An Innovative Measurement in Musculoskeletal Rehabilitation Using 3D Motion Analysis

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Background

**LBP**
- musculoskeletal dysfunction
- high prevalence & demand on medical care / rehabilitation

People with CLBP
- various forms of impaired movement pattern / motor control of the lumbopelvic and hip region

Extent of such impairments and their recovery
- associated with the clinical outcomes e.g. pain intensity, functional capability ...
Kinematics of Spine During Lumbar Flexion

- For healthy individuals, the spine maintains a neutral posture and the lower spine rounds forward.
- For low back pain patients, movement occurs from the hip joint.
Evaluation of Low Back Pain Patients

- 30 adults were recruited in the study movement analysis with 15 paired age and gender matched healthy controls.

- A novel functional assessment protocol was used with repeated forward bending tasks executed at various level of pace.

- The patients undergone a 6-week structured fitball exercise class training session (12 sessions in total).

- Measurement of their lumbopelvic movement and motor control using Vicon system.

- Measurement of pain intensity, functional capacity and fear of movement before and after the program.

- A clinical study conducted at our centre in 2016-2017 in evaluating the recovery of lumbopelvic movement and motor control of individuals with nonspecific LBP.
Measurement of Kinematics Using Vicon System
Measurement of Kinematics Using Vicon System

- Direct Linear Transformation from 10 Raw Cameras
- Identified Markers
- 3D Images
- Reconstruct Skeleton
- Kinematics & Kinetics
Novel Evaluation Protocol at a Self Preferred Speed
Novel Evaluation Protocol at Five Different Speeds

Novel evaluation protocol randomized from 20 to 60 bpm
Intervention and Evaluation with Vicon System

Baseline Evaluation

Exercise Training

Post Exercise Training Evaluation
Main Findings of the Clinical Study

* significant difference between healthy & LBP (pre: baseline difference)
§ significant difference between LBP (pre & post: intervention effect)

Fig 1. Time required for completing 7 repeated cycles of forward bending task
Main Findings of the Clinical Study

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§ significant difference between LBP (pre & post: intervention effect)

Fig 2. Mean velocity at lumbar spine and hip joints during forward bending
Limitations of the Vicon System in Clinical Application

- Routine application using Vicon system for objective movement analysis has limitations
- Practically difficult in demanding clinical settings (take 1-2 hours in measuring one single subject)
- Limitation of marker-based optical tracking system in daily monitoring & outdoor measurement
To Overcome This Challenge

- Our centre explored the applicability of a handy & portable, commercially available industrial-grade tri-axial inertial sensors (the LORD micro-strain 3DM-GX5-25)
- Each sensor contains tri-axial gyroscopes, accelerometers and magnetometers
- Dimension: 44mm (h) x 25mm (w) x 11mm (d) and weights 19g each
- Accuracy of $\pm 0.5^\circ$ (static testing) and $\pm 2.0^\circ$ (dynamic testing)
Application of Inertial Sensors in Various Field

Exploration of the inertial sensor in the medical field for clinical use (e.g. assessment and treatment evaluation)
Objectives of the Study

- Validate the Inertial system with the golden standard 3D motion analysis system (Vicon system)
- Kinematics (full body model of plug-in-gait)

- Examine the reliability of this Inertial system in clinical use for measuring
  - Range of motion
  - Angular velocities
Methodology

- The healthy subjects and LBP patients perform forward bending in self preferred speed, 20 and 40 bpm
- The kinematics and kinetics of the subjects were analyzed using both the Vicon system and Inertial system
- The sensors were connected to a purpose built data logger and software
- Baseline & post exercise training evaluation with the Inertial system
Acquisition of 3D Kinematics with Inertial Sensors

- Sensors placement of the inertial sensors for the lumbar spine:
  - One over spinous process of L1
  - Another over spinous process of S1

(Williams JM et al, 2013)
Motion Capture and Movement Analysis with Vicon and Inertial System

Preferred Speed  20bpm  40bpm
Validation between Vicon and Inertial System

The tri-axial trajectory of the lumbar spine during repeated forward bending task (captured by Vicon system)

The trajectory of L1 during repeated forward bending task (captured by Inertial system)
## Summary Table of the Lumbar Flexion Range and Mean Velocity (During Flexion and Extension Phase)

<table>
<thead>
<tr>
<th>Trial</th>
<th>ROM</th>
<th>Angular Velocities</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Lumbar flexion range (deg)</td>
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<tr>
<td></td>
<td>PS</td>
<td>20bpm</td>
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<tr>
<td></td>
<td>IMU</td>
<td>19.4</td>
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</tbody>
</table>

IMU: Inertial Measurement Unit
Validation of Lumbar Flexion Range of Motion
Linear Regression: Coefficient of Determination

$R^2$ Linear = 0.905

$y = 5.73\times 10^{-3} + 0.91x$
Validation of Mean Lumbar Flexion Velocity
Linear Regression: Coefficient of Determination

\[ y = 4.03 + 0.92x \]

\[ R^2 \text{ Linear} = 0.779 \]
Validation of Mean Lumbar Extension Velocity
Linear Regression: Coefficient of Determination

\[ y = 2.95 + 0.97x \]

\[ R^2 \text{ Linear} = 0.877 \]
Intervention and Evaluation with Inertial System

Baseline Evaluation

Exercise Training

Post Exercise Training Evaluation
Evaluation with Inertial System (Lumbar Spine Kinematics)

Both the mean velocity of lumbar spine (in the speed of 40bpm) during flexion and extension phase was significantly improved (* \( p<0.05 \))
Clinical Application and Significance

- Movement velocity
  - is a robust and sensitive parameter to identify and quantify movement and motor control impairment in patients with LBP

- The tri-axial inertial system is a highly practical tool
  - as handy and convenient to use
  - can use in both assessment and treatment evaluation
  - offers reliable and useful data for revealing the lumbo-pelvic movement impairments
Clinical Application and Significance

- Apart from LBP patients
- Use of inertial system in the rehabilitation of various musculoskeletal conditions involving peripheral joints (e.g. shoulder or knee joints ...)

With the wearable sensor technology, movement analysis can be done outside the special room with Vicon cameras and force platform (e.g. gait analysis, agility evaluation ...
References

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