Skin MountedAccelerometer System for Measuring Knee Range of Motion
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Background

• Knee range-of-motion (ROM) is an important indicator of joint mobility in knee osteoarthritis, and during recovery from joint injury and surgical intervention (Ersoz & Ergun 2003; Su, et. al, 2010).
• ROM is typically assessed in the clinic using a handheld goniometer (Lenssen, et. al, 2007).
• Goniometric measurements suffer from poor inter- and intra-rater reliability and require the presence of trained personnel to palpate bony anatomical landmarks and take measurements (Holla, et. al 2011; Piriyaprasarth & Morris 2007).
• Limitations can be addressed by measuring ROM using an array of wearable sensors during clinical tests of knee function.

We establish the accuracy of knee angle and ROM estimates enabled by a conformal, wearable accelerometer system by comparing to clinical gold-standard goniometric measurements.

Experimental Methods

• N=10 subjects (sex: 9M, 1F; age: 30.7 +/- 7.9 years)
• Protocol:
  1. Collect written, informed consent
  2. Secure BioStampRC sensors to thigh and shank
     • Accelerometer (+/- 4g, 50 Hz)
  3. Palpate to identify anatomical landmarks
  4. Perform functional calibration activities (standing, walking)
  5. Perform knee functional assessment activities (3x maximum extension, 3x flexion – 45 deg, 90 deg, maximum)
     i. Two raters independently measure the extreme knee angle achieved during each assessment activity using manual, handheld goniometer
     ii. Angles recorded in BioStampRC Investigator Mobile Application

Results

Goniometer Inter-Rater Agreement

Knee ROM

Goniometer–Accelerometer Agreement

Comparison 95% CI Correlation Bias Scale Factor
A–B Angle (-4.30°, 5.87°) > 0.99 -0.15° 1.02
A–B ROM (-3.28°, 8.55°) > 0.99 -5.89° 1.03

Discussion

• Goniometer inter-rater agreement similar to literature (Lenssen, et al. 2007)
• Rater A measures larger amplitude knee angles in both directions
• Rater A measures larger ROM than Rater B (Bias = 5.89°)
• Knee angle from accelerometer system biased
  • Bias due to subject-specific knee angle during standing (+/- 15 deg)
  • Tracks differences in knee angle to within 1% (Scale Factor = 1.01)
• Knee ROM from accelerometer system agrees with goniometer measurements
  • 95% confidence interval for difference consistent with goniometer
  • Bias less than half of inter-rater bias with goniometer (2.39° vs. 5.89°)
  • Tracks differences in ROM to within less than 1% (Scale Factor = 1.00)

Summary

• We present a conformal, wearable accelerometer system for characterizing knee mobility outside of clinical settings.
• We establish the accuracy of knee angle and ROM by comparing to clinical gold-standard goniometric measurements from two raters.
• System tracks differences in knee angle to within 1%
• System characterizes knee ROM to levels of agreement no worse than goniometer inter-rater agreement.
• Performance opens door to future deployment of system in clinical populations, and outside of clinical settings.