts at 4 weeks. This compares to 6 to 8 weeks in a cast for a Brostrom repair. These earlier recovery protocols and a stronger reconstruction should result in an earlier return to work, less chronic pain conditions, and a better long term ankle stability without arthritic change.

This information has been disseminated by national and international presentations. This study would not have been possible without the support of the worker's compensation board.

Context of Research

Injuries to the lateral ligaments of the ankle is a common occurrence in the work place as this is one of the most common injuries seen by physicians^{7 12}. Most patients are managed by rehabilitation^{2 5 9 10 19 25 8 22 31 33}. However 10 to 20 percent have recurrent instability and require a ligament operation^{4 21}.

Most patients will receive a repair of the ligaments of the ankle presently⁸. In the commonly used Brostrom repair, the injured ligaments are divided and repaired in a shortened position^{4 15 20 28}. While this preserves ankle motion better than older reconstruction techniques such as an Evans procedure^{32 1}, the quality of the ligaments can be poor. The repair may have to be protected by casting and delayed mobilization causing a prolonged recovery time and potentially increasing poor outcomes from pain syndromes etc. There is a documented higher failure rate of Brostrom repairs compared to anatomic ligament reconstructions³².

We have been using an anatomic reconstruction of the ligaments of the ankle using gracilis tendon as a free graft harvested from behind the knee. This reconstruction requires more dissection than a Brostrom repair, but has the potential advantage of creating a stronger reconstruction. We have been mobilizing patients early and have not been using a cast.

The primary objective of this study was to determine the effects of a Brostrom repair and an anatomical gracilis graft reconstruction on ankle kinematics in the axes of applied loads, while allowing unconstrained motion.

Experimental Method

Seven cadaveric ankle specimens were tested independently in the intact condition, after an injury model, a Brostrom repair and a gracilis graft reconstruction. The fresh-frozen cadaveric ankle specimen were harvested below mid-shank and thawed at room temperature before testing. Once thawed, the soft tissue around the proximal end of the

tibia and fibula was dissected to provide a bonding surface for the potting material used to secure the proximal aspect of the specimen. Pins were transversely inserted in both bones at the proximal end to minimize rotation and were subsequently positioned in dental stone with the fibula neutral. A mounting plate was used to provide a coupling for an applied moment in different configurations. To affix the foot to the mounting plate screws were inserted into the calcaneus and metatarsal bones through counter-bored holes in the plate. X-rays were used to verify that the location of the screws avoided the transverse tarsal joint. The plate was fabricated such that inversion-eversion (IE) and plantarflexion-dorsiflexion (PD) could be obtained. Non-invasive screws were inserted into the distal end of the fibula and into the talus for mounting infrared markers. The distal ends of the medial and lateral malleoli were found by palpation and marked for positional reference.

Plexiglas marker carriers that contained four non-collinear infrared LEDs were rigidly attached to the talus, calcaneus, fibula and tibia (Figure 1). During the test, the positions of these LEDs were monitored at 20 Hz using a precision optoelectronic camera system [Optotrak 3020, Northern Digital Inc., Waterloo, ONT] and the relative joint motions were calculated. This measurement system records the coordinates of the markers within 0.1mm within the test area volume. The lateral malleolus, medial malleolus, and the tibial shaft were digitized during calibration for the purpose of determining reference frame axes.

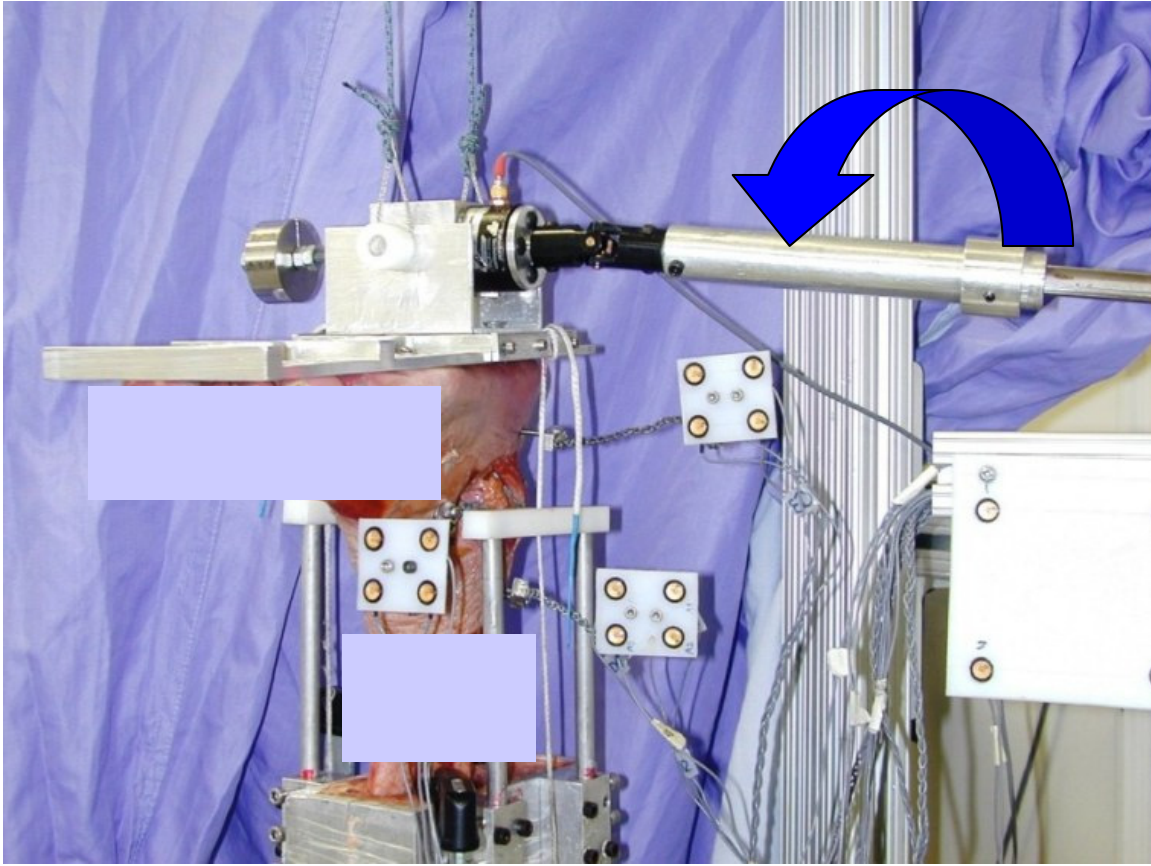


Figure 1. *View of the ankle, loading device and Optotrak markers in plantarflexion-dorsiflexion configuration.*

The specimens were tested in the intact condition, the injury model, the Brostrom repair, and the gracilis graft reconstruction following removal of Brostrom sutures. For the injury condition, the anterior talofibular ligament (ATFL), the calcaneofibular ligament (CFL), and the lateral joint capsule were sectioned. Repair by the Brostrom method was a direct, non-augmented repair of both the ATFL and CFL ligaments with 0 gauge polyester braided sutures (Ethibond, Johnson and Johnson, Markham, ON). The graft reconstruction utilized a harvested gracilis tendon that was woven through the calcaneus and fibula, and anchored to the talus. Locations of the anchor and bone tunnels dually reconstructed the ATFL and the CFL ligaments in an anatomical manner.

Pure moments were applied to the unloaded, unconstrained ankle complex in three cycles in plantarflexion-dorsiflexion, and inversion-eversion. Moment was applied to the foot, first along the PD axis followed by the IE axis. Maximum cycle load was set to 3 Nm

and 2 Nm for plantarflexion-dorsiflexion and inversion-eversion respectively. Motion was applied such that the motor rotated at a rate of approximately 3°/second, where the data from the third cycle was processed for analysis. For the IE motion, the motor and mounting plate were re-configured to apply IE torque without changing the specimen position.

The applied moment was measured with a Transducer Techniques TRT-200 torque transducer located at the mounting plate. The torque signal was amplified and conditioned through a Transducer Techniques TMO-2 signal conditioner that results in measurements within 0.02 Nm. Control and acquisition of the data at 20 Hz was accomplished with customized Labview software (Labview 6.1, National Instruments, Austin, TX). Optotrak data was synchronized with data collected through the Labview routines. A custom designed biomechanical testing machine allowed pure moment to be applied in three orthogonal orientations¹³. The moment was applied by a Designatronic H50R10 servo motor through a low-backlash Wainbee gearbox. A linkage provided transmission of only pure moments while allowing unconstrained motion (five degrees of freedom of motion (DOF) and one DOF applied force). A mounting block attached to the free end of the linkage was used to affix the mounting plate. To offset the weight of the mounting plate and coupling fixture, a pulley counter weight system was used.

The kinematic data was analyzed using a Cartesian coordinate system where the origin was determined as the midpoint between the distal ends of the malleoli, and the line connecting the malleoli define the primary axis. The origin to the center of the mid-shank tibia defined the secondary axis. Range of motion (ROM) was calculated in the axis of applied moment for the calcaneus with respect to the tibia. Statistical analysis was conducted using analysis of variance (ANOVA) followed by Student Newman-Keuls post-hoc test, and a p-value of 0.05 was considered significant.

Research Findings

Results

Typical motion response of the calcaneus to applied moment is shown in Figure 2 and Figure 3 for in-eversion and plantarflexion-dorsiflexion respectively. The ROM increased from the intact to injury in both directions of motion, 103% in IE ($p=0.001$) and 6% in PD ($p = 0.62$) (Figure 4). The Brostrom repair resulted in 49% more motion than the intact condition in IE ($p=0.064$) and 3% in PD ($p=0.58$). The gracilis reconstruction resulted in 22% more motion than the intact condition in IE ($p = 0.46$) and 4% less motion in PD ($p=0.26$). While no significant differences were found for ROM between intact and treatments in either configuration, the anatomic reconstruction motion behaved closer to kinematics of the intact ankle. Of note, the Brostrom-repaired ATFL failed in two specimens before reaching the maximum load during the first cycle of applied inversion, and these ROM values were excluded from the analysis.

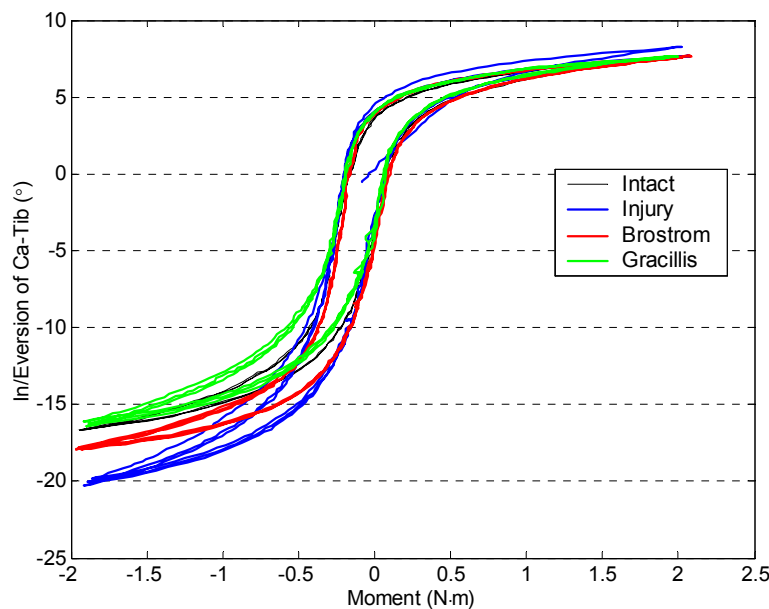


Figure 2. Typical response of calcaneus to inversion-eversion moment.

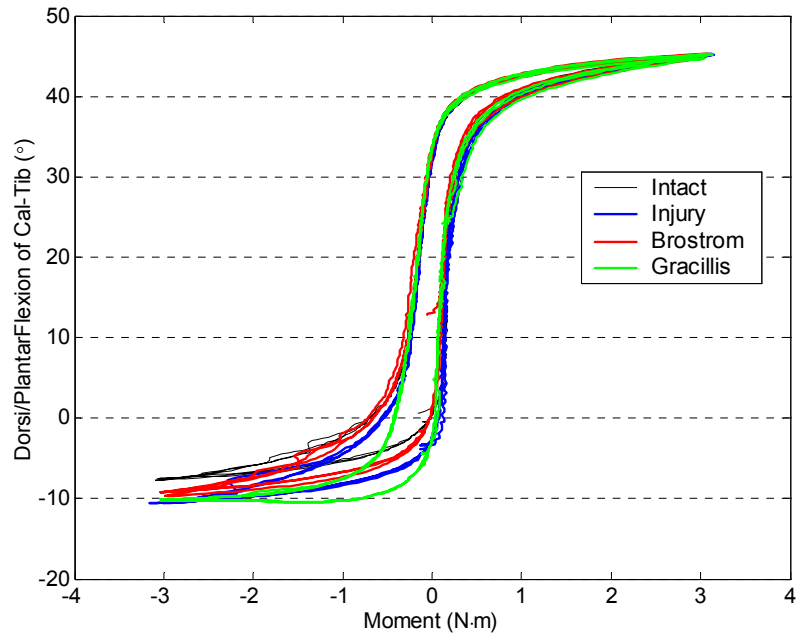


Figure 3. Typical response of the calcaneus to plantarflexion- dorsiflexion moment.

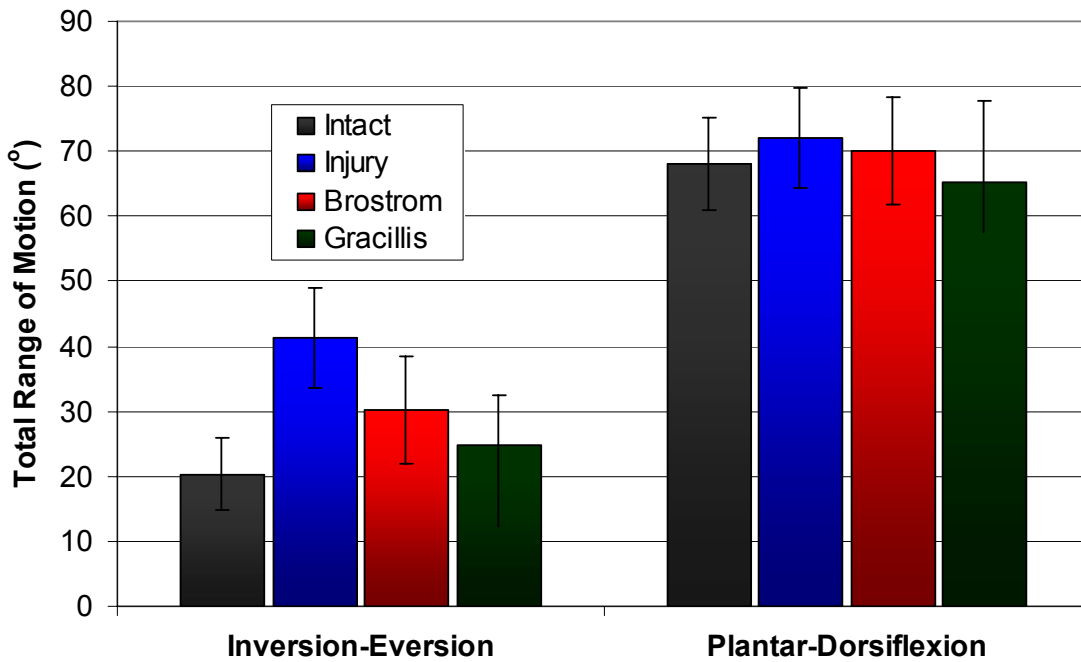


Figure 4. Total range of motion \pm one standard deviation for each condition in in-eversion and plantarflexion-dorsiflexion.

Discussion

Through testing kinematics in unloaded, unconstrained conditions, only the soft tissues guide the motion of the ankle and thereby isolate the effects of altering ligament conditions. Several studies have been conducted using constrained motion and recently there have been investigations into compressively loaded ankles^{27 1 35}. In these tests, motion differed from unloaded conditions as it was dictated by deformation of articular cartilage in addition to ligament and surface geometry guidance. Limited studies^{34 26} have examined ankle joint kinematics while allowing unrestricted motion, where Leardini made some clarification in the service of specific ligaments in joint motion. In addition, rotational motion would be constrained to a fixed axis. This non-physiologic loading would likely change the response of the articular cartilage that normally supports a considerable portion of compressive ankle loading. It has been shown constraining the axis of motion alters the ankle biomechanics including and severely restricting the normal range of motion⁶. As such, to improve kinematic accuracy and isolate the effects of changing condition of the ligaments, it was decided to apply only pure moments and allow unconstrained ankle motion. Using unrestricted joint motion is a unique method for comparing reconstructive surgical techniques. The largest disadvantage of such an in vitro study is the inability to predict the effects of biological healing response of the reconstructed tissue on joint kinematics.

The injury and reconstructions are most sensitive to applied IE moment as opposed to PD motion. This is consistent with the clinical picture of ankle instability, and the anatomy of the collateral ligaments of the ankle. Based on the ROM data analysis, the Brostrom repair and gracilis reconstruction appear to behave similar to intact motion. This is encouraging for a good clinical outcome. The previous non anatomic reconstructions, such as an Evans repair, stabilized the ankle while sacrificing range of motion³. This can lead to a feeling of subjective instability and may be the cause of subsequent arthritis^{18 29 30}. A non-anatomic ligament reconstruction may also fail to restore stability²⁴.

Differences in Brostrom repair are likely due to failure at the sutures. Qualitatively, the intact patterns of IE and PD motion appear preserved by both repairs. However, failure

of some Brostrom repairs compared to the absence of gracilis failures at the loads tested suggests that the gracilis-graft reconstruction is initially a stronger repair. This supports our clinical impression, that the Brostrom repair may not be strong enough at the initial repair to allow early rehabilitation. Most papers therefore support protection of the Brostrom repair during the rehabilitation phase, or augment the repair with the extensor retinaculum or a portion of the peroneus brevis^{4 8 11 23 16}. One paper describing the outcome of Brostrom repairs reports the use of a cast postoperatively for six weeks²⁸.

This paper does not predict the biological response of the tendon during healing. However the reconstruction was designed to ensure that all ends of the tendon were placed on denuded bone, or within bone tunnels to allow appropriate incorporation within bone in time in a manner seen in ACL reconstruction^{17 14}.

Implications for Future Research on Occupational Health

The studies show that the anatomic ligament reconstruction using gracilis may be a better alternative than a Brostrom repair, and that the earlier rehabilitation protocol may be justified. The reconstruction is stiffer than the Brostrom repair and restores the mechanics more towards the intact ligament condition. Based on the results of this study, earlier mobilization and earlier rehabilitation has been adopted for patients undergoing the gracilis ligament reconstruction. No clinical failures secondary to instability have been observed to date. This however, needs to be verified by an appropriate review.

As the cadaver study appears to support the use of the anatomic ligament reconstruction, clinical studies comparing the two techniques should be undertaken. Ideally a randomized prospective double blind study should be performed. However this may be difficult to do as the recovery protocols are different. Outcome measures such as cost of treatment, recovery time, patient satisfaction and time to return to work should be recorded. Differences in outcomes between the non WCB patient population and the WCB patient population should be performed as outcomes measures can be hard to interpret in the WCB population.

Policy and Prevention

Surgeons performing ligament reconstructions for the board should be made aware of the two techniques of ligament reconstruction, and the outcomes of this study. Surgeons should be taught the technique of gracilis ligament reconstruction and can use their expertise to judge which patients are most eligible for reconstruction versus repair. Surgeons treating osteochondral lesions of the talus should rule out ankle instability, and treat both lesions if identified. The information from this study has changed the educational talks provided by Dr. Younger to incorporate this information (see knowledge dissemination).

Although outside the scope of this study, with regards to prevention, standard rehabilitation of ankle sprains should be adopted by primary care physicians. Primary care physicians should be taught how to examine for ligament instability in the chronically painful ankle, and be able to identify the associated features of osteochondral lesions of the talus and hindfoot varus.

Knowledge Dissemination

Conferences:

Larson, C R; Awwad, M A; Devries, G; Sjovold, S G; Veri, J P; Oxland, T R, Younger, A E; *Kinematic Comparison Of Ankle Ligament Reconstructive Techniques*, 51st Annual Meeting of the Orthopaedic Research Society, Washington DC, Feb 2005.

(Poster presentation).

Larson, C R; Awwad, M A; Devries, G; Sjovold, S G; Veri, J P; Oxland, T R, Younger, A E; *Kinematic Comparison Of Two Ankle Ligament Reconstructive Techniques*, 39th Annual Meeting of the Canadian Orthopaedic Research Society, Montreal QC, June 2005.

(Podium presentation)

Larson, C R; Awwad, M A; Devries, G; Sjovold, S G; Veri, J P; Oxland, T R, Younger, A E; *Kinematic Comparison Of Two Ankle Ligament Reconstructive Techniques*. Arthroscopy Association of North America Annual Meeting, Vancouver, BC, May 13th 2005.

(Podium presentation)

Educational sessions utilizing information from this study:

Primary care:

Physical examination of the Foot and Ankle for Physicians: Nighttime seminar March 9th 2005, Executive Inn, Burnaby, B. C. (Attended by 110 physicians).

Family Practice Rounds: St. Paul's Hospital: How to make the most of your foot and ankle referrals: November 28 2004.

Foot and Ankle: How a GP may help: General Practice Rounds, Mount St. Joseph's Hospital. August 2004.

Referring tips for family physicians: Evening conference at Science World sponsored by Kintec. November 3rd 2004.

Surgeons:

"The diagnosis and treatment of the failed ligament reconstruction". Invited Symposium presentation at the American Orthopaedic Foot and ankle society, Seattle, Washington July 2004.

Ankle Arthroscopy: Indications and techniques. Fall Course, Arthroscopy Association of North America. Palm Springs, December 2004.

Treatment options for osteochondral injuries of the talus: Arthroscopy association of North America specialty day at the American Academy of Orthopaedic Surgeons. Washington, D.C. February 2005.

Gracilis ligament reconstruction for ankle instability. Canadian Orthopaedic Foot and Ankle Society symposium, Vancouver, B,C, April 7 to 9, 2005.

Management of the Cavus foot in the Athlete; The American Orthopaedic Foot and Ankle Society Sports medicine of the foot and ankle course: Scottsdale, Arizona April 29th, 2005.

The Role of Arthroscopy in Ankle Instability: The American Orthopaedic Foot and Ankle Society Sports Medicine of the Foot and Ankle Course: April 28th to May 1st, 2005.

Osteochondral lesions of the talus: Primary treatment: Arthroscopy association of North America Annual Meeting. May 2005. Vancouver, BC.

Canadian Orthopaedic Residents Association Meeting, Montreal, Quebec: Guest Lecture: Foot and ankle surgery: Past, present and future. June 3^r 2005.

Journals:

Submission to the Journal of Arthroscopy, April 2005.

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