Development of advanced techniques

for osteoarthritis diagnosis and assessment

Thesis submitted by

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Statement of Ethics

The research presented and reported in this thesis was conducted within the guidelines for research ethics outlined in the Australian code of practice for the care and use of animals for scientific purposes (2004), and in accordance with the Queensland Animal Care and Protection Act (2001), The Australian Code for the Responsible Conduct of Research (2007), and the James Cook University Code for the Responsible Conduct of Research (2009). The proposed research methodology received clearance from the James Cook University Animal Research Ethics Committee (approval number A1470).

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Statement on the Contribution of Others

Nature of Assistance	Contribution	Names, Affiliations of Co-Contributors
Intellectual support	Project initiation, framework and management; thesis supervision	Dr Zhongxiao Peng, University of New South Wales (UNSW) & James Cook University (JCU)
	Data Analysis	Mr Jian Wang, University of Huddersfield (UoH)
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Other	Family Members	Ultimate thanks to my parents and my wife Mrs Lin Gan for their full support during my study

List of Publications

The publications in this list were written during the PhD candidature and include the project outcomes.

Peer-Reviewed Journal Publications

Z. Peng, C. Yuan, X. Yan, Z. Li, **Y. Tian**, *Wear debris analysis for Osteoarthritis assessment*, Lubrication Engineering **35** (2010) 11-14.

Y Tian, Z Peng, D Gorton, Y Xiao and N Ketheesan, *Immunohistochemical analysis of structural changes in collagen for the assessment of osteoarthritis*, Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine **225** (2011) 680-687.

Y. Tian, J. Wang, Z. Peng, X. Jiang, *Numerical analysis of cartilage surfaces for osteoarthritis diagnosis using filed and feature parameters*, Wear **271** (2011) 2370-2378.

Y. Tian, J. Wang, Z. Peng, X. Jiang, *A new approach to numerical characterisation of wear particle surfaces in three-dimensions for wear study*, Wear **282-283** (2012) 59-68.

Peer-Reviewed Conference Publication

Y. Tian, Z.Peng, X. Liu, *Development of an expert system for automatic osteoarthritis diagnosis using numerical characterisation of articular cartilage and wear particles*, The 7th Australasian Congress on Applied Mechanics (ACAM 7), Adelaide Australia, 9-12 December 2012, Submitted.

Abstract

Osteoarthritis (OA) is a common joint wear degenerative disease mainly found in older people. In 2010, the disease affected approximately 1.6 million Australians, resulting in high OA related public health costs. OA patients suffer both physically and psychologically, with worsening chronic pain and increasing disability. Early and accurate OA diagnosis and assessment are not only beneficial to improve OA patients' quality of life, but also significantly reduce public health expenditure. Currently, clinical OA diagnosis is primarily based on specialists' judgment, gathered from qualitative instrumental images analysis including radiography, magnetic resonance imaging and arthroscopy.

In recent years, numerical analysis studies have been conducted to establish a quantitative and more objective OA evaluation technique. This summarized numerical analysis data could then be used to establish software for an automatic and accurate OA diagnosis. Numerical analysis and software establishment can potentially reduce the degree of specialist involvement and may be widely applicable in regional Australia. In this thesis, three sub-projects have been carried out, which are

- Immunohistochemical (IHC) staining technique to study collagen type II matrix within articular cartilage under OA development,
- Numerical analysis using International Organization for Standardization (ISO)/ Final Draft International Standard (FDIS) 25178-2: 2010 defined field and feature parameters for articular cartilage and wear particles evaluation,
- Development of an expert system for automatic OA diagnosis.

As OA progresses, articular cartilage within the joint deteriorates and its major component-collagen type II matrix loses its integrity. To distinguish the collagen II protein from other tissue types, the IHC staining method uses specific primary antibodies against collagen type II. This method was applied in the current study, in which sheep leg joints were tested. The sheep joints were selected because the weight of sheep is close to that of human beings. After the IHC staining procedures were completed, chromagen successfully illuminated the collagen type II network when observed under a microscope. With cartilage deterioration, the superficial surface layer of the collagen network starts abrading. Gradually, fissures reach the intermediate and deep zones of cartilage in middle- and late-OA stages. In addition, the IHC fluorescent staining technique was also implemented to study the collagen II meshwork under laser scanning confocal microscopy (LSCM), which displayed the target with powerful, three-dimensional image resolution. The IHC staining project offered a new approach to revealing the collagen type II matrix alteration, by eliminating background tissue interference.

As well as articular cartilage degrading due to OA, particles containing valuable wear information are released from the cartilage. To numerically analyze both articular cartilage and wear debris surface textures alteration during OA progression, ISO/FDIS 25178-2: 2010 suggested field and feature parameters should be applied. The two parameters include a summary of conventional engineering surface parameters and feature parameters which are defined as novel pattern recognition for describing sample surfaces with functional properties. It is the first time feature parameters were applied to cartilage and particles' surface characterization. After numerical analysis, the majority of field and feature parameters showed significant changes in the target surface textures. Through statistical

and correlation analysis, ten cartilage and seven particle key surface topographic parameters were determined to representatively evaluate the articular cartilage and wear particle surface alteration during OA development. In addition, a wear debris boundary morphology study was also conducted to enrich the previous particles planar studies data group. The current study showed that the ISO/FDIS 25178-2: 2010 defined parameters are appropriate for joint OA evaluation, and a high correlation exists between cartilage and particles under wear development.

From the numerical analysis of this project and previous studies, results were summarized for building up an expert system for intelligent OA diagnosis purposes. Using the key parameters selected from field and feature parameters, a knowledge base was established integrating previous numerical studies for articular cartilage and wear particles. The software process involved inputting data and utilizing predefined data within an inference engine. Using this data, the system makes a decision on the degree of OA. The program was also equipped with user-friendly graphical interfaces (GUIs) for easy data inputs and outputs. As current clinical OA assessment methods are completely based on cartilage description, the validity of using wear debris for disease evaluation was able to be examined by the software. This software function could promote the use of wear particles for OA characterization in the future. The resultant expert system offers an objective and reliable means for OA diagnosis, which has the potential to reduce the financial cost of OA. It is hoped this procedure will be widely implemented in regional Australia.

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