Long-term monitoring of lower limb joint loads using wearable sensors: Application in sports and orthopaedics

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Financial disclosures

A/Prof Besier is a previous co-Founder of IMeasureU and now consults to Vicon-IMeasureU

All other authors have nothing to disclose
Mechanical loads play a critical role in the maintenance, regulation and regeneration of musculoskeletal tissue. If we understand the mechanical environment of the tissue and the tissue response to loading, we can design appropriate treatment and prevention strategies.

[Carter & Beaupré, 2001, Skeletal Function and Form]
The need for personalised medicine

Population Health Management
(based on Evidence-Based Medicine)

VS

Precision Medicine
(based on Data-Driven Healthcare)

All patients are the same

Every patient is unique

Estimating subject-specific musculoskeletal loads

Laboratory-based modelling to estimate tissue loads is complex, and does not account for the total load exposure in the real world...

Fatigue-related musculoskeletal injury
Bone modelling and remodelling

Calibrated EMG Informed NeuroMusculoSkeletal Modelling
[CEINMS, SimTK.org]

[Lloyd & Besier, 2003, J Biomech; Pizzolato, 2015, J Biomech]
Wearable sensors are now a feasible option for tracking athletes and patients outside the laboratory. 

...but do they measure the appropriate biomechanical variable of interest?
To present a framework to integrate data from body worn inertial measurement units (IMUs) with biomechanical and statistical models to measure and monitor lower limb loads.

Two applications of this framework include:
1. Impact load monitoring for basketball athletes, and
2. Knee load monitoring for patients who have experienced total knee joint replacement
Framework to estimate cumulative load

Raw sensor data

Mechanobiology Model
Daily Load Stimulus (DLS)

\[ DLS = \left( \sum_{j=1}^{k} N_j E_j^m \right)^{1/m} \]

Cumulative load

Musculoskeletal Atlas Project

Subject height and mass

Gait data

Inverse Kinematics
Inverse Dynamics
Motion Capture

Mechanistic Model

Partial Least Squares Regression (PLSR)

Surrogate Model

Mechanobiology Model
Daily Load Stimulus (DLS)
Daily load stimulus (DLS)

\[ DLS = \left( \sum_{j=1}^{k} n_j (\sigma_j)^m \right)^{1/m} \]

- \( n_j \): Number of cycles
- \( \sigma_j \): Peak impact acceleration


Empirical constant

Cumulative bone load

Raw IMU data

Mechanobiology Model

Daily Load Stimulus (DLS)
Application 1: Impact load monitoring for basketball athletes

Challenge:
Basketball athletes experience many impact loads over the course of a game/season/career. Cumulative mechanical loading is believed to be related to the high rate of metatarsal fracture and other fatigue-related injury in basketball athletes.

Solution:
Measure and monitor the impact load of every foot strike for every athlete
Data collection and dashboard

- 21 Week Prospective Data
- 13 NZ Basketball athletes
- Monitored bi-lateral limb loading using inertial sensor@500Hz
- Captured peak impact acceleration for every step
- Calculated a cumulative load score using adjusted daily load stimulus
- Provided feedback to coaching staff using a dashboard to adjust training workload

[with Kaitlyn Weiss, Chris Whatman and Mike McMGuigan, AUT]
Latest Session 9/02/17
(Left and Right Leg Step Count vs. Intensity Bin (1-26))

Weight: 119 kg  Height: 215 cm

Position: C

8/02/17 9/02/17

# Total Steps 6,867 5,797
# High 833 620
% High 12.13% 10.70%
Session Bone Load 371 361
A-C (Bone Load) 2.08 1.34
Session Minutes 118 101

All Sessions by Day
(Intensity Bins showing Left Leg and Right Leg Asymmetry Levels vs. All Sessions by Day)

KEY
Symmetry (%)
50
Asymmetry (Colour)
-50.0  50.0
Date Fidelity
Day
Surrogate modelling of joint contact forces

Knee joint contact force

Surrogate Model
Partial Least Squares Regression (PLSR)

Knee joint contact force
Application 2: Knee joint load monitoring following total joint replacement

Challenge:
How much load should patients place on their knee joint replacement following arthroplasty?

Solution:
Measure and monitor the knee contact forces of patients following joint replacement.
Data collection and surrogate model

- 6 Week Postoperative follow up
- 11 total knee joint replacement patients
- Monitored bi-lateral limb loading using inertial sensor@500Hz
- Estimated knee contact forces for each patient at two time points
- Develop surrogate models for each patient to monitor joint loading

[with Shasha Yeung, Alex Wilson and Justin Fernandez, ABI]

Results in concurrent session!
Summary

• Wearable sensors provide an opportunity to incorporate load exposure into our biomechanical studies
• Integration into mechanobiological framework
• Surrogate modelling can be used to capture the information of interest
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