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Quantifying the force transmission through the pelvic joints during total hip arthroplasty: A pilot cadaveric study

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ABSTRACT

Background: Total hip arthroplasty is one of the most successful and cost effective procedures in orthopedics. The purpose of this study is to investigate force transmission through the sacroiliac joint as a possible source of post-operative pain after total hip arthroplasty through the following three questions: Does the ipsilateral sacroiliac joint, contralateral sacroiliac joint, or pubic symphysis experience more force during placement? Does the larger mallet used to seat the implant generate a higher force? Does the specimen's bone density or BMI alter force transmission?

Methods: A solid design acetabular component was impacted into five human cadaver pelves with intact soft tissues. The pressure at both sacroiliac joints and the pubic symphysis was measured during cup placement. This same procedure was replicated using an existing pelvis finite element model to use for comparison.

Findings: The location of the peak force for each hammer strike was found to be specimen specific. The finite model results indicated the ipsilateral sacroiliac joint had the highest pressure and strain followed by the pubic symphysis over the course of the full simulation. The heft of the mallet and bone mineral density did not predict force values or locations. The largest median force was generated in extremely obese specimens.

Interpretation: Contrary to previous ideas, it is highly unlikely that forces experienced at the pelvic joints are large enough to contribute post-operative pain during impaction of an acetabular component. These results indicate more force is conveyed to the pubic symphysis compared to the sacroiliac joints.

1. Introduction

Today, total hip arthroplasty (THA) is one of the most successful and cost effective procedures in orthopedics. Patient satisfaction is relatively high because preoperative pain is eliminated and functional mobility is restored. Occasionally, patients may report low back pain after hip replacement. Resultant leg length discrepancy, altered femoral offset, unrecognized spinal abnormalities, and muscle deconditioning have been recognized as underlying causes (Kemper et al., 2008; Kiapour et al., 2012; Swaminathan et al., 2014).

A study by Pap et al. (Pap et al., 1987) reported up to 30% of patients could develop sacroiliac joint (SIJ) pain after THA. Numerous articles (Dalstra and Huiskes, 1995; Miller et al., 1987; Shi et al., 2014; Tile, 1996) have investigated the forces imparted on the pelvis during various activities but few accounted for the motion at the SIJs. The primary purpose of this study is to investigate force transmission through the SIJ as a possible source of post-operative pain after THA.

During loading of the native acetabulum, the force expands medially toward the acetabular fossa before being transmitted through the bony pelvis (Widmer et al., 2002). Three distinct regions of force concentration have been defined during loading of a press-fit acetabular component (Vasu et al., 1982). Both Widmer (Widmer et al., 2002) and Small (Small et al., 2013) noted the bony regions of the ilium followed by the ischium experience the majority of forces with modest contributions from the pubis. Cross-sectional anatomy of the pelvis at the level of the acetabulum reveals organized cancellous trabeculations responsible for directing forces toward the SIJ (Antoniades and Pellegrini Jr., 2012) and pubic symphysis (PS) (Pignatti et al., 2003).

This cadaver study is the first attempt to quantify the forces transmitted through the pelvis by measuring resultant forces at the SIJs and

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PS during impaction of a press-fit acetabular component. This paper seeks to answer the following questions:

(1) Does the ipsilateral SIJ, contralateral SIJ, or PS experience more force during placement of an acetabular cup?
(2) Does the second, larger mallet used to seat the implant generate a higher force at the pelvic joints?
(3) Does the specimen's bone density or BMI alter force transmission from the acetabulum to the pelvic joints?

2. Methods

Five human cadaver pelves with intact muscle and soft tissues were obtained from the Anatomy Gifts Registry (Hanover, MD, USA). Exclusion criteria for the specimens included prior hip/pelvis fracture, hip/pelvis surgery, or cancer metastasis. The soft tissue envelope was retained for each pelvis to simulate operative conditions.

The iliacus muscles were dissected from their origin along the inner table of the ilium, to expose the anterior ligaments of both SIJs. Next, a No. 10 scalpel blade was used to localize the most superior aspect of the joint without violating the iliolumbar ligaments. Proceeding inferiorly, the anterior SI ligaments were incised to fully define the convoluted SIJ along the full anterior surface. Dissection was stopped one centimeter short of the greater sciatic notch.

Following exposure of the joint, a 1/4 inch osteotome was gently inserted into the middle portion of each SIJ to distract the joint surfaces enough to accommodate one limb of the pressure sensor (Model #:6900-1100, Tekscan, Boston, MA, USA). The sensors were positioned near the anteroinferior portion of the SIJs to include the portion of the joint that experiences the highest stress concentration under load according to Shi et al. (Shi et al., 2014) (Fig. 1). Pressure data was collected I-Scan (Tekscan, Boston, MA, USA).

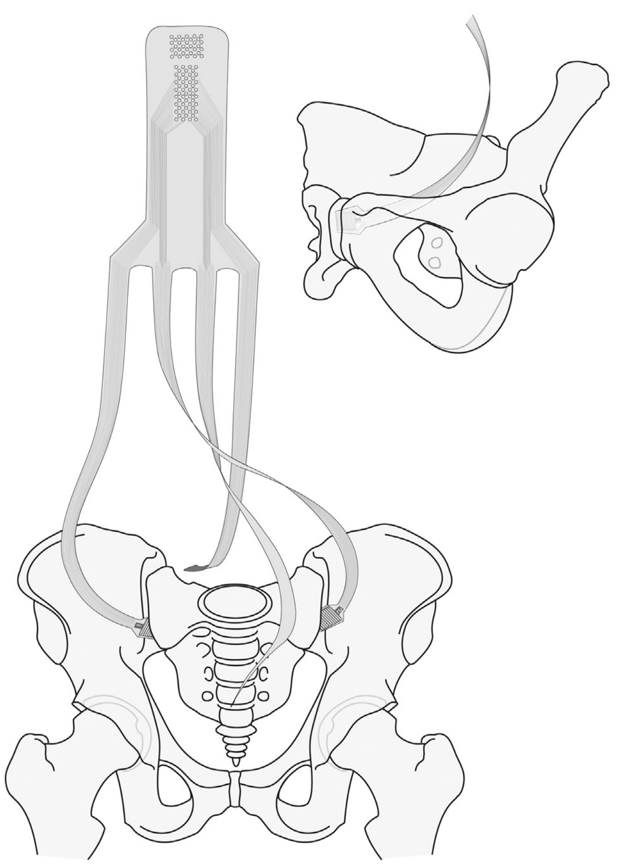

Fig. 1. Experimental Setup. Tekscan 6900 sensor shown as implemented during the experiment - One arm in each SIJ and one arm in the pubic symphysis.

Sensor calibration was conducted prior to testing using a materials testing machine that applied known forces covering the range of expected experimental loads over the full sensor area.

After the PS was identified posterior to the anterior abdominal musculature, a vertical incision was made in the mid-portion of the cartilaginous disc ending one centimeter short of the inferior boarder. A third arm of the Tekscan sensor with accompanying cardboard insert was then introduced into the disc with a small amount of cyanoacrylate adhesive to secure it in place.

Pelves were positioned laterally on a pegboard system (Medicus Health, Kentwood, MI, USA) with an overlying 1.25 cm thick gel patient return electrode pad (Megadyne, Draper, UT, USA) to replicate operating room position for a posterolateral (Kocher-Langenboch) total hip approach. Four posts (two anterior, two posterior) were positioned to secure the specimen to the pegboard in a lateral decubitus position. A cloth towel roll was used to support the perineal region of the pelvis inferiorly. Two additional pegs and a cushioned metal plate prevented superior migration of the specimen.

For each specimen, the labrum, fat, and remaining ligamentum teres were removed via sharp dissection. Reaming progressed in 1-millimeter increments while matching the specimen's native anteversion and abduction angle until the reamer made full contact with all aspects of the acetabulum.

Next, a porous-coated non-spiked acetabular shell (Smith & Nephew Reflection) one size larger than the last reamer was selected for each specimen. A solid cup design was utilized instead of multi-hole components to ensure uniform force distribution through the acetabulum during impaction. A standard, two-pound, stainless steel mallet (Zimmer 155-02, Andover, MA, USA) was used to seat the acetabular component into the cadaver specimen. Impaction ceased once a pitch change was audible. A three-pound stainless steel mallet (K-Medic KM 46-667, Morrisville, NC, USA) was employed to finish seating the implant. During the full course of implant placement, data was collected from the sensors at the bilateral SIJs and PS. Two impaction trials were completed for each acetabulum.

Post-test, each specimen underwent a computerized tomography scan to examine bone density. The scanning protocol was a standard trauma scan with an in-table calcium phantom reference (Image Analysis, Inc., Columbia, KY, USA). Average bone mineral density measurements were calculated from measured Hounsfield units (AquariusNet Viewer, TeraRecon, Foster City, CA, USA) from three locations in the iliac wing trabecular bone adjacent to the acetabulum. After all testing was complete, cadaver specimens were disposed of according to laboratory protocol.

For comparison to the cadaveric data, implant placement was simulated using a finite element model (FEM). The FEM selected for this study was the existing Global Human Body Models Consortium (GHBMC) M50 version 4.2, a model of an average sized male (distributed by Elemance, LLC, Winston-Salem, NC, USA). The pelvic bone and all pelvic ligaments were isolated from the model. This whole body FEM has been previously validated in automotive testing configurations (Vavalle et al., 2013).

The boundary conditions for the FEM were idealized. The pelvis was assumed to be rigidly fixed on the contralateral side. The right acetabulum had an applied load along the same axis of impact as the experimental set-up with the load defined by the force versus time curve published in Kroeber et al. (Kroeber et al., 2002). All simulations were conducted using LSDYNA MPP R6.1.1 (LSTC, Livermore, CA, USA) on a computer cluster. This FEM analysis serves as a no-pathology, symmetric pelvis to compare the stress distribution in an ideal case to the data collected in the cadaveric specimens.

2.1. Data analysis

Three regions of interest were investigated: The ipsilateral SIJ