

**Diagnostic Accuracy of the Anterior Drawer Test and Internal Rotation Test on Isolated
Anterior Talofibular Ligament Injuries using Wearable Sensors
Lack of Standardization of Ankle Orthopedic Care**

A Thesis Prospectus

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By

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On my honor as a University student, I have neither given nor received unauthorized aid
on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

To test ankle instability, a series of standardized mechanical tests, each indicating laxity of specific ligaments, are performed by an orthopedic clinician. Currently, these tests are *subjectively measured* by the degree of mechanical laxity detected by clinician discretion and expertise. Due to this, these tests lack objective measurement. In addition, little comprehensive research on the diagnostic accuracy of these standardized tests has been completed (Croy et al., 2013; Netterström-Wedin et al., 2021). Both of these confounding variables lead to high subjectivity and inconsistency in diagnosis and treatment plans from provider to provider, highlighting the *lack of standardization* within orthopedic care. Diagnostic accuracy of ankle instability is crucial to patient treatment and clinical outcomes as judgement of these tests determine and guide clinical decisions. If ankle instability is left untreated, post-traumatic osteoarthritis (PTOA), a painful and disabling degeneration of cartilage and bone following recurrent injury (Thomas et al., 2017), is very likely as 80-90% of arthritic change in the ankle is post-traumatic (Delco et al., 2017; Song et al., 2019). Patients with a history of recurrent ankle sprains comprise 70–85% of end-stage ankle PTOA surgeries (Delco et al., 2017). Lateral ankle ligament damage due to lateral sprains are the main cause for developing ligamentous PTOA (Valderrabano et al., 2006).

Of particular importance, the anterior talofibular ligament (ATFL), the lateral ligament connecting the fibula to the talus (Figure 1), injuries account for up to 73% of the two million acute ankle injuries that occur each year (Herzog et al., 2019). This is the most common ligament injured in lateral ankle sprains



Figure 1: Anatomy of Ankle. Adapted from J Bernstein, ed: Musculoskeletal Medicine. Rosemont, IL, American Academy of Orthopedic Surgeons, 2003. Retrieved October 26, 2022, from <https://orthoinfo.aaos.org/en/diseases--conditions/sprained-ankle/>

due to its low strength and low ultimate load, the force or load required for complete breakage (Fong et al., 2009; Dubin et al., 2011). By clinical standards, testing of this ligament is done through the anterior drawer test (ADT), a forward translational ankle movement exam (Figure 2A). Concerns regarding this test have been raised by researchers due to its “limited ability to detect excessive anterior talocrural joint laxity” (Croy et al., 2013) and high specificity but low sensitivity (Li et al., 2020).

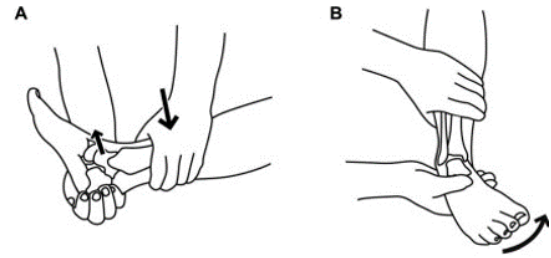


Figure 2: Standardized Ankle Instability Tests. A) Anterior Drawer Test, B) Talar Tilt Test. Reproduced from Clinical tests of the lateral ligament complex. (A) The anterior drawer... (n.d.). ResearchGate. Retrieved October 26, 2022, from https://www.researchgate.net/figure/Clinical-tests-of-the-lateral-ligament-complex-A-The-anterior-drawer-test-for-the_fig4_224940665

To this concern, I propose to develop an objective and quantitative way to measure ankle instability utilizing wearable sensors aided with a computational program. In order to address the issue of diagnostic accuracy of the standardized mechanical tests, particularly the ADT for testing of the ATFL, I will utilize my tool to evaluate the diagnostic accuracy of the clinical standard ADT by comparing it to a novel test, an internal rotation test (IRT) (Figure 3).

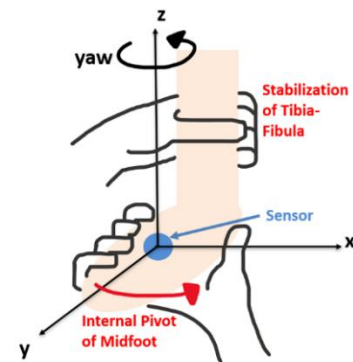


Figure 3: Internal Rotation Test. Created by Haley Frye utilizing Microsoft PowerPoint.

Technology has the ability to revolutionize industries and ways of practice. Due to the current lack of objective measurement in this field, quantifiable standards have not been placed around the degree of ankle laxity appropriate for differing medical treatments, procedures, or surgeries. To indirectly estimate the impact of this technology on the standardization of orthopedic care, actor-network theory (ANT) will be utilized to map the current orthopedic ecosystem surrounding lack of standardization around ankle instability testing. This analysis will shed light on how subjectiveness and current ankle instability testing procedures effect patient

care and procedure requirements, quantification of ankle surgical technique effectiveness, training new healthcare professionals, and lack of orthopedic medical expertise in medically underserved areas (MUAs).

Technical Topic

Stated with more clarity, the problem associated with ankle instability testing is its subjective, qualitative, and inconsistent nature. This is largely due to the inability to quantitatively and objectively measure ankle instability and the research deficit on the diagnostic accuracy of the standardized mechanical tests. In order to combat this subjectivity and inconsistency, research must be conducted on the diagnostic accuracy of these tests, and to do this, a tool must be created to objectively measure the displacement and degree changes in movements within these tests to allow successful comparison and conclusion.

My solution to the first problem is to develop a computational program to calculate the angle change and displacement of the ankle utilizing kinematic data provided from wearable sensors. These wearable sensors will be worn by clinical patients during mechanical testing of the ankle through the series of standardized instability tests. The MATLAB computational program, consisting of the standardized tests' algorithms, will receive raw kinematic data from the Xsens MTw Awinda Sensors and compute the appropriate parameter, either degree change or displacement change, depending on the test selected and performed.

My solution to the second problem is to investigate the diagnostic accuracy of standardized tests utilizing the computational program and sensors. As stated previously, ATFL injuries disproportionately affect individuals due to its mechanical weakness (Fong et al., 2009; Dubin et al., 2011). Its uncharacteristic importance among ankle instability compels me to

challenge the ADT's, the test utilized to test the ATFL, diagnostic accuracy and two other tests, the IRT and the talar tilt test (TTT) (Figure 2 and Figure 3).

We suspect an IRT will provide *earlier* and *more precise* indication of an isolated ATFL injury and that anterior drawer, or forward translation, is not changed with this injury. We believe a positive, abnormal ADT results from more extensive ligamentous damage to the ankle, specifically a conjunction of the deltoid or medial ligament, ATFL, and other ligaments, rather than isolated injury to the ATFL alone. In contrast, isolated injury to the ATFL will result in an increase in internal rotation instability, which is suspected to cause a positive, abnormal IRT result. We propose to also evaluate the standardized mechanical TTT to test inversional rotation and laxity. The mechanism of injury to this ligament consists of a combination of plantar flexion, the motion associated with pointing your toes, and inversion (Melanson et al., 2022), justifying the evaluation of ATFL influence on an inversional rotation test. The proposed approach has the potential to serve as an establishment of a new standardized test, the IRT, to detect isolated injury to the ATFL. In addition, it will investigate the current “gold standard” test, the ADT, in the diagnostic accuracy of an isolated ATFL injury and to evaluate the ATFL's influence on the TTT.

STS Topic

Creation of the ankle instability objective measurement tool, if adopted among orthopedic physicians, will advance the orthopedic care industry and its standardization. Current subjectivity and inconsistency within orthopedic care has a multitude of societal impacts upon health providers, patients, and researchers. In order to indirectly quantify the tool's impacts, the current multifaceted state of the orthopedic care field centered around lack of standardization and subjective measurement will be investigated using ANT. This STS framework will explore “both

human and non-human elements equally as actors within a network” (Cressman, 2018, p.3) with the intent to uncover the current deficits in ankle orthopedic care. Researchers have argued the importance to evaluate technology in health services utilizing ANT (Cresswell et al., 2010). This theory can be simplified as a fluid web of nodes with each node being human or non-human. Every node has its own inherent, enabling and constricting characteristics, its socially constructed role, and impact on other nodes (Latour, 2005, *Third Source of Uncertainty: Objects too Have Agency*). The relationship between the nodes or actors can be explored through careful and intricate analysis, and a working conclusion regarding their relationships and call for action can be crafted.

Actors within my research network will consist of the mechanical instability tests, other instability measures or test, patients, orthopedic physicians, medical students, researchers, other health providers, orthopedic associations, and other nonhuman factors. The relationships between the actors within this large web will be explored utilizing research techniques outlined in a section below. The actors chosen are expected to be significantly impacted and constructed in different ways by the lack of standardization within ankle orthopedic care as briefly presented below. Through this analysis, other unexpected actors will certainly be uncovered too.

Medical Students & Orthopedic Physicians

Medical students undergoing orthopedic specialized training are provided these subjective stress tests and other subjective questionnaires as a way to quantify ankle instability. Frequently, training is on-the-job at their particular practice or hospital and not in a formalized setting, giving rise to further inconsistency in practice among providers. Inconsistent training of a multitude of subjective tests among new medical providers is a concerning issue for patient wellbeing. These medical students mature to clinicians with their own teachings and

conservative or liberal opinions regarding patient care, impacted by their varying backgrounds, clinical experiences, and age. This inconsistency and subjectiveness directly impacts patient treatment, recovery, and future activity level.

Researchers, Instability Tests, & Other Instability Measures

Given the subjective nature of these tests, equivalent comparison across research studies in order to evaluate treatment effectiveness is near impossible. In a retrospective analysis of post-surgery instability using subjective questionnaires, researchers concluded “the disparity of the results obtained with the different scores shows the *necessity* to establish a common evaluation system in the literature to assess ankle instability and its treatment options” (Buerer et al., 2013). Other researchers have denoted integration of patient presentation and perception into stress test judgement, reducing applicability in longitudinal and postoperative evaluation due to a potential systemic bias (Wenning et al., 2021). This conflicting situation does not allow comparable or productive research in this field on instability and effectiveness of procedures, which is necessary to halt the perpetual inconsistencies and lack of standardization.

Patients & Other Physicians

A large disruption in the standardization of orthopedic care is the lack of access to orthopedic care in particular areas and to particular social groups, and the resultant societal ramifications. Salazar et al. denoted barriers such as lack of staffing, insurance, physical location, and access to appointments increase this gap in care, leading to preventable, yet devastating complications (2019). The density of orthopedic surgeons in the US is 9.25 per 100,000 population with the proportion of foot and ankle surgeons a fraction at 5.2% (American Academy of Orthopaedic Surgeons, 2019). Estimated demand for future orthopedic care is said

to heighten 20% in 10 years due to increasing age population, yet the population of current, new, and future ankle orthopedists has not kept pace (Day et al., 2016; American Academy of Orthopaedic Surgeons, 2016; Chan et al., 2020). Training of other healthcare providers pose a solution to this shortage, which would be extremely benefitted by a standardized and consistent tool. Early diagnosis by unspecialized providers will reduce patient spending cost, patient time, and patient volume inside of orthopedic clinics, alleviating the demand for specialized orthopedic attention. The relationship between the barriers to standardized care and the societal effects must be researched in order to emphasize and estimate this detrimental problem.

Research Question and Methods

Research Question: How does the lack of standardization of ankle orthopedic care impact patients and the healthcare ecosystem?

The identified actors within the ANT mapping will each be researched through personalized methods, resulting in meaningful data collection and conclusions. Semi-structured interviews will be conducted with no less than eight orthopedic physicians, orthopedic clinicians, and medical students to evaluate mechanical ankle instability training and subjective use of the tests. PearlDiver, a medical research database, will be utilized to estimate the difference between patients who elect for ankle surgery procedures and do not within the United States. This will be accompanied with literature review of articles pertaining to surgery selection criteria in order to highlight differing procedure requirements among orthopedist, creating inconsistency in orthopedic medical decisions and treatment. Literature review of pre- and post-surgery comparison of ankle instability research papers will result in data collection of current comparison techniques, highlighting the multitude of options that are not equivalently comparable from study to study. Literature review of articles highlighting access barriers

aforementioned will be conducted to give context surrounding how it impacts patients and providers alike. PearlDiver can also be used to gather orthopedic physician metrics to get more up-to-date data regarding the trends of orthopedic specialist recruitment.

Conclusion

The lack of standardization surrounding ankle instability quantification stems from the subjective nature of the commonly used ankle stress tests. This subjectivity begets inconsistency in medical decisions and patient diagnosis. Diagnostic accuracy of ankle instability is pertinent to patient treatment and outcome. Currently, limited research has been conducted for these stress tests most used in practice. To combat these issues, I propose to create a wearable sensor technology that calculates ankle displacement and angle change during instability testing. This tool will be utilized in a research study to quantify the diagnostic accuracy of the current standardized ankle mechanical tests. Study results will identify the most precise test to utilize in ATFL injuries. Indirectly estimating the impact of this tool, the current ecosystem surrounding ankle instability tests will be explored and mapped utilizing ANT. This analysis will uncover deficits within the current state of standardization and the societal relationships affected, stressing the importance of the topic. Standardization of ankle orthopedic care, testing, and diagnosis is a necessity to establish and must be propelled to the forefront of issues present within orthopedics.

References

- American Academy of Orthopaedic Surgeons. (2016). *Will We Soon Be A Few Orthopaedists Short?* Retrieved October 25, 2022, from <https://www.aaos.org/aaosnow/2016/jul/youraaos/youraaos01/>
- American Academy of Orthopaedic Surgeons. (2019). *AAOS Orthopaedic Surgeon Census*. Retrieved October 25, 2022, from <https://www.aaos.org/quality/practice-management/aaos-orthopaedic-surgeon-census/>
- Buerer, Y., Winkler, M., Burn, A., Chopra, S., & Crevoisier, X. (2013). Evaluation of a modified Broström-Gould procedure for treatment of chronic lateral ankle instability: A retrospective study with critical analysis of outcome scoring. *Foot and Ankle Surgery: Official Journal of the European Society of Foot and Ankle Surgeons*, 19(1), 36–41.
- Chan, J. Y., Charlton, T. P., & Thordarson, D. B. (2020). Analysis of Orthopaedic Job Availability in the United States Based on Subspecialty. *JAAOS Global Research & Reviews*, 4(11), e20.00195. <https://doi.org/10.5435/JAAOSGlobal-D-20-00195>
- Clinical tests of the lateral ligament complex. (A) The anterior drawer... (n.d.). ResearchGate. Retrieved October 26, 2022, from https://www.researchgate.net/figure/Clinical-tests-of-the-lateral-ligament-complex-A-The-anterior-drawer-test-for-the_fig4_224940665
- Cressman, D. (2018). Actor-Network Theory. In *The Blackwell Encyclopedia of Sociology* (pp. 1–2). John Wiley & Sons, Ltd. <https://doi.org/10.1002/9781405165518.wbeosa009.pub2>
- Cresswell, K. M., Worth, A., & Sheikh, A. (2010). Actor-Network Theory and its role in understanding the implementation of information technology developments in healthcare. *BMC Medical Informatics and Decision Making*, 10(1), 67. <https://doi.org/10.1186/1472-6947-10-67>

- Croy, T., Koppenhaver, S., Saliba, S., & Hertel, J. (2013). Anterior talocrural joint laxity: Diagnostic accuracy of the anterior drawer test of the ankle. *The Journal of Orthopaedic and Sports Physical Therapy*, 43(12), 911–919. <https://doi.org/10.2519/jospt.2013.4679>
- Day, C. S., Boden, S. D., Knott, P. T., O'Rourke, N. C., & Yang, B. W. (2016). Musculoskeletal Workforce Needs: Are Physician Assistants and Nurse Practitioners the Solution?: AOA Critical Issues. *JBJS*, 98(11), e46. <https://doi.org/10.2106/JBJS.15.00950>
- Delco, M. L., Kennedy, J. G., Bonassar, L. J., & Fortier, L. A. (2017). Post-Traumatic Osteoarthritis of the Ankle: A Distinct Clinical Entity Requiring New Research Approaches. *Journal of Orthopaedic Research : Official Publication of the Orthopaedic Research Society*, 35(3), 440–453. <https://doi.org/10.1002/jor.23462>
- Donahue, M., Simon, J., & Docherty, C. (2011). Critical Review of Self-Reported Functional Ankle Instability Measures. *Foot & Ankle International / American Orthopaedic Foot and Ankle Society [and] Swiss Foot and Ankle Society*, 32, 1140–1146. <https://doi.org/10.3113/FAI.2011.1140>
- Dubin, J. C., Comeau, D., McClelland, R. I., Dubin, R. A., & Ferrel, E. (2011). Lateral and syndesmotic ankle sprain injuries: a narrative literature review. *Journal of chiropractic medicine*, 10(3), 204–219. <https://doi.org/10.1016/j.jcm.2011.02.001>
- Fong, D. T., Chan, Y. Y., Mok, K. M., Yung, P. S., & Chan, K. M. (2009). Understanding acute ankle ligamentous sprain injury in sports. *Sports medicine, arthroscopy, rehabilitation, therapy & technology : SMARTT*, 1, 14. <https://doi.org/10.1186/1758-2555-1-14>

Herzog, M. M., Kerr, Z. Y., Marshall, S. W., & Wikstrom, E. A. (2019). Epidemiology of Ankle Sprains and Chronic Ankle Instability. *Journal of Athletic Training*, 54(6), 603–610.

<https://doi.org/10.4085/1062-6050-447-17>

J Bernstein, ed: *Musculoskeletal Medicine*. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2003. Retrieved October 26, 2022, from <https://orthoinfo.aaos.org/en/diseases--conditions/sprained-ankle/>

Latour, B. (2005). *Reassembling the social: An introduction to actor-network-theory*. Oxford University Press.

Li, Q., Tu, Y., Chen, J., Shan, J., Yung, P. S.-H., Ling, S. K.-K., & Hua, Y. (2020). Reverse anterolateral drawer test is more sensitive and accurate for diagnosing chronic anterior talofibular ligament injury. *Knee Surgery, Sports Traumatology, Arthroscopy: Official Journal of the ESSKA*, 28(1), 55–62. <https://doi.org/10.1007/s00167-019-05705-x>

Melanson, S. W., & Shuman, V. L. (2022). Acute Ankle Sprain. In StatPearls. *StatPearls Publishing*. <http://www.ncbi.nlm.nih.gov/books/NBK459212/>

Netterström-Wedin, F., Matthews, M., & Bleakley, C. (2021). Diagnostic Accuracy of Clinical Tests Assessing Ligamentous Injury of the Talocrural and Subtalar Joints: A Systematic Review With Meta-Analysis. *Sports Health*, 14(3), 336–347.

<https://doi.org/10.1177/19417381211029953>

Salazar, D. H., Dy, C. J., Choate, W. S., & Place, H. M. (2019). Disparities in Access to Musculoskeletal Care: Narrowing the Gap. *The Journal of Bone and Joint Surgery. American Volume*, 101(22), e121. <https://doi.org/10.2106/JBJS.18.01106>

Song, K., & Wikstrom, E. A. (2019). Plausible mechanisms of and techniques to assess ankle joint degeneration following lateral ankle sprains: A narrative review. *The Physician and Sportsmedicine*, 47(3), 275–283. <https://doi.org/10.1080/00913847.2019.1581511>

Thomas, A. C., Hubbard-Turner, T., Wikstrom, E. A., & Palmieri-Smith, R. M. (2017). Epidemiology of Posttraumatic Osteoarthritis. *Journal of Athletic Training*, 52(6), 491–496. <https://doi.org/10.4085/1062-6050-51.5.08>

Types of Ankle Sprains by Alila Medical Images, Alamy Stock Photo Online. Retrieved October 26, 2022, from <https://www.alamy.com/stock-photo-types-of-ankle-sprains-49341645.html?imageid=42C5D22E-209A-4D0A-8EB7-FE91DC94A125&p=178046&pn=1&searchId=a359183e22521b92c8da7108d7ba1767&searchtype=0>

Valderrabano, V., Hintermann, B., Horisberger, M., & Fung, T. S. (2006). Ligamentous Posttraumatic Ankle Osteoarthritis. *The American Journal of Sports Medicine*, 34(4), 612–620. <https://doi.org/10.1177/0363546505281813>

Wenning, M., Gehring, D., Lange, T., Fuerst-Meroth, D., Streicher, P., Schmal, H., & Gollhofer, A. (2021). Clinical evaluation of manual stress testing, stress ultrasound and 3D stress MRI in chronic mechanical ankle instability. *BMC Musculoskeletal Disorders*, 22(1), 198. <https://doi.org/10.1186/s12891-021-03998-z>