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Original Research

Quantification of Equine Sacral and Iliac Motion During Application of Manual Forces and Comparison Between Motion Capture With Skin-Mounted and Bone-Fixated Sensors

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ABSTRACT

Diagnosis of sacroiliac dysfunction in horses includes manual motion palpation of the equine ilium and sacrum. Motion of the ilium and sacrum during manual force application to the equine pelvis has been measured previously in vitro. The aim of this study was to measure the amount and direction of motion in vivo, including comparison of bone-fixated and skin-mounted inertial sensors. Sensors were skin-mounted over tuber sacrale (TS) and third sacral spinous process of six Thoroughbred horses and later attached via Steinmann pins inserted into the same bony landmarks. Orientations of each TS and sacrum were recorded by one investigator during six trials of manual force applied to the pelvis, inducing cranial, caudal, and oblique rotations. Mean values were reported in Euler angles for the three orthogonal planes lateral bending, flexion–extension (FE), and axial rotation (AR). Differences between skin- and bone-fixated markers were determined with significance set at $P < .05$. The largest mean values recorded during rotations applied to the pelvises were for FE, ($2.08^\circ \pm 0.35^\circ$) with bone-fixated sensors. AR gave the largest values recorded with skin mountings ($1.70^\circ \pm 0.48^\circ$). There was a poor correlation between skin-mounted and bone-fixated markers with AR being the orthogonal plane in which results from skin mounting were closest to results from bone-fixated sensors Bony kinematics during external movement applied to the pelvis cannot be predicted from skin-mounted sensors, due to differences between skin- and bone-mounted sensors.

1. Introduction

In human physiotherapy, composites of motion palpation and provocation tests of the sacroiliac joint (SIJ) together have reliability sufficiently high for use in clinical assessment of sacroiliac dysfunction (SID) [1,2]. In horses, manual motion tests and provocation tests have been extrapolated from the human model. Establishing the nature and extent of equine SIJ motion is important to assist clinicians in determining if such tests are valid for the diagnosis of SID in horses.

Measurement of three-dimensional (3-D) movement at the SIJ presents a challenge in horses due to the location of the joint within the pelvis. Despite this, successful recordings of movements at both the sacral vertebral segment and the pelvis have been performed. Measurements of these two articulating segments of the SIJ allow an indication of motion that may occur at the SIJ. In vivo studies during treadmill locomotion have been performed in sound horses [3–10]. In vitro measurements limited to the sagittal plane revealed that less than 1° of movement existed at the SIJ, where the sacrum was moved against a fixed ilium [11]. Subsequent in vitro research using cadaveric equine specimens measured the amount of 3-D

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rotation occurring at the ilium with respect to a fixed sacrum. This was recorded with inertial sensors, during the application of movements based on manual motion tests that were applied to cadaveric pelvises [12]. Movement recorded in the sagittal rotation plane was only slightly greater than that recorded by Degueurce et al (2004) [11], but the range of motion of the ilium was greatest in the transverse or coronal plane, when lateral ($2.56^\circ \pm 0.29^\circ$) and oblique ($2.25^\circ \pm 0.29^\circ$) rotations were applied to the pelvis [12].

Relative movement between the ilium and the sacrum has also been noted as a change in cross-sectional area of the dorsal sacroiliac ligament (running from the tuber sacrale of the pelvis to the sacrum) occurring during application of manual forces to the pelvis in standing horses [12]. There has not, however, been a kinematic evaluation of the rotations that may occur during application of manual motion tests used in musculoskeletal examination of the SIJ in the horse to the pelvis in vivo.

The aim of this study was to measure the amount and direction of movement of the ilium relative to the sacrum in vivo, during the application of manual forces that are consistent with those used during a clinical physiotherapy examination of the equine pelvis. A further aim was to compare bone-fixated and skin-mounted inertial sensors.

2. Materials and Methods

2.1. Animals

Six thoroughbred horses were recruited, two geldings and four mares, mean age 7.6 years (range 4–14 years), mean weight 519.6 kg (range 480–553 kg), and mean height 159 cm (SD 3.2). The history of the horses was unavailable as horses were acquired from a sale yard. The horses were assessed by a veterinarian and a physiotherapist and judged to be sound.

2.2. Measurement and Sensors

Segment angles of both the sacral vertebral segment (S3) and the ilium (tuber sacrale [TS]) were recorded using three wireless inertial sensors numbered 1, 2, and 3 (Inertia Cube 3; InterSense, Bedford, MA www.intersense.com/InertiaCube_Sensors.aspx). The Inertia Cube 3 (IC3) sensors measure absolute orientation of any object relative to gravity and magnetic north. The collection frequency for the sensors was 100 Hz. Previous work has shown that the sensors have a static accuracy of better than 0.05° when appropriately configured [13].

The IC3 sensors contain an accelerometer, a magnetometer, and a gyroscope in each orthogonal plane. The orthogonal planes referred to are those denoted by the standard right-handed orthogonal Cartesian coordinate system. Flexion–extension (FE) is described as rotation around the x-axis; lateral bending (LB) is described as rotation around the z-axis; axial rotation (AR) is described as rotation around the y-axis. Orientation in this study was reported as Euler angles. All data were collected and analyzed using LabVIEW 7.1 (National Instruments, Austin, TX).

2.3. Skin-Mounted Sensors

Xylazine 150 mg was administered intravenously to each horse, before the horse being clipped over the regions of the TS, sacral dorsal spinous processes (SP), and caudal lumbar SP, to ensure an adequate area for adhesion of sensors and their batteries. Adhesive stretch tape (Fixomull) was applied over the bony prominences of both TS and the SP of S3, and an ink marker denoted the midpoint of each bony prominence (in the horse standing squarely). IC3 sensors were placed over the ink mark on the bony prominences, fastened with double-sided tape, and further fastened down with adhesive stretch tape.

Sensor 1 was attached onto the left TS; sensor 2 was attached onto the right TS; and sensor 3 was attached onto the sacral vertebral segment, for each horse. Horses were placed in stocks and were encouraged to stand squarely at all times during the testing. For applications of manual forces to the left side of the pelvis, only data from sensors 1 and 3 were recorded. Orientations of the left ilium and the sacrum were simultaneously recorded by the two sensors in three orthogonal planes, LB, FE, and AR, during rotational manual forces applied to the left pelvis by a physiotherapist (L.M.G.). The movements were assessed to the end of available passive range, reported as firm resistance to the induced motion [14,15]. The manual forces were applied in the following directions:

1. Cranial pelvic rotation (sagittal plane).
2. Caudal pelvic rotation (sagittal plane).
3. Oblique rotation (transverse-frontal plane).

The induced motions were applied via the therapist's hands placed over the ipsilateral tuber coxa and the tuber ischium for cranial and caudal rotations and the ipsilateral tuber coxa and contralateral tuber ischium for oblique rotation.

Before data collection, at least one test application of each rotation was applied to the pelvis, on each side. During manual force application, if the horse moved from the square standing position or there was muscle contraction, the application of rotation to the pelvis was repeated. There were three trials recorded for each application. For applications of manual forces to the right side of the pelvis, data from sensors 2 and 3 were recorded.

Data were sampled at 20 samples per second. Data was collected using a custom analysis program (LabVIEW 7.1), where they were represented as graphs. The difference between maximum and minimum values on the graph was calculated for each sensor and recorded as the Euler angle for each orthogonal plane.

2.4. Bone-Implanted Sensors

Bone implantation was carried out following the testing of the horses with skin-mounted inertial sensors without randomization of order due the possibility of bone implantation affecting the overlying skin. Horses were sedated with xylazine 200 mg and butorphanol 20 mg IV. Before pin insertion, gentamicin (6.6 mg/kg) and 2 g phenylbutazone were administered IV. A 4- to 8-cm-long, 3.0-mm-thick Steinmann pin was placed into the SPs (last lumbar and S2 or 3) and both TS without predrilling and was cut so that each pin protruded approximately 1 cm above the skin. Custom-built light-weight brackets, weighing 9 g and measuring $34 \times 25 \times 20$ mm (Fig. 1) with an IC3 sensor screwed to the same, were fixed, via two tightening nuts, to the protruding end of each Steinmann pin on the left and right TS, the S3 SP in the same configuration for the skin-mounted situation. There was a fourth sensor pinned into the last lumbar vertebral SP. Sensor 1 was pinned into the left TS; sensor 2 was pinned into the right TS; and sensor 3 was pinned into the SP of the sacral segment.

The procedure of testing was identical to that of the skin-mounted inertial sensors. Orientation of the left and right ilium and the sacrum was simultaneously recorded by the sensors in three orthogonal planes. Data were collected and recorded in the same manner as for the skin-mounted sensors.

2.5. Statistical Analysis

For each direction of applied rotation, the degree of motion of LB, FE, and AR was recorded at each sensor. The results were