Dynamic CT Analysis of Normal Syndesmosis Motion and Syndesmosis Motion after Static and Dynamic Fixation

I. Specific Aims

Despite injuries to the syndesmosis complex being a common orthopaedic problem, significant variability in surgical treatment remains. This is likely due to a poor understanding of normal dynamic syndesmosis motion and the resultant impact of static and dynamic fixation on post-injury syndesmosis kinematics. Investigation is warranted to better characterize normal and post-injury syndesmosis position and motion. This novel study will use dynamic CT to image uninjured ankles and those which have undergone static or dynamic fixation throughout ankle range of motion (ROM). The specific aims of this study are:

1) To quantify normal syndesmosis kinematics through ankle ROM.
2) To quantify side-to-side variability in syndesmosis kinematics in healthy participants.
3) To compare syndesmosis kinematics following dynamic and static syndesmosis fixation to normal, uninjured motion.
4) To describe the relationship between abnormal syndesmosis motion and functional outcomes.

We hypothesize that:

1) The relative position of the distal tibia and fibula will change significantly throughout ankle range of motion in uninjured ankles.
2) There will be minimal side-to-side variability in uninjured ankles.
3) Dynamic fixation following syndesmosis injury will more accurately reproduce normal, uninjured motion, compared to static fixation.
4) Functional outcomes will be worse in patients with abnormal syndesmotic kinematics that deviate from uninjured motion.

The null hypothesis states that there will be no side-to-side difference in syndesmosis kinematics between uninjured ankles and that there will be no difference between syndesmosis kinematics in injured and uninjured ankles.

II. Background and Significance

Ankle fractures are the 3rd most common fracture treated in the emergency department.[1] Of these injuries, one quarter to one third have a recognized syndesmosis injury.[2,3] When injured, malreduction of the syndesmosis has been found to be the most important independent factor which contributes to inferior functional outcomes including pain, instability, stiffness, and ankle arthritis.[4,5] Static screw fixation of syndesmosis injuries can lead to a higher risk of symptomatic malreduction compared to dynamic fixation with heavy suture and an endobutton spanning the distal tibio-fibular joint.[6] This dynamic method of fixation has been shown to achieve more anatomic reduction and improved functional outcomes compared with screw fixation.[7-9] However, these studies are based on static computed tomography (CT) images. Additionally, these studies compare the injured ankle to the contralateral, uninjured ankle, however normal side-to-side variation is unknown.

The syndesmosis complex is a dynamic structure, therefore conventional CT does not provide a complete picture of changes in syndesmosis position, giving potentially inaccurate results. Dynamic CT is an emerging technology which can be used to image joints in real time, as they are moved through a range of motion (ROM). Dynamic CT has been recently used to show syndesmosis position changes at maximal dorsiflexion and plantar flexion,[10,11] however continuous kinematic analysis of the tibio-fibular joint has not been performed to date.

Given the importance of accurate syndesmosis reduction, we propose a novel application of dynamic CT to determine the relative position of the distal tibio-fibular joint throughout the full ankle ROM, rather than a single, non-standardized position as evaluated by conventional CT. This study will be the first to: a) define normal syndesmosis motion throughout a full ankle ROM, b) quantify normal side-to-side differences in syndesmosis motion throughout ankle ROM and c) compare syndesmosis motion and quality of reduction following static and dynamic fixation throughout ankle ROM. The new knowledge gained from this study may be used to optimize syndesmosis reduction methods, improve patient outcomes, guide development of new image processing techniques, and highlight the benefits of dynamic CT for future orthopaedic research.

III. Research Design and Method

Study Design: The proposed research project has two, independent single-centre, prospective cohort studies to evaluate normal and post-injury syndesmosis motion. Eligible volunteers and patients will be approached by the research manager for participation. Once informed consent has been obtained, baseline data and bilateral ankle dynamic CT scans will be collected.

Study 1: The first study is a prospective cohort of healthy, adult volunteers recruited from our level 1 trauma centre and affiliated university who have not previously sustained lower extremity injuries. We aim to recruit 20 participants for bilateral ankle dynamic CT scans (n=40 ankles).

> *Inclusion Criteria:* Skeletally mature adult volunteers, aged 18 years or older, with bilateral uninjured ankles.
>
> *Exclusion Criteria:* Participants with prior lower leg fractures or ankle ligamentous injuries. Non-ambulatory participants or participants requiring gait aids. Congenital lower extremity deformities or neuromuscular disease.

Study 2: The second, non-contingent study is a prospective cohort of adult patients who present to our level 1 trauma centre cast clinic after open-reduction-internal fixation of an AO/OTA 44-C injury with dynamic or static syndesmosis fixation (single or double screw fixation). We aim to recruit 20 patients for each group within 21 days of surgery for bilateral ankle dynamic CT scans (n=80 ankles).

> *Inclusion Criteria:* Skeletally mature trauma patients, aged 18 years or older, who underwent dynamic or static fixation of a syndesmosis injury (AO/OTA 44-C1, 44-C2, 44C3).
>
> *Exclusion Criteria:* Patients with additional tibial or fibular fractures on the ipsilateral side or any contralateral tibia or fibula fractures. Prior ankle surgery or known syndesmotic injury on either side. Non-ambulatory patients. Patients who have lower extremity weight-bearing restrictions for injuries other than their ankle fracture.

Outcome Measures (all outcomes will be collected for volunteers and patients):
Primary Outcome: The primary outcome measures will be the anterior tibio-fibular distance, midpoint tibio-fibular distance, and posterior tibio-fibular distances in injured ankles at 5 degree increments of ankle dorsi/plantar-flexion.

Secondary Outcomes: Secondary outcome measures will include: a) the side-to-side differences between the above measurements, b) patient-reported outcome measures including the validated American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot, foot and ankle ability measure (FAAM), and short form 12 (SF-12) questionnaires.

Methods for Data Acquisition:
Baseline Data: Patient demographics including age, sex, ethnicity, body mass index, medical comorbidities, injury mechanism, associated injuries, fracture classification (if applicable), and fixation method will be recorded when enrolled by a member of the study team and entered into the Research Electronic Database Capture (REDCap) study database.

Clinical Data: Clinical parameters including ROM, visual analog pain score, and patient-reported questionnaires will be recorded and entered into REDCap. For patients with syndesmosis injuries, these parameters will be recorded at baseline (within 21 days of surgery), 6-week, and 3-month follow-up and entered into REDCap.

Dynamic CT Imaging: Patients will undergo dynamic CT scans (GE Revolution CT) of their bilateral ankles, as per our institutional image acquisition protocol. Subjects will more their ankles from maximal plantar flexion to maximal dorsiflexion during the imaging sequence. In injured patients, these will be completed 3 months after their index operation, in order to allow for patient comfort and ROM rehabilitation, but prior to any planned removal of syndesmosis fixation.

Data Analysis:
Assessment of Specific Aim 1: From these CT scans anterior tibio-fibular distance, midpoint tibio-fibular distance, and posterior tibio-fibular distance 1cm above the ankle joint at each 5 degree increment of ankle range of motion as measured on axial slices. Ankle position will be defined as the angle on a sagittal CT slice between the tibial plafond and the talar body. These parameters will be automatically extracted from CT data using a custom developed computer program, integrating numerical analysis and computer aided design (CAD) software (Matlab). Uninjured ankles will be analyzed to determine physiologic syndesmosis kinematics throughout range of motion.

Assessment of Specific Aim 2: Using the healthy volunteer cohort, side-to-side differences in syndesmosis kinematics will be calculated.

Assessment of Specific Aim 3: For both the static and dynamic fixation groups syndesmosis kinematics will be determined. This motion will be compared to the patient's nonoperative ankle. Differences in syndesmosis kinematics between dynamic and static syndesmosis fixation compared to normal, uninjured motion will be calculated.

Assessment of Specific Aim 4: Patients will complete AOFAS, FAAM, and SF-12 questionnaires. Patient-reported outcome measures, ROM, and visual analogue pain score will then be correlated with syndesmosis motion and accuracy of reduction, if applicable.

Sample Size Calculation:
Given the lack of dynamic CT literature, we are unable to complete a formal sample size calculation, however we believe that the proposed cohorts of 20 volunteers and 40 post-injury patients will provide substantial imaging for analysis, can be achieved within the proposed budget, and will provide the required information for a formal sample size calculation for any future research.

Statistical Analysis:
All continuous data will be reported as mean and standard deviation of the mean. Independent samples t-tests will be used for comparing dynamic CT parameters and clinical outcome scores between the groups. Repeated measures t-tests will be used for within-patient comparisons. All categorical data will be reported as proportions, and, where appropriate, tested for significance using Chi-squared or Fisher's exact tests. Significance of $\alpha \leq 0.05$ will be used. A biostatistician will assist with the analysis.

Feasibility and Timeline

We anticipate that we will easily secure 20 volunteers for study 1 from the research community including graduate students, medical students, and residents. For study 2, last year 1829 patients were seen in our centre's cast clinic for a new assessment. Based on the incidence of ankle fractures accounting for 18% of all fractures[12] and syndesmotic injuries requiring fixation occurring in 25%,[2] we estimate that 82 patients with syndesmosis fixation present to cast clinic per year (approximately 7/month) in roughly equal proportion between static and dynamic fixation. If one-half of these are eligible for study participation, patient enrollment is estimated at 12 months, which will allow for imaging analysis and manuscript preparation within the granting period. Enrollment for the two studies are not contingent on one another.

IV. Role of the Resident

This study will form the basis of the resident's Master of Science thesis in biomedical engineering. He will be taking a year long leave of absence from residency training to dedicate to project completion. The resident will first be responsible for developing a study protocol under the supervision of the attending Co-Principal Investigator and obtaining ethics approval for this protocol. The resident will be an active participant in implementing the protocol. He is also responsible for developing a computer-based model of ankle motion based on dynamic CT data. The resident will use this model to automatically analyse participant dynamic CT scans to determine baseline normal syndesmosis motion and quantify reduction after static and dynamic fixation. Finally, the resident will synthesize this data to prepare manuscripts for submission to the Journal of Orthopaedic Trauma as well as to the Orthopaedic Trauma Association conferences. We anticipate two separate manuscripts will be submitted, one for each study.

References

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4) Naqvi GA, Cunningham P, Lynch B, Galvin R, Awan N. Fixation of Ankle Syndesmotic Injuries. Am J Sports Med. 2012;40(12):2828–35.

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8) LaMothe JM, Baxter JR, Murphy C, Gilbert S, DeSandis B, Drakos MC. Three-Dimensional Analysis of Fibular Motion After Fixation of Syndesmotic Injuries with a Screw or Suture-Button Construct. Foot Ankle Int. 2016;37(12):1350–6.

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11) Schneider PS, Wiens C, Buckley R, Duffy P, Korley R, Martin CR, Harrison T, Sanders D. Dynamic CT can Distinguish Differences in Tibio-fibular Motion Following Syndesmotic Injury. Poster session presented at: Orthopaedic Trauma Association Annual Meeting; 2018 Oct 17-20; Orlando, FL.

12) Miller AN, Paul O, Boraiah S, Parker RJ, Helfet DL, Lorich DG. Functional outcomes after syndesmotic screw fixation and removal. J Orthop Trauma. 2010;24(1):12-16.

Names of specific individuals and names of institutions should NOT be in the body of the budget.

BUDGET

SALARIES AND WAGES (List all personnel for whom money is requested)	% effort on project	Requested from OTA (round to $)
Research Manager $42/hr x 50 hours (22.5% fringe benefits already included)	%	$ $ 2,100
REDCap Data Analyst $31/hr x 10 hours (22.5% fringe benefits already included)	%	$ 310
Biostatistician $200/hr x 3hours (fringe benefits not applicable)	%	$ 600
	%	
Fringe Benefits 0.00 % of Salaries and Wages Salaries and Wages plus Fringe Benefits	TOTAL	$ 3,010

PERMANENT EQUIPMENT (append justification)	
Subtotal	$ 0

CONSUMABLE SUPPLIES (exclude animals and animal care)	
Dynamic CT scan $250/pt x 60 participants	$ 15,000
Participant Parking $15/pt x 60 participants	$ 900
RedCAP Account activation and server charges	$ 440
Data Storage - 5 years	$ 150
Subtotal	$ 16,490

ANIMALS AND ANIMAL CARE	
Subtotal	$ 0

ALL OTHER EXPENSES	
Matlab software license	$ 500
Subtotal	$ 500

TOTAL DIRECT COSTS $ 20,000