MEASURING CONTACT PRESSURE AND CONTACT AREA IN ORTHOPEDIC APPLICATIONS: FUJI FILM VS. TEKSCAN

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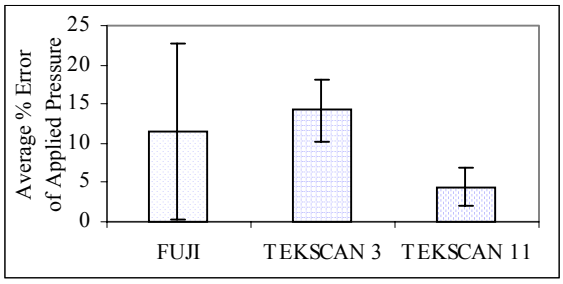
INTRODUCTION:
Accurately measuring contact pressure and contact area is key to understanding the loading environment of diarthrodial joints. Many orthopedic research studies involve measuring contact pressures and contact areas in total joint arthroplasties. Since 1980, when Fukubayashi and Kurosawa introduced Fuji Film Prescale Pressure Measuring System (Fuji Photo Film Co., Ltd., Tokyo, Japan) as a method for observing contact pressure and contact area distribution patterns in joints, this film system has become a standard tool used in orthopedic research. The film is comprised of two separate sheets that when compressed together produce pink stains of varying intensity based on the magnitude of the applied load. Over the past 19 years, the use of Fuji film has evolved into a highly technical science and has spread out to encompass a wide range of applications in orthopedic research. There has, however, been a recent introduction of digital pressure sensor devices, which have a number of important advantages over the Fuji film. These include dynamic testing capabilities, ease of calibration, reusability of the sensor, and direct computer interface. Specifically used in this study was the Tekscan *I-Scan*™ Pressure Measurement System (Tekscan, Inc., South Boston, MA) which works via an array of dielectric pressure transducers. It is the goal of this study to compare the performance of the Tekscan *I-Scan*™ Pressure Measurement System to the current standard, Fuji film. The hypothesis of this study is that the Tekscan *I-Scan*™ Pressure Measurement System can be used to measure contact area and contact pressure distribution patterns and yield results that are equally or more accurate than those obtained using the Fuji film system.

METHODS:
FUJI: For this study, low pressure Fuji film, with a sensitivity range of 2.5-10 MPa, was used. To achieve the most accurate film readings possible, the calibration techniques documented by Liggins et al. (1), which have been shown to maximize the effectiveness and accuracy of Fuji film, were used. The film was calibrated by applying and analyzing eleven known loads within the sensitivity range of the film. Each loading consisted of a one minute ramp up, one minute hold, and one minute ramp down by an Instron 8500 materials testing machine (Instron, Canton, MA) equipped with a calibrated 5.0kN load cell. Loads were transferred through a spherical joint adapter to a cylindrical Delrin peg (25 mm diameter, 50 mm high) with a rubber damping layer on the end of the peg. The Fuji film was placed between this rubber damper and a flat, smooth aluminum plate. This setup allowed for even load distributions. Each image was scanned into a PC using a Hewlett Packard ScanJet 5100C (Hewlett-Packard Co., Palo Alto, CA). Analysis of the Fuji film stains was performed using the digital imaging software Scion Image for Windows 98 Version Beta 3b (Scion Corp., Frederick, MD). Using Microsoft Excel and MATLAB®5 (The Math Works, Inc., Upper Saddle River, NJ), calibration curves were created. To test the Fuji film system for accuracy, these calibration curves were used to analyze 8 additional loads within the sensitivity range of the film. The calibrated results were then compared to their theoretical values.
TEKSCAN: Tekscan sensor #5051 with a sensitive range of 0-2500 psi was used for this study. Because Tekscan results are independent of the loading rate, applied loads were ramped up and held constant until an image was recorded at the same eleven intervals that were used for the Fuji calibration. This was done to achieve a calibration curve similar to the Fuji. The 11-point calibration curve was found using Microsoft Excel and MATLAB®. The same additional 8 loads used in the Fuji film test were tested and analyzed using this calibration curve. In addition, the Tekscan software was used to compute a 3-point power function calibration curve given recorded outputs at 1.5kN and 3.5kN and the point (0,0). From this 3-point curve, the program automatically computes the measured pressures. For the Tekscan analysis, data was recorded, saved, and analyzed. Then, the same additional 8 loads were tested and analyzed with this 3-point curve.
Statistical analyses were performed using an ANOVA to detect differences in the three methods (Fuji film, Tekscan 3-point calibration, and Tekscan 11-point calibration). Statistical significance was determined at $p \leq 0.05$ and power ≥ 0.80. Confidence intervals were reported at 95%.

RESULTS:
Significant differences were found between the 3 techniques (Fuji, Tekscan 3, and Tekscan 11) with a p-value of 0.004 and a power value of 0.909. Using the Fisher's PLSD post hoc test, a significant difference in percent pressure error was not measured between Fuji and Tekscan 3. However, this same test revealed significant differences between Fuji and Tekscan 11 as well as Tekscan 3 and Tekscan 11. Further analysis showed an average error over 11% when compared to the known applied load using the Fuji method. Tekscan 3 had an average error of over 14% and Tekscan 11 was found to have an average error of over 4%. The percent error using the Fuji film system had a range of 47.6 which was approximately 4 times the range found for both Tekscan 3 and Tekscan 11.

Figure: Average percent error for each measurement technique.



DISCUSSION:
Demonstrating the reliability and accuracy of the Tekscan *I-Scan*™ Pressure Measurement System could prove to be an important building block for the use of digital pressure sensor devices in orthopedic research. The results from this study indicate that the Tekscan system, when accurately calibrated, yields contact pressure and contact area distribution pattern data more accurately than the current standard, the Fuji film system. In addition to the increased accuracy achieved with the Tekscan system, there are a number of other significant advantages to using the Tekscan system over the Fuji film system. Some of these advantages are the increased range of loading possibilities; quicker, easier setup and calibration; less complex analysis requirements; and reusability of the device. Overall, due to the simplicity of the Tekscan system when compared to the Fuji film system, opportunity for user error is dramatically decreased. It is important to note that although the Tekscan 11 point calibration system yielded the most accurate measurements, the percent error was still not zero, it had an average of approximately 4% error. While this method is not perfect, it yields results that are approximately 2.5 times more accurate than the Fuji film method. Furthermore, there is a significant difference between the amount of variation associated with the systems, indicating the Tekscan 11 point calibration system to be the more reliable and accurate method for measuring contact pressures and contact areas for orthopedic applications.

REFERENCE:
(1) Liggins AB et al. *In* Experimental Mechanics: Technology transfer between high tech engineering and biomechanics, edited by E.G.Little. Elsevier Science Publishers, Amsterdam, 61-70, 1992.

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