LOCATING FATIGUE MICROCRACKS OCCURRING IN CEMENTED TOTAL HIP ARTHROPLASTY

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INTRODUCTION

Accumulation of fatigue microcracks (MCs) has been reported as a major cause of the loosening of cemented total hip arthroplasty (THA). Although experimental models were developed to locate MCs in the cement layer [1-2], they were often limited to certain cross-sections and loading cycles. Acoustic emission (AE) is a non-destructive technique that is capable of locating a MC when its signals are received by four or more AE sensors, but the traditional AE algorithm using an iterative approach worked poorly when applied to THA specimen that had multiple layers of materials [3]. The purposes of this work were to: 1) investigate the drawbacks of the traditional algorithm and improve it accordingly; and 2) examine the error level of calculated locations of fatigue MCs.

METHODS

A cemented THA specimen was prepared for this study using Spectron stem, Palacos R cement and Sawbone femurs. 8 AE sensors were attached on the specimen's surface to monitor the MCs. Theoretically, parameters involved in MC location calculation included: receiving time and velocity of the AE signals, and the sensors spatial coordinates. There were three layers of materials in THA specimen, AE signals reflected and/or refracted a number of times at the interfaces before being received by sensors. Inhomogeneity and anisotropy of cement and bone complicated the signal propagation as well. As a result, the velocity was frequently delayed (receiving time was linear correlated to velocity and ignored in analysis). The delay induced significant errors in MC locations when using the traditional algorithm, in which velocity was an estimated constant assigned to all signals. In the improved algorithm, velocity was set as a variable that could be adjusted based on the magnitude of the residual of the signal's receiving time. The improved algorithm was first verified using artificial MCs (pencil lead break, PLB) generated on the THA surface. Then it was used to locate fatigue MCs. The area that the most MCs cumulated was sectioned and inspected using SEM. Location error was evaluated by overlaying the calculated MCs to the observed MCs.

RESULTS AND DISCUSSION

The improved algorithm reduced location errors of artificial MCs from 7.1 mm (using the traditional algorithm) to 4.2 mm. Most calculated fatigue MCs located in the proximal THA, whereas many of them were out of THA when computed by the traditional algorithm (Fig. 1). Six short discontinuities were observed along the stem-cement interface on Section A, adjacent to most calculated MCs (Fig. 2). When comparing the locations of these two sets of MCs overlaid on the same section image, the average error in X direction was 3.3 mm and 1.7 mm in Y direction. Considering the overlay could induce an average error of 3 mm (generally less than this), the total absolute error in X-Y plane was 4.77 mm. Error in Z direction was unavailable because the information was limited to only one section.

It was found that the range of adjustment on velocity was different among sensors. Generally the range was small for sensors that were close to the MC, and large for sensors far away from the MC. The range was small in artificial MCs (high strength) and large in fatigue MCs. This indicated that the delay of velocity was influenced by material distribution, signal strength and travel path (related to signal attenuation).

CONCLUSIONS

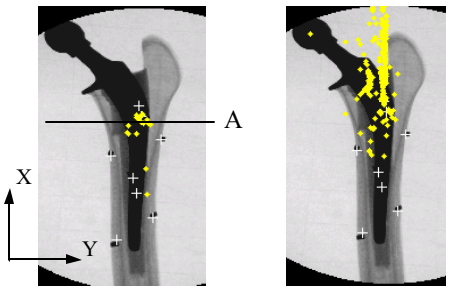
This study found that, in the traditional AE location algorithm, the major reason for inaccurate MC locations was the delay of signal velocity. The algorithm was improved by adjusting the value of velocity in computation. The new algorithm improved the accuracy of MC location significantly and achieved an average error of 4.77 mm in the X – Y plane.

REFERENCES

[1] McCormack et al., J Biomech 1999; [2] Race et al., ibid, 2003; [3] Qi et al., J Biomed Mater Res. 2004.

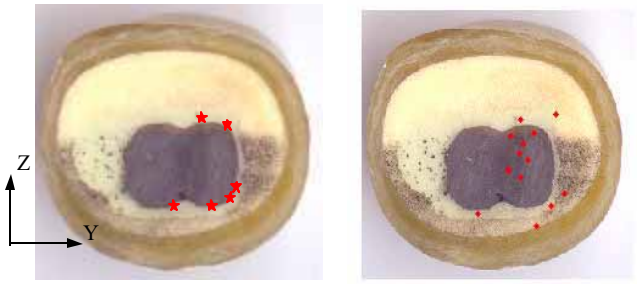
ACKNOWLEDGEMENTS

The project was supported in part by the Whitaker Foundation RG-01-0482.



(a) (b)

Fig. 1 (a) Calculated MCs using improved algorithm. The specimen was sectioned at A. (b) Calculated MCs using original algorithm.



(a) (b)

Fig. 2 (a) MCs distribution on Section A observed by SEM, (b) calculated MC locations on section A.