A FRAMEWORK FOR DESIGNING, ANALYZING AND CLASSIFYING CEMENTLESS FEMORAL STEM FOR MALAY POPULATION

MOHD YUSOF BAHARUDDIN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Biomedical Engineering)

Faculty of Bioscience and Medical Engineering
Universiti Teknologi Malaysia

OCTOBER 2014

Thank you ALLAH SWT for your help and guidance.

This work is dedicated to my beloved parents and sister who constantly supports me throughout these years.

ACKNOWLEDGEMENTS

Firstly, I would like to thank Allah SWT for all his guidance and blessings allowing me to finish this study.

I am grateful to the Bright Sparks Unit (BSU), University of Malaya for sponsoring my studies at the Universiti Teknologi Malaysia (UTM) and constantly providing training to produce high impact journals.

I appreciate the research grants awarded to me from the Universiti Teknologi Malaysia (UTM), University Malaysia Perlis (UniMAP), Ministry of Science and Technology Malaysia (MOSTI) and Ministry of Education Malaysia (MOE).

My genuine appreciation to my supervisor (Prof Ir Dr Sheikh Hussain Shaikh Salleh), co-authors (especially Prof Dr Muhammad Hisyam Lee), technicians (Wan, Saleem, Zul, Fadli, and Redzuan), friends and colleagues at the Center for Biomedical Engineering Transportation Research Alliances, for their help and encouragement. I am indebted to my family members for their prayers, absolute love, encouragement, and fabulous support.

ABSTRACT

Asian hip morphology differs from western populations due to their lifestyle and physical stature. This was confirmed by the modification of commercial hip implants to address these differences and to improve the primary fixation stability inside the femoral canal. This study provided a framework for designing, analyzing and classifying cementless femoral stem for Malay population. The process began with a three dimensional (3D) morphology study, followed by a femoral stem design, fit and fill analysis, and nonlinear finite element analysis (FEA). Various femur parameters for periosteal and endosteal canal diameters were measured from the osteotomy level to 150 mm below, to determine the isthmus position. The 3D morphology study provided accurate dimensions that ensured primary fixation stability for the stem – bone interface and prevented stress shielding at the calcar region. The results showed better total fit (53.7%) and fill (76.7%) in the canal for this newly designed metaphyseal loading with mediolateral flared femoral stem. The FEA showed the maximum equivalent von Misses stress was 66.88 MPa proximally with a safety factor of 2.39 against endosteal fracture, and micromotion was 4.73 µm, which promotes osseointegration. The prototype was fabricated using 316L stainless steel by using investment casting techniques to reduce manufacturing cost without jeopardizing implant quality. Most researchers validated FEA with biomechanical testing but this increases computational time with different preset parameters. Any changes to these parameters will lead to different results, which are not in compliance with the experimental results. A new method for primary stability classification using support vector machine classifier and several time domain features for feature extraction (TDF – SVM) was proposed to overcome this FEA limitation. Thirteen different time domain features feed the classifier with polynomial kernel that mapped the datasets into separable hyper planes. Multiclass support vector machines considered three classes of micromotion and four classes of strain by mapping the original data into a feature space. A one-against-all method was chosen because of its easy application, reduced computational time, and accurate results. The results demonstrated more than 97% classification accuracy using several time domain features (mean absolute value, maximum peak value, mean value, root mean square) for both strain and micromotion. This indicated that TDF – SVM could be applied as preclinical tool to provide functional information for implant stability prior clinical use.

ABSTRAK

Morfologi pinggul bagi penduduk di Asia dan Barat adalah berbeza kerana perbezaan cara hidup dan bentuk fizikal. Fakta ini disokong dengan pengubahsuaian implan pinggul komersial bagi mengatasi masalah ini dan meningkatkan kestabilan penetapan utama implan di dalam femur. Kajian ini menyediakan kerangka kerja bagi rekabentuk, analisis dan pengelasan linggi femur tanpa simen bagi penduduk Melayu, bermula daripada analisis morfologi secara tiga dimensi (3D), diikuti dengan rekaan linggi femur, analisis padan dan isi, dan analisis unsur terhingga (FEA). Pelbagai parameter bagi bahagian dalam dan luar femur telah diukur dari aras osteotomi ke 150 mm ke bawah bagi menentukan kedudukan istmus. Analisis morfologi 3D memberikan dimensi yang tepat bagi memastikan kestabilan penetapan utama bagi permukaan tulang – linggi femur dan menghalang perisaian tegasan pada bahagian kalkar. Keputusan menunjukkan keputusan lebih baik bagi padanan keseluruhan (53.7%) dan pengisian (76.7%) bagi rekabentuk baru linggi femur yang mempunyai pembebanan metafisial dan suar mediolateral. FEA menunjukkan nilai maksimum tegasan setara von Misses adalah 66.88 MPa di bahagian proksimal dengan faktor keselamatan 2.39 menentang kepatahan endosteal, dan pergerakan miko sebanyak 4.73 µm yang menggalakkan pertumbuhan tulang. Prototaip telah difabrikasi menggunakan kekuli tahan karat 316L dengan mengaplikasikan teknik penuangan lilin yang mengurangkan kos pengilangan tanpa mempengaruhi kualiti implan. Kebanyakan penyelidik mengesahkan FEA dengan pengujian biomekanik yang secara umumnya mengambil masa yang lama dengan pelbagai parameter praset. Perubahan pada parameter ini akan membawa keputusan yang berbeza yang tidak selari dengan keputusan eksperimen. Kaedah baru bagi pengelasan penetapan utama menggunakan mesin sokong vektor sebagai pengelas dan beberapa sifat domain masa bagi mengekstrak sifat (TDF – SVM) telah dicadangkan bagi mengatasi kekangan FEA ini. Tiga belas sifat domain masa berbeza menyuap pengelas dan kernel polinomial yang memetakan set data kepada hiper satah berlainan. Pelbagai kelas mesin sokong vektor telah digunakan untuk mengkategorikan tiga kelas pergerakan mikro dan empat kelas terikan dengan memetakan data sebenar kepada ruang sifat. Kaedah satu-lawan-semua telah digunakan kerana teknik ini mudah digunakan, tempoh masa pengiraan yang cepat dan menghasilkan keputusan yang tepat. Keputusan menunjukkan lebih daripada 97% ketepatan pengecaman corak menggunakan beberapa sifat domain masa (nilai mutlak min, nilai maksimum puncak, nilai min, punca min kuasa dua) bagi kedua-dua terikan dan pergerakan mikro. Ini menunjukkan TDF – SVM boleh digunakan dalam menentukan kestabilan penetapan linggi femur dengan memberikan maklumat berkenaan kestabilan implan sebelum digunakan secara klinikal.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

N	-	Newton
Pa	-	Pascal
μm	-	micrometre
kV	-	kilovolts
mAs	-	milli Ampere seconds
ε	-	Strain
σ	-	Stress
E	-	Young's Modulus
ν	-	Poisson's ratio
ρ	-	Density
Ω	-	Ohm
ξ	-	Distance of misclassified point from hyper plane

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

The development of hip arthroplasty began in 1962 and was initiated by Sir John Charnley which showed tremendous results in orthopaedic surgery. Hip joint arthroplasty has increase in popularity as a way to restore the function of the hip joint damage by degenerative diseases such as osteoarthritis and rheumatoid arthritis (Ethgen et al., 2004, Learmonth et al., 2007). Osteoarthritis is normally related to the deterioration of cartilage, while rheumatoid arthritis is associated with autoimmune responses. In 2006 alone, Europe reported 650 000 hip replacement cases and revision surgeries, followed by the United States with 420 000 cases, and 70 000 cases in Japan and South Korea (Kiefer, 2007). The high prevalence of hip arthroplasty encouraged implant manufacturers to produce better designs that optimized fixation stability based on advice from orthopedic surgeons.

However, there is no universal design for hip implants that will fit all femoral types (Noble et al., 1988, Husmann et al., 1997, Laine et al., 2000). Noble et al. (1988) classified the endosteal canal into three different shapes according to the canal flare index (CFI). These categories are stovepipe shape (CFI < 3.0), normal shape ($3.0 < \text{CFI} < 4.7$) and champagne flute shape (CFI > 4.7) (Noble et al., 1988). Even if universal stems were suitable for a variety of sizes, the possibility of an implant being over or under sized are high. Oversized implants risk more bone stock due to over reaming during surgery. In the worst cases, it can lead to bone fractures. On the other hand, undersized implants cause micromotion, fibrous tissue formation, loosening, and thigh pain. The common problems that lead to the hip arthroplasty failure are dislocation, stress shielding, and aseptic loosening (Karrholm, 2010). These problems can be solved by well-designed hip implants that fit optimally inside the femoral canal (Cristofolinia et al., 2003).

Several studies have shown the differences in femoral morphology between Asian and Western populations (Mahaisavariya et al., 2002, Hoaglund and Low, 1980, Mishra et al., 2009). Typically, Asians have a small stature (Siwach and Dahiya, 2003), and peculiar endosteal canal characteristics, especially in metaphyseal region (Ando et al., 1999, Kawahara et al., 2010) that contribute to the biological fixation of the hip implant. Ignoring this fact jeopardizes stability and shortens the lifespan of the implant. Mismatched prosthesis were reported due to these morphological differences (Leung et al., 1996, Mishra et al., 2009).

Currently, implant manufacturers try to produce hip implants with smaller femoral head offsets and stem lengths (Sivananthan et al., 2003, Fang et al., 2010, Kaya et al., 2008, Ohsawa et al., 1998, Cheh et al., 2009, Chiu et al., 2011). Although the implant had excellent medium and long term results (Sivananthan et al., 2003, Cheh et al., 2009, Chiu et al., 2011), a few cemented hip stem failures were reported in young and active patients (Joshi et al., 1993, Chandler et al., 1981). This phenomenon lead to the development of cementless hip stems for Asian populations that were better designed for their peculiar femoral morphology (Fang et al., 2010, Kaya et al., 2008, Ohsawa et al., 1998).

Several studies have been performed regarding cementless femoral stems using finite element analysis (FEA) and experimental methods (Dopico-Gonzalez et al., 2010, Pettersen et al., 2009a, Pettersen et al., 2009b). Dopico – Gonzalez et al. (2010) presented a robust tool for probabilistic FEA for cementless stems that focused on femur characteristics and the implant design geometry between the Proxima short stem and IPS stem which showed good agreement with the in-vitro study (Dopico-Gonzalez et al., 2010). In addition, Pettersen et al. (2009a) and Pettersen et al. (2009b) supported the excellent correlation between an actual human cadaver and FEA while investigating the feasibility of subjects specific to stress shielding and micromotion using a cementless Summit stem (Pettersen et al., 2009a, Pettersen et al., 2009b). Ando et al. (1999) also performed FEA to compare their stems for Japanese dysplastic hip (FMS and FMS-anatomic) with other commercial stems such as Omnifit, Omniflex, and IDS (Ando et al., 1999). They focused on contact stress, relative motion, and load transfer prior to clinical use. Their results showed that the load was transferred mostly in the proximal region with low micromotion value, which explained the excellent success rate of this implant (Kawahara et al., 2010, Kokubo et al., 2013). Furthermore, Rawal et al. (2012a) manufactured an Indian femoral stem using a 3 axis CNC machine after finding that the equivalent von Misses stress result from FEA was below 160 MPa and prevented endosteal fractures (Rawal et al., 2012a). In this study, a similar method was used as a nonlinear three dimensional FEA in the design process of a cementless stem for Malays. Finite element analysis has become a useful tool for researchers for predicting early and medium term results (O'Toole et al., 1995).

Although FEA can predict the results for implants, there are several limitations that influence this in-silico method, such as boundary and loading conditions, material properties, contact bodies, and mesh convergence. Any changes to these parameters will lead to different results, which are not in compliance with the experimental results. Pattern recognition of the primary stability of the cementless femoral stem is a new field of study and it could determine the stable phase during biomechanical testing. In this study, digital signal processing (DSP) was applied to the strain and micromotion signals for feature extraction and pattern recognition of primary stability when the active features were clearly differentiated. This DSP method was not only easily applied, but it also saved computation time, and achieved reasonable results. In addition, the results of the DSP were in compliance with FEA. This suggests that DSP could be used for determining primary stability and could become an efficient preclinical tool for newly designed implants.

1.2 Research Scope

This study covered the development of cementless femoral stems for the Malay population. Data was acquired from 60 healthy subjects after receiving approval from the hospital committee and the National Medical Research Register (NMRR). A femur was then reconstructed into three dimensional (3D) models from raw computed tomography (CT) datasets using commercial medical imaging software. The dimensions were carefully measured according to the standard measurements for periosteal and endosteal canal diameters using computer aided design (CAD) software. These anatomical features were then used for designing the cementless femoral stem for the Malay population. Computational simulation was performed through finite element analysis (FEA) to study stress distribution, displacement, and micromotion of the cementless femoral stem inside the medullary canal. The prototype was fabricated using 316L stainless steel and an investment casting technique. FEA was experimentally validated using composite femoral. Micromotion was measured using a linear variable direct transducer (LVDT) proximally and distally, while the strain was measured using four tri axial rosette medially and laterally. The data was then processed using thirteen time domain features for feature extraction and a support vector machine classifier with a polynomial kernel. This new method discovered each strain and micromotion signal that could be used as a preclinical tool before clinical trials. The information benefit researchers by determining the stable phase of the femoral stem, thus preventing loosening and stress shielding from occurring post-surgery. Conventional method validated FEA and experimental testing consumed a great deal of time as it dealt with a variety of preset parameters that could create different results, whereby the proposed TDF – SVM classification demonstrated better pattern recognition accuracy for the implant's primary stability during biomechanical testing.

1.3 Objective of the Study

The goal of this study was to develop a cementless femoral stem for the Malay population tailored with the morphology study, which was subsequently analyzed using computational simulation and was experimentally validated using the composite femora. The objectives of this study were as follows:

a) To model the three dimensional femoral morphology and analyze using finite element method for femoral stem design of Malays.

b) To develop a systematic framework for the development of a cementless femoral stem for the Malay population.

c) To extract features and classify the primary stability of the newly designed femoral stem using a proposed method time domain features – support vector machine (TDF – SVM) that could be used as a preclinical tool for biomechanical testing.

1.4 Importance of Research

A rapidly aging population leads to a higher prevalence of the hip fractures, bone diseases, and other musculoskeletal disorders, which required more hip arthroplasty. The Malaysia Informative Data Center (MysIDC) reported that the Malay population in Malaysia, 50 years of age or older, increased from 1.37 million in 2000, to 2.21 million in 2010. This phenomenon also occurred in Western countries where the growing aging population is increasing the demand for hip replacement for primary osteoarthritis (Kiefer, 2007).

The orthopaedic community in Malaysia has mutually agreed that the bone morphology of Malay skeletal systems is different from those found in American and European countries. Hip prostheses are mostly designed and manufactured by

European and American implant manufacturers. The size as well as other parameters, such as the collo diaphyseal angle (CDA), femoral head offset, femoral head position, and endosteal canal diameters particularly for the isthmus canal, were developed according to their respective morphology.

The physical size and stature of Asians are smaller than Western populations. Asian femora morphology also differs from the Western morphology in the metaphyseal region where proximal fixation is essential for the primary and secondary stability of the implant. This was further confirmed by new implant designs developed by global implant manufacturers to cater to the Asian market (Kaya et al., 2008, Ohsawa et al., 1998). An optimized hip implant ensures the stability of the implant inside the femoral. Kaya et al. (2008) reported that a modification to the Anatomic Medullary Locking (AML) stem (Depuy, Warsaw, IN, USA) at the metaphyseal (called medial modified aspects (MMA) was due to the narrower and shorter hips of Japanese patients (Kaya et al., 2008).

The universal hip stem with its number of sizes is not applicable for all types of femur and it might cause the varus or valgus position of the femoral stem inside the medullary canal. A few cases of implant mismatch were reported to be caused by the peculiar morphology of the Asian population (Reddy et al., 1999, Koval, 2007, Gadegone and Salphale, 2007). A mismatched implant could complicate surgeries while implanting the stem inside the femoral canal, and hamper the function of the implant, which could affect post-surgery outcomes. Several studies have developed new implants to cater to the unique hip morphology of different populations (Fang et al., 2010, Ando et al., 1999, Kawahara et al., 2010, Kokubo et al., 2013, Rawal et al., 2012a). Kokubo et al. (2013) reported a 100 % success rate in anatomic fit after 7.1 years for an implant that was specially designed for Japanese dysplastic hip patients (Kokubo et al., 2013). This implant optimized fixation stability between the bone – stem interface, promoted osseointegration, and prolonged the lifespan of the implant. Furthermore, the implant also prevented unnecessary removal of bone stock for future revision surgery (Mishra et al., 2009).

1.5 Organization of the Thesis

This thesis consists of six chapters. The introduction in Chapter 1 explained the background study, research scope, objectives, and importance of this research. Chapter 2 provided a brief review of the literature that could help readers comprehend this study, the anatomical structure of the femur, cementless femoral stems, and the analysis methods used.

Chapter 3 describes the methodology implemented in the development of the cementless femoral stem for the Malay population. The computed tomography images were acquired prior to designing the cementless femoral stem in accordance with the morphology for an Asian population. The fabrication process used an investment casting technique before sand blasting with a silicon carbide mesh for surface roughness. For validation purposes, strain was measured with four tri-axial rosettes at the metaphyseal region, and micromotion was measured using linear variable direct transducers proximally and distally on the composite femora.

In Chapter 4, the results from the analysis completed in Chapter 3 are discussed. The morphology study showed that Asian femurs are smaller than Western femurs, except in the metaphyseal region. The newly designed femoral stem had a better total fit (53.7%) and fill (76.7%) canal, with more load distributed proximally to prevent stress shielding in the calcar region. The stem demonstrated lower displacement and micromotion (less than 40 μm) promoting osseointegration between at the stem–bone interface and provided primary fixation stability.

Chapter 5 proposes a new method for the application of various time domain feature extractions and support vector machine classifiers (TDF – SVM) to classify different states of an implant's primary stability using interface micromotion and strain signals. The conventional method used experimental validation with finite element analysis (FEA) to evaluate the fixation stability of the implant, which generally took more computational time and involved different preset parameters. Finally, the conclusion of this study and a discussion of future work to improve the methodical and quality of the femoral stem are discussed in Chapter 6.

REFERENCES

Abbaszadeh, F., Farahmand, F., Rahmati, S. and Fatollahzadeh, R. (2009) Novel methodology in design of custom-made hip prosthesis. *Innovative Developments in Design and Manufacturing.* In da Silva, C. S. G. (Eds.) (pp. 117-126). London: CRC Press.

Abdul-Kadir, M. R. (2005) *Interface Micromotion in Cementless Hip Prostheses.* Doctor Philosophy, Imperial College, London.

Abdul-Kadir, M. R., Hansen, U., Klabunde, R., Lucas, D. and Amis, A. (2008) Finite element modelling of primary hip stem stability: The effect of interference fit. *Journal of Biomechanics,* 41(3)**,** 587-594.

Abdul-Kadir, M. R. and Kamsah, N. (2009) Interface micromotion of cementless hip stems in simulated hip arthroplasty. *American Journal of Applied Sciences,* 6(9)**,** 1682-1689.

Ablett, E. (2011) *Skeletal System*. San Francisco: Tangient LLC.

Adam, F., Hammer, D. S., Pape, D. and Kohn, D. (2002) Femoral anatomy, computed tomography and computer-aided design of prosthetic implants. *Archive Orthopedic Trauma Surgery,* 122, 262-268.

Alpaydin, E. (2004) *Introduction to machine learning.* Massachussets: MIT Press.

Anda, S., Svenningson, S., Dale, L.G. and Benum, P. (1986) The acetabular sector angle of the adult hip determined by computed tomography. *Acta Radiology Diagnostic,* 27, 443-7.

Anda, S., Terjesen, T. and Kvistad, K. A. (1991) Computed tomography measurements of acetabulum in adult dysplastic hips: which level is appropriate? *Skeletal Radiology,* 20, 267-71.

Anderson, A. E., Ellis, B. J., Maas, S. A., Peters, C. L. and Weiss, J.A. (2008) Validation of finite element predictions of cartilage contact pressure in the human hip joint. *Journal of Biomechanics Engineering,* 130(5)**,** 171-184.

Ando, M., Imura, S., Omori, H., Okumura, Y., Bo, A. and Baba, H. (1999) Nonlinear three-dimensional finite element analysis of newly designed cementless total hip stems. *Artificial Organs,* 23(4)**,** 339-346.

Antapur, P. and Prakash, D. (2006) Proximal femoral geometry: a radiological assessment. *Journal of Arthroplasty,* 21(6)**,** 897-898.

Atilla, B., Oznur, A., Caglar, O., Tokgozoglu, M. and Alpaslan, M. (2007) Osteometry of the femora in Turkish individuals: a morphometric study in 114 cadaveric femora as an anatomic basis of femoral component design. *Acta Orthopedic Traumatology Turkey,* 41(64-68.

Balakrishnama, S. and Ganapathiraju, A. (1998) *Linear discriminant analysis-a brief tutorial.* Institute for Signal and Information Processing.

Bargar, W. L. (1989) Shape the implant to the patient. A rationale for the use of custom-fit cementless total hip implants. *Clinical Orthopedic Related Research,* 249**,** 73-78.

Bayraktar, H. H., Morgan, E. F., Niebur, G. L., Morris, G. E., Wong, E. K. and Keaveny, T. M. (2004) Comparison of the elastic and yield properties of human femoral trabecular and cortical bone tissue. *Journal of Biomechanics,* 37, 27-35.

Bergmann, G. 2001. HIP98 - Loading of the hip joint. Berlin: Free University Berlin.

Bieger, R., Ignatius, A., Decking, R., Claes, L., Reichel, H. and Dürselen, L. (2012) Primary stability and strain distribution of cementless hip stems as a function of implant design. *Clinical Biomechanics,* 27(2)**,** 158-164.

Bo, A., Imura, S., Okumura, Y., Omori, H., Ando, M. and Baba, H. (1995) *The femoral component for secondary osteoarthritis of the hip joints in Japan.* Berlin: Springer.

Bo, A., Imura, S., Omori, H., Okumura, Y., Ando, M., Baba, H., White, P. and Zarnowski, A. (1997) Fit and fill analysis of a newly designed femoral stem in cementless total hip arthroplasty for patients with secondary osteoarthritis. *Journal of Orthopedic Science* 2, 301-312.

Bourne, R. B. and Rorabeck, C. H. (2002) Soft tissue balancing: the hip. *Journal of Arthroplasty,* 17, 17-22.

Bourne, R. B., Rorabeck, C. H., Burkart, B. C. and Kirk, P.G. (1994) Ingrowth surfaces. Plasma spray coating to titanium alloy hip replacements. *Clinical Orthopedic Related Research,* 298, 37-46.

Bourne, R. B., Rorabeck, C. H., Patterson, J. J. and Guerin, J. (2001) Tapered titanium cementless total hip replacements: a 10 to 13 year followup study. *Clinical Orthopedic Related Research,* 393, 112-120.

Bow, S. T. (2002) *Pattern recognition and image preprocessing.* New York: Marcel Dekker.

Bu, N., Okamoto, M. and Tsuji, T. (2009) A hybrid motion classification approach for emg-based human-robot interfaces using bayesian and neural networks. *IEEE Transactions on Robotics,* 25(3)**,** 502-511.

Bugbee, W. D., Culpepper, W. J., Engh, C. A. Jr. and Engh, C. A. Sr. (1997) Long-term clinical consequences of stress-shielding after total hip arthroplasty without cement. *Journal of Bone Joint Surgery America,* 79(7)**,** 1007-1012.

Carter, D. and Hayes W. C. (1977) The behavior of bone as a two- phase porous structure. *Journal of Bone Joint Surgery,* 59A(7)**,** 954-962.

Carter, L. W., Stovall, D. O. and Young, T. R. (1995) Determination of accuracy of preoperative templating of noncemented femoral prostheses. *Journal of Arthroplasty,* 10, 507-513.

Chandler, H. P., Reineck, F. T., Wixson, R. L. and Mccarthy, J. C. (1981) Total hip replacement in patients younger than thirty years old. A five-year follow-up study. *Journal of Bone Joint Surgery America,* 63A, 1426-1434.

Chantarapanich, N., Sitthiseripratip, K., Mahaisavariya, B., Wongcumchang, M. and Siribodhi, P. (2008) 3D geometrical assessment of femoral curvature: a reverse engineering technique. *Journal of Medical Associated Thai,* 91, 1377-1381.

Charnley, J. (1970) Total hip replacement by low friction arthroplasty. *Clinical Orthopedic Related Research,* 72, 7-21.

Chauhan, R., Paul, S. and Dhaon, B. K. (2002) Anatomical parameters of the North Indian hip joints: Cadaveric study. *Journal of Anatomy Society India,* 51, 39-42.

Cheh, C. T., Hui, Y. N., Azlina, A. A., Azhar, M. M., Siew, K. C. (2009) First series of Exeter small stem primary total hip arthroplasty 5 years follow up. *Journal of Arthroplasty,* 24(8)**,** 1200-1204.

Chiu, C. K., Chan, C. Y. and Singh, V. A. (2009) Is the femoral neck geometry adequate for placement of the proximal femoral nail in the Malaysian population? A review of 100 cases. *Medical Journal Malaysia,* 64(1)**,** 22-6.

Chiu, K. H., Cheung, K. W., Chung, K. Y. and Shen, W. Y. (2011) Exeter small femoral stem for patients with small femurs. *Journal of Orthopedic Surgery,* 19(3)**,** 279-283.

Chiu, K. Y. and Fang, D. (1997) Endosteal shape of the proximal femur in Chinese. *Journal of Orthopedic Surgery,* 5, 21-24.

Chiu, K. Y., Ng, T. P., Tang, W. M., Cheng, H. C., Tung, T. S. L., Tse, P. Y. T. and Ko, P. S. (2003) The shape and size of femoral components in revision total hip arthroplasty among Chinese patients. *Journal of Orthopedic Surgery (Hong Kong),* 11, 53-58.

Choi, K. and Cichocki,A. (2008) Control of a wheelchair by motor imagery in real time. *Intelligent Data Engineering and Automated Learning-IDEAL 2008.* Springer.

Corten, K., Bourne, R. B., Charron, K. D., Au, K. and Rorabeck, C. H. (2011) What work best, a cemented or cementless primary total hip arthroplasty? Minimum 17-year followup of a randomized controlled trial. *Clinical Research,* 469, 209-217.

Cristofolini, L., Viceconti, M., Cappello, A. and Toni, A. (1996) Mechanical validation of whole bone composite femur models. *Journal of Biomechanics,* 29, 525-535.

Cristofolinia, L., Teutonicoa, A. S., Montia, L., Cappello, A. and Aldo, T. (2003) Comparative in vitro study on the long term performance of cemented hip stems: validation of a protocol to discriminate between ‘‘good’’ and ‘‘bad’’ designs. *Journal of Biomechanics* 36(11)**,** 1603-1615.

Da Silva, V., Oda, Jy. and Santana D.M.G. (2003) Anatomical aspects of the proximal femur for adult Brazilians. *International Journal of Morphology,* 21(4)**,** 303-308.

De Sousa, E., Fernandes, R. M. P., Mathias, M. B., Rodrigues, M.R., Ambram, A. J. and Babinski, M. A. (2010) Morphometric study of the proximal femur extremity in Brazilians. *International Journal of Morphology,* 28(3)**,** 835-840.

Dobbin, K. K. and Simon, R.M. (2011) Optimally splitting cases for training and testing high dimensional classifiers. *BMC Medical Genomics,* 4(31)**,** 1-8.

Dopico-Gonzalez, C., New A. M. and Browne, M. (2010) Probabilistic finite element analysis of the uncemented hip replacement - effect of femur characteristics and implant design geometry. *Journal of Biomechanics,* 43, 512-520.

Dorr, L. D. (1986) Total hip replacement using APR system. *Tech Orthopedic,* 3, 22-34.

Dorr, L. D., Absatz, M., Gruen, T. A., Saberi, M. T.and Doerzbacher, J. F. (1990) Anatomic Porous Replacement hip arthroplasty: first 100 consecutive cases. *Semin Arthroplasty,* 1(1)**,** 77-86.

Duda, G. N., Schneider, E. and Chao, E. Y. S. (1997) Internal forces and moments in the femur during walking. *Journal of Biomechanics,* 30, 933-941.

Elhadi, S., Alexandre, M., Gilles, P. and Ernesto, D. (2009) Three-dimensional hip anatomy in osteoarthritis analysis of the femoral offset. *Journal of Arthroplasty,* 24(6)**,** 990-997.

Engh, C. A. and Bobyn, J.D. (1988) The influence of stem size and extent of porous coating on femoral bone resorption after primary cementless hip arthroplasty. *Clinical Orthopaedics,* 231, 7-28.

Engh, C. A., Bobyn, J. D. and Glassman, A. H. (1987) Porous-coated hip replacement: the factors governing bone ingrowth, stress shielding, and clinical results. *Journal of Bone Joint Surgery British,* 69(1)**,** 45-55.

Engh, C. A., Hooten, J. P., Zettl-Schaffer, K. F., Ghaffarpour, M., Mcgovern, T. F. and Bobyn, J. D. (1995) Evaluation of bone ingrowth in proximally and extensively porous-coated anatomic medullary locking prostheses retrieved at autopsy. *Journal of Bone Joint Surgery America,* 77, 903-910.

Engh, C. A. and Massin, P. (1989) Cementless total hip arthroplasty using the anatomic medullary locking stem. *Clinical Orthopedic,* 249, 141-158.

Engh, C. A., O'connor, D., Jasty, M., Mcgovern, T. F., Bobyn, J. D and Harris, W. H. (1992) Quantification of implant micromotion, strain shielding, and bone-resorption with porous-coated anatomic medullary locking femoral prostheses. *Clinical Orthopaedics and Related Research,* 285, 13-29.

Eppright, R. H. (1975) Dial aosteotomy of the acetabulum in the treatment of dysplasia of the hip. *Journal of Bone Joint Surgery America,* 57, 1172.

Ethgen, O., Bruyere, O., Richy, F., Dardennes, C. and Reginster, J. Y. (2004) Health-related quality of life in total hip and total knee arthroplasty. A qualitative and systematic review of the literature. *Journal of Bone Joint Surgery America,* 86-A(5)**,** 963-974.

Fackler, C. D. and Poss, R. (1980) Dislocation in total hip arthroplasty. *Clinical Orthopedic,* 151, 169-178.

Fang, C., Chiu, K. Y., Tang, W. M. and Fang, D. (2010) Cementless total hip arthroplasty specifically designed for Asians: clinical and radiologic results at a mean of 10 years. *Journal of Arthroplasty,* 25(6)**,** 873-879.

Faulkner, K. G., Cumming, S.R., Black, D., Palermo, L., Gluer, C.C.,and Genant, H. K. (1993) Simple measurement of femoral geometry predicts hip fracture: the study of osteoporotic fractures. *Journal Bone Mineral Research,* 8, 1211-1217.

Fessy, M. H., Seutin, B. and Bdjui, J. (1997) Anatomical basis for the choice of the femoral implant in the total hip arthroplasty. *Surgical Radiology Anatomy,* 19, 283-286.

Firoozabadi, S. M. P., Oskoei, M.A. and Hu, H. (2008) A human-computer interface based on forehead multi-channel bio-signals to control a virtual wheelchair. 14th Iranian Conference on Biomedical Engineering (ICBME), Iran: Citeseer, 272-277.

Fredenborg, N. (1976) The CE angle of normal hips. *Acta Orthop Scand,* 47, 403-405.

Fukunaga, K. (1990) *Introduction to statistical pattern recognition.* Academic Press Professional.

Gadegone, W. M. and Salphale, Y. S. (2007) Proximal femoral nail - an analysis of 100 cases of proximal femoral fractures with an average follow up of 1 year. *International Orthopedic,* 31(3)**,** 403-408.

Ganz, R., Klaue, K., Vinh, T. H. and Mast, J. W. (1988) A new periacetabular osteotomy for the treatment of hip dysplasias: Technique and preliminary results. *Orthopedic Related Research,* 232, 26-32.

Genda, E., N. Iwasaki, G. Li, B.A. Macwilliams, P.J. Barrance and Chao, E. Y. S. (2001) Normal hip joint contact pressure distribution in single-leg standing - effect of gender and anatomic parameters. *Journal of Biomechanics,* 34, 895-905.

Glassman, A. H., Bobyn, J. D., Tanzer, M. (2006) New femoral designs: do they influence stress shielding? *Clinical Orthopedic Related Research,* 453, 64-74.

Götze, C., Steens, W., Vieth, V., Poremba, C., Claes, L. and Steinbeck, J. (2002) Primary stability in cementless femoral stems: custom-made versus conventional femoral prosthesis. *Clinical Biomechanics,* 17(4)**,** 267-273.

Gueiral, N. and Nogueira, E. (2012) *Acoustic Emission Studies in Hip Arthroplasty - Peak Stress Impact In Vitro Cemented Prosthesis.* Rijeka: InTech.

Gurmanik, K., Arora, A. S. and Jain, V. K. (2010) EMG diagnosis via AR modeling and binary support vector machine classification. *International Journal of Engineering Science and Technology,* 2.

Hamedi, M., Salleh, S. H., Astaraki, M. and Noor A.M. (2013) EMG-based facial gesture recognition through versatile elliptic basis function neural network. *BioMedical Engineering OnLine* 12, 73-94.

Hamedi, M., Salleh, S.H., Tan, T.S. and Kamarulafizam (2011) Surface electromyography-based facial expression recognition in bi-polar configuration. *Journal of Computer Science,* 7(9)**,** 1407-1415.

Han, C. D., Yoo, J. H., Lee, W. S. and Choe, W. S. (1998) Radiographic parameters of acetabulum for dysplasia in Korea adults. *Yonsei Medical Journal,* 39, 405-408.

Harada, Y., Mitsuhashi, S., Suzuki, C., Yamashita, K., Watanabe, H., Akita, T. and Moriya, H. (2007) Anatomically designed prosthesis without cement for the treatment of osteoarthritis due to developmental dysplasia of the hip: 6- to 13-year follow-up study. *Journal of Orthopedic Science,* 12, 127-133.

Harma, A., Germen, B., Karakas, H. M., Elmali, N. and Inan, M. (2005) The comparison of femoral curves and curves of contemporary intramedullary nails. *Surgical Radiology Anatomy,* 27, 502-506.

Harma, A. and Karakas, H. M. (2007) Determination of sex from femur in Anatolian Caucasians: a digital radiological study. *Journal of Forensic Leg Medical,* 14, 190-194.

Harris, W. H. (1986) Etiology of osteoarthritis of the hip. *Clinical Orthopedic Related Research,* 213, 20-33.

Heinert, G. and Parker, M. J. (2007) Intramedullary osteosynthesis of complex proximal femoral fractures with the Targon PF nail. *Injury,* 38(11)**,** 1294-1299.

Heller, M. O., Bergmann, G., Kassi, J.P., Claes, L., Haas, N.P. and Duda, G.N. (2005) Determination of muscle loading at the hip joint for use in pre-clinical testing *Journal of Biomechanics,* 38, 1155-1163.

Hendrikus, J. A., Armand, C., Laumen, C. V. and Mourik, J. A. (2008) New digital preoperative planning method for total hip arthroplasties. *Journal of Clinical Orthopedic,* 467, 909-916.

Henninger, H. B., Reese, S. P., Anderson, A. E. and Weiss, J. A. (2010) Validation of computational models in biomechanics. *Proceedings of Institute Mechanical Engineering: Part H,* 224(7)**,** 801-812.

Hoaglund, F. T. and Low, W. D. (1980) Anatomy of the femoral neck and head, with comparative data from Caucasians and Hong Kong Chinese. *Clinical Orthopedic Related Research,* 152, 10-16.

Holzwarth, U. and Cotogno, G. (2012) *JRC scientific and policy reports: Total hip arthroplasty. State of the art, challenges and propects*. Ispra, Italy: Joint Research Centre of the European Commission.

Hozack, W. J., Parvizi, J. and Bender, B. (2010) *Surgical treatment of hip arthritis: reconstruction, replacement and revision.* Philidelphia: Saunders Elsevier.

Hsu, C. W. and Lin, C. J. (2002) A comparison of methods for multiclass support vector machines. *IEEE Transactions Neural Networks,* 13(2)**,** 415-425.

Huiskes, R. (1990) *Preclinical testing of noncemented total hip arthroplasty.* Stuttgart: Georg Thieme Verlag.

Husmann, O., Rubin, P. J., Leyvraz, P. F., De Roguin, B. and Argenson, J. N. (1997) Three-dimensional morphology of the proximal femur. *Journal of Arthroplasty,* 12(4)**,** 444-50.

Igbigbi, P. S. (2003) Collo-diaphysial angle of the femur in East African subjects. *Clinical Anatomy,* 16(5)**,** 416-419.

Iguchi, H., Hua, J. and Walker, P. S. (1996) Accuracy of using radiographs for custom hip stem design. *Journal of Arthroplasty,* 11(3)**,** 312-321.

Imura, S., Omori, H., Bo, A., Ando, M. and Baba, H. (1999) *Development and preclinical tests of FMS and FMS-Anatomic cementless total hip stems.* Tokyo: Springer.

Ito, H., Matsuno, T., Hirayama, T., Tanino, H., Yamanaka, Y. and Minami, A. (2009) Three-dimensional computed tomography analysis of non-osteoarthritic adult acetabular dysplasia. *Skeletal Radiology,* 38, 131-139.

Jajodia, N. K., Jain, S. K., Victor, T. J. W. and Shamal, D. D. (2010) Medium-term outcome of total hip replacement for dysplastic hips in Singapore. *Journal of Orthopaedic Surgery* 18(3)**,** 296-302.

Jasty, M., Bragdon, C., Burke, D., O'Connor, D., Lowenstein, J. and Harris, W. H. (1997) In vivo skeletal responses to porous-surfaced implants subjected to small induced motions. *Journal of Bone Joint Surgical America,* 79, 707-714.

Jiang, L. S., Shen, L. and Dai, L. Y. (2007) Intramedullary fixation of subtrochanteric fractures with long proximal femoral nail or long gamma nail: technical notes and preliminary results. *Annal Academic Medical Singapore,* 36(4)**,** 324-327.

Joshi, A. B., Porter, M. L., Trail, I. A., Hunt, L. P., Murphy, J. C. and Hardinger, K. (1993) Long-term results of Charnley low-friction arthroplasty in young patients. *Journal of Bone Joint Surgical British,* 75, 616-623.

Jun, Y. and Choi, K. (2010) Design of patient-specific hip implants based on the 3D geometry of the human femur. *Advances in Engineering Software,* 41(4)**,** 537-547.

Kaptoge, S., Dalzell, N., Loveridge, N., Beck, T. J., Khaw, K. T. and Reeve, J. (2003) Effects of gender, anthropometric variables, and aging on the evolution of hip strength in men and women aged over 65. *Bone,* 32, 561-570.

Karakas, H. M. and Harma, A. (2008) Femoral shaft bowing with age: a digital radiological study of Anatolian Caucasian adults. *Diagnostic Intervention Radiology,* 14, 29-32.

Karrholm, J. (2010) The Swedish hip arthroplasty register. *Acta Orthopedic,* 81(1)**,** 3-4.

Kassi, J. P., Heller, M. O., Stoeckle, U., Perka, C. and Duda, G. N. (2006) Response to: "Stair climbing is more critical than walking in pre-clinical assessment of primary stability in cementless THA in vitro". *Journal of Biomechanics,* 39(16)**,** 3087-3090.

Kawahara, H., Kokubo, Y.,Yayama, T., Uchida, K., Kobayashi, S., Nakajima, H., Oki, H., Negoro, K., Mwaka, E. S., Orwotho, N. T. and Baba, H. (2010) Metaphyseal loading anterolaterally flared femoral stem in cementless total hip arthroplasty: five to eleven year follow up evaluation. *Artificial Organs,* 34(5)**,** 377-383.

Kawamura, H., Dunbar, M. J., Murray, P., Bourne, R. B. and Rorabeck, C. H. (2001) The Porous Coated Anatomic total hip replacement. *Journal of Bone Joint Surgical America,* 83(9)**,** 1333-1339.

Kawate, K., Ohneda, Y., Ohmura, T., Yajima, H., Sugimoto, K. and Takakura, Y. (2009) Computed tomography based custom made stem for dysplastic hips in Japanese patients. *Journal of Arthroplasty,* 24(1)**,** 65-70.

Kaya, M., Nagoya, S., Sasaki, M., Kukita, Y. and Yamashita, T. (2008) Primary total hip arthroplasty with Asian-type AML total hip prosthesis: follow-up for more than 10 years. *Journal of Orthopaedic Science,* 13(4)**,** 324-327.

Keaveny, T. and Bartel D. (1993) Efects of porous coating, with and without collar support, on early relative motion for a cementless hip prosthesis. *Journal of Biomechanics,* 26(12)**,** 1355-1368.

Kenny, T. M., Christopher A. V., Kevin, C., Yury, S., Louis, R. and Clifford, W. C. (2010) Cementless femoral fixation in total hip arthroplasty. *America Journal of Orthopedic,* 39(3)**,** 126-130.

Khanuja, H. S., Vakil, J. J., Goddard, M. S. and Mont, M. A. (2011) Cementless femoral fixation in total hip arthroplasty. *Journal of Bone Joint Surgical America,* 93(500-509.

Kiefer, H. (2007) Differences and opportunities of THA in the USA, Asia and Europe. In Chang, J. D. (Eds.) *Bioceramics and Alternative Bearings in Joint Arthroplasty* (pp. 3-8). Darmstadt, Germany: Steinkopff-Verlag.

Kil, D. H. and Shin, F.B. (1996) *Pattern recognition and prediction with applications to signal characterization*. New York: America Institute of Physics.

Kim, S. S., Frick, S. L. and Wenger, D. R. (1999) Anteversion of the acetabulum in the development of dysplasia of hip: Analysis with computed tomography. *Journal of Pediatric Orthopedic,* 19, 438-442.

Kim, Y. H., Park, Y. P. and Suh, J. S. (1988) Cementless bony ingrowth total hip prosthesis (anatomical contact porous coated total hip prosthesis) design using computed axial tomography and computer aid design. *Yonsei Medical Journal,* 29, 139-159.

Kim, Y. H. (2008) The results of a proximally coated cementless femoral component in total hip replacement. A five to 12 year follow up. *Journal of Bone Joint Surgical British,* 90, 299-305.

Kokubo, Y., Uchida, K., Oki, H., Negoro, K., Nagamune, K., Kawaguchi, S.,Takeno, K., Yayama, T., Nakajima, H., Sugita, D.,Yoshida, A. and Baba,

H. (2013) Modified metaphyseal-loading anterolaterally flared anatomic femoral stem: five- to nine-year prospective follow-up evaluation and results of three-dimensional finite element analysis. *Artificial Organs,* 37(2)**,** 175-182.

Koval, K. J. (2007) Intramedullary nailing of proximal femur fractures. *America Journal of Orthopedic,* 36(4)**,** 4-7.

Krishnan, S. P., Carrington, R. W. J., Mohiyaddin, S. and Garlick, N. (2006) Common misconceptions of normal hip joint relations on pelvic radiographs. *Journal of Arthroplasty,* 21, 409-412.

Kurtz, S., Ong, K., Lau, E., Mowat, F. and Halpern, M. (2007) Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. *Journal of Bone and Joint Surgery,* 89(4)**,** 780-785.

Laine, H. J., Lehto, M. U. K. and Moilanen, T. (2000) Diversity of proximal femoral medullary canal. *Journal of Arthroplasty,* 15(1)**,** 86-92.

Lane, N. E., Nevitt, M. C., Cooper, C., Pressman, A., Gore, R. and Hochberg, M. (1997) Acetabular dysplasia and osteoarthritis of the hip in elderly white women. *Annals of Rheumatic Diseases,* 56, 627-30.

Lau, H. Y., Tong, K. Y. and Zhu, H. (2008) Support vector machine for classification of walking conditions using miniature kinematic sensors. *Medical and Biological Engineering and Computing,* 46(6)**,** 563-573.

Lavy, C. B. D., Msamati, B. C. and Igbigbi, P. S. (2003) Racial and gender variations in adult hip morphology. *Journal of International Orthopedic,* 27, 331-333.

Leali, A., Fetto, J., Insler, H. and Elfenbein, D. (2002) The effect of a lateral flare feature on implant stability. *International Orthopaedics,* 26, 166-169.

Leali, A. and Fetto, J. (2007) Promising mid-term results of total hip arthroplasties using an uncemented lateral-flare hip prosthesis: a clinical and radiographic study. *International Orthopaedics,* 31, 845-849.

Learmonth, I. D., Young, C. and Rorabeck, C. (2007) The operation of the century: total hip replacement. *Lancet,* 370, 1508-1519.

Lequesne, M., Malghem, J. and Dion, E. (2004) The normal hip joint space: Variations in width, shape and architecture on 223 pelvic radiographs. *Annals of Rheumatic Diseases,* 63, 1145-1151.

Leung, K. S., Procter, P., Robioneck, B. and Behrens, K. (1996) Geometric mismatch of the gamma nail to the Chinese femur. *Clinical Orthopaedics and Related Research,* 323, 42-48.

Lewinnek, G. E., Lewis, J. L., Tarr, R. and Compere, C. L. (1978) Dislocations after total hip replacement arthroplasties. *Journal of Bone and Joint Surgery America,* 60, 217-220.

Li, P. L. S., Jones, N. B. and Gregg, P. J. (1995) Loosening of total hip arthroplasty: diagnosis by vibration analysis. *Journal of Bone and Joint Surgery British,* 77-B(4)**,** 640-644.

Liu, Y. E. B., Hu, S., Chan, S. P. and Sathappan, S. S. (2009) The epidemiology and surgical outcomes of patients undergoing primary total hip replacement: an Asian perspective. *Singapore Medical Journal,* 50(1)**,** 15-19.

Loder, R. T., Mehbod, A. A., Meyer, C. and Meisterling, M. (2003) Acetabular depth and race in young adults: A potential explanation of the difference in the prevalence of slipped capital femoral epiphysis between different racial groups. *Journal of Pediatric Orthopedic,* 23, 699-702.

Lotte, F. (2006) The use of fuzzy inference systems for classification in EEG-based brain-computer interfaces. *3rd international Brain-Computer Interface workshop*, 21-24 September. Graz, Austria: Citeseer, 12-13.

Lucas, M. F., Gaufriau, A., Pascual, S., Doncarli, C., Farina, D. (2008) Multi-channel surface EMG classification using support vector machines and signal-based wavelet optimization. *Biomedical Signal Processing and Control*, 3(2), 169-174.

Mahaisavariya, B., Sitthiseripratip, K., Tongdee, T., Bohez, E. L. J., Vander Sloten, J. and Oris, P. (2002) Morphological study of the proximal femur: a new method of geometrical assessment using 3-dimensional reverse engineering. *Medical engineering and physics,* 24(9)**,** 617-622.

March, L. M. and Bachmeier, C. J. M. (1997) Economics of osteoarthritis: a global perspective. *Baillieres Clinical Rheumatology,* 11, 817-834.

Massin, P., Geais, L., Astoin, E., Simondi, M. and Lavaste, F. (2000) The anatomic basis for the concept of lateralized femoral stems: a frontal plane radiographic study of the proximal femur. *Journal of Arthroplasty,* 15, 93-101.

Materialise (2008) *Mimics help manual Version 12.1.* Leuven, Materialise.

McAuley, J. P., Moore, K. D., Culpepper, W. J. and Engh, C. A. (1998) Total hip arthroplasty with porous-coated prostheses fixed without cement in patients who are sixty-five years of age or older. *Journal of Bone and Joint Surgery America,* 80(11)**,** 1648-1655.

McCarthy, J. C., Bono, J. V. and O'Donnel, P. J. (1997) Custom and modular components in primary total hip replacement. *Clinical Orthopedic Related Research,* 344, 162-171.

McGrory, B. J., Morrey, B. E., Cahalan, T. D., An, K. N. and Cabanela, M. E. (1995) Effect of femoral offset on range of motion and abductor muscle strength after total hip arthroplasty. *Journal of Bone and Joint Surgery British,* 77, 865-869.

Merx, H., Dreinhöfer, K., Schräder, P., Stürmer, T., Puhl, W., Günther, K-P. and Brenner, H. (2003) International variation in hip replacement rates. *Annals of Rheumatic Diseases,* 62, 222-226.

Mishra, A. K., Chalise, P., Singh, R. P. and Shah, R. K. (2009) The proximal femur-a second look at rational of implant design. *Nepal Medical Collage Journal,* 11(4)**,** 278-280.

Mitchell, T. M. (1997) *Machine learning.* New York: Mac Graw Hill.

Monti, L., Cristofolini, L. and Viceconti, M. (1999) Methods for quantitative analysis of the primary stability in uncemented hip prostheses. *Artificial Organs,* 23, 851-859.

Msamati, B. C., Igbigbi, P. S. and Lavy, C. B. D. (2003) Geometric measurements of the acetabulum in adult malawians: radiographic study. *East African Medical Journal,* 80(10)**,** 546-549.

Murlimanju, B., Prabhu, L., Pai, M., Kumar, B., Dhananjaya, K. and Prashanth, K. (2012) Osteometric study of the upper end of femur and its clinical applications. *European Journal of Orthopaedic Surgery and Traumatology,* 22(3), 227-230.

Murray, D. W. (1993) The definition of measurement of acetabular orientation. *Journal of Bone and Joint Surgery British,* 75, 228-232.

Murray, R. O. (1965) The aetiology of primary osteoarthritis of the hip. *British Journal Radiology,* 38, 810-824.

Naito, M., Shiramizu, K. and Akiyoshi, Y. (2005) Curved periacetabular osteotomy for treatment of dysplastic hip. *Clinical Orthopedic Related Research,* 433, 129-135.

Nelitz, M., Guenther, K. P., Guenkel, S. and Puhl, W. (1999) Reliability of radiographic measurement in the assessment of hip dysplasia in adults. *British Journal Radiology,* 72, 331-4.

Nieves, J. W., Formica, C., Ruffing, J., Zion, M., Garrett, P., Lindsay, R. and Cosman, F. (2005) Males have larger skeletal size and bone mass than females, despite comparable body size. *Journal Bone Mineral Research,* 20, 529-535.

Ninomiya, S. and Tagawa, H. (1984) Rotational acetabular osteotomy for the dysplastic hip. *Journal of Bone and Joint Surgery America,* 66, 430-436.

Noble, P. C., Alexander, J. W., Lindahl, L. J., Yew, D. T., Granberry, W. M. and Tullos, H. S. (1988) The anatomical basis of femoral component design. *Clin. Orthop. Relat. Res.,* 235(148-165.

O'Rahilly, R. (1983) *Basic Human Anatomy.* Darthmouth: Dartmouth Medical School.

O'Toole, R. V., Jaramaz, B., Digioia, A. M., Visnic, C. D. and Reid, R. H. (1995) Biomechanics for preoperative planning and surgical simulations in orthopaedics. *Computers in Biology and Medicine,* 25(2)**,** 183-191.

Ohsawa, S., Fukuda, K., Matsushita, S., Mori, S., Norimatsu, H. and Ueno, R. (1998) Middle-term results of anatomic medullary locking total hip arthroplasty. *Archives of Orthopaedic and Trauma Surgery,* 118(1)**,** 14-20.

Oki, H., Ando, M., Omori, H., Okumura, Y., Negoro, K., Uchida, K. and Baba, H. (2004) Relation Between vertical orientation and stability of acetabular component in the dysplastic hip simulated by nonlinear three-dimensional finite element method. *Artif icial Organs,* 28(11)**,** 1050-1054.

Oskoei, M. A. and Hu, H. (2008) Support vector machine-based classification scheme for myoelectric control applied to upper limb. *IEEE Transactions On Biomedical Engineering,* 55(8)**,** 1956-1965.

Otsianyi, W. K., Naipanoi, A.P. and Koech, A. (2011) The femoral collodiaphyseal angle amongst selected Kenyan ethnic groups. *Journal of Morphology Science,* 28(2)**,** 129-131.

Parvizi, J., Keisu, K.S., Hozack, W.J., Sharkey, P.F. and Rothman, R.H. (2004) Primary total hip arthroplasty with an uncemented femoral component: a long-term study of the Taperloc stem. *Journal of Arthroplasty,* 19, 151-156.

Pastrav, L. C., Jaecques, S. V. N., Jonkers, I., Der Perre, G. V. and Mulier, M. (2009) In vivo evaluation of a vibration analysis technique for the per-operative monitoring of the fixation of hip prostheses. *Journal of Orthopaedic Surgery and Research,* 4, 1-10.

Pettersen, S. H., Wik, T. S. and Skallerud, B. (2009a) Subject specific finite element analysis of implant stability for a cementless femoral stem. *Clinical Biomechanics,* 24(6)**,** 480-487.

Pettersen, S. H., Wik, T. S. and Skallerud, B. (2009b) Subject specific finite element analysis of stress shielding around a cementless femoral stem. *Clinical Biomechanics,* 24(2)**,** 196-202.

Pilliar, R. M., Lee, J. M. and Maniatopoulos, C. (1986) Observations on the effect of movement on bone ingrowth into porous-surfaced implants. *Clinical Orthopedic,* 208, 108-113.

Population and Demography Statistics Division (2010) *Population by age group, sex and ethnic group*. In Department of Statistics Malaysia (Ed.). Putrajaya: Malaysia Informative Data Center.

Pyburn, E. and Goswami T (2004) Finite element analysis of femoral components paper III - hip joints. *Materials and Design,* 25(8)**,** 705-713.

Rahmati, S., Abbaszadeh, F. and Farahmand, F. (2012) An improved methodology for design of custom-made hip prostheses to be fabricated using additive manufacturing technologies. *Rapid Prototyping Journal,* 18(5)**,** 389-400.

Rahmati, S., Farahmand, F. and Abbaszadeh, F. (2010) Application of rapid prototyping for development of custom-made orthopaedic prostheses: An investigation study. *Majlesi Journal Mechanical Engineering,* 3, 11-16.

Ramesh, K. S., Sujit, K. T. Raj, K., Amitt, K., Sarvdeep, D., Mandeep, S. D., Nagi, O. N. and Madhu, G. (2010) Proximal femoral medullary canal diameters in Indians: correlation between anatomic, radiographic, and computed tomographic measurements. *Journal Orthopedic Surgery,* 18, 189-194.

Rancourt, D., Shirazi-Adl, A., Drouin, G. and Paiement, G. (1990) Friction properties of the interface between porous-surfaced metals and tibial cancellous bone. *Journal of Biomedical Materials Research,* 24, 1503-1519.

Rawal, B. R., Ribeiro, R., Malhotra, R., Bhatnagar, N. (2011) Design and manufacture of short stemless femoral hip implant based on CT images. *Journal of Medical Sciences,* 11(8), 296-301.

Rawal, B. R., Ribeiroa, R., Malhotrab, R. and Bhatnagara, N. (2012a) Design and manufacturing of femoral stems for the Indian population. *Journal of Manufacturing Processes,* 14(3), 216-223.

Rawal, B. R., Ribeiro, R., Malhotra, R. and Bhatnagar, N. (2012b) Anthropometric measurements to design best-fit femoral stem for the Indian population. *Indian Journal of Orthopedic,* 46, 46-53.

Rechy-Ramirez, E. J. and Hu, H. (2011) Stages for developing control systems using EMG and EEG signals: A survey. *TECHNICAL REPORT: CES-513.* United Kingdom: School of Computer Science and Electronic Engineering, University of Essex

Reddy, V. S., Moorthy, G. V. S. and Reddy, S. G. (1999) Do we need a special design of femoral component of total hip prosthesis in our patient? *Indian Journal Orthopedic,* 33, 282-284.

Reitman, R. D., Emerson, R., Higgins, L. and Head, W. (2003) Thirteen year results of total hip arthroplasty using a tapered titanium femoral component inserted without cement in patients with type C bone. *Journal of Arthroplasty,* 18(7 Suppl 1)**,** 116-121.

Ries, M. D., Suzuki, Y., Renowitzky, G., Lotz, J. C. Barrack, R. L., Bourne, R. B. and Rorabeck, C. H. (2003) Effect of cementless bowed stem distal surface contour and coronal slot on femoral bone strains and torsional stability. *Journal of Arthroplasty,* 18, 494-498.

Rønold, H. J., Lyngstadaasb, S. P. and Ellingsena, J. E. (2003) Analysing the optimal value for titanium implant roughness in bone attachment using a tensile test. *Biomaterials,* 24, 4559-4564.

Rubin, P. J., Leyvraz, P. F., Aubaniac, J. M., Argenson, J. N., Esteve, P. and De Roguin, B. (1992) The morphology of the proximal femur. A three-dimensional radiographic analysis. *Journal of Bone and Joint Surgery British,* 74(1)**,** 28-32.

Rubin, P. J., Leyvraz, P. F. and Heegaard, J. H. (1989) Radiological variations in the anatomical parameters of the proximal femur in relation to rotation. *France Journal Orthopedic Surgery,* 3, 121-127.

Ruther, C., Timm, U., Ewald, H., Mittelmeier, W., Bader, R., Schmelter, R., Lohrengel, A. and Kluess, D. (2012) *Current Possibilities for Detection of Loosening of Total Hip Replacements and How Intelligent Implants Could Improve Diagnostic Accuracy.* Rijeka: InTech.

Sabatini, A. L. and Goswami, T. (2008) Hip implants VII: Finite element analysis and optimization of cross-sections. *Materials and Design,* 29(7)**,** 1438-1446.

Saikia, K. C., Bhuyan, S. K. and Rongphar, R. (2008) Anthropometric study of the hip joint in Northeastern region population with computed tomography scan. *Indian Journal Orthopedic,* 42(3)**,** 260-266.

Sanchez-Sotelo, J., Berry, D. J. and Trousdale, R. T. (2002) Surgical treatment of developmental dysplasia of the hip in adults: I. Nonarthroplasty options. *Journal America Academic Orthopedic Surgery,* 10(5)**,** 321-333.

Senalp, A. Z., Kayabasi, O. and Kurtaran, H. (2007) Static, dynamic and fatigue behavior of newly designed stem shapes for hip prosthesis using finite element analysis. *Materials and Design,* 28(5)**,** 1577-1583.

Sharkey, P. F., Albert, T. J., Hume, E. L. and Rothman, R. H. (1990) Initial stability of a collarless wedge-shaped prosthesis in the femoral canal. *Semin Arthroplasty,* 1, 87-90.

Sharp, I. K. (1961) Acetabular dysplasia: the acetabular angle. *Journal of Bone and Joint Surgery British,* 43, 268-72.

Shirazi-Adl, A., Dammak, M. and Paiement, G. (1993) Experimental determination of friction characteristics at the trabecular bone/porous-coated metal interface in cementless implants. *Journal Biomedical Material Research,* 27, 167-176.

Shirazi-Adl, A., Dammak, M. and Zukor, D. J. (1994) Fixation pull-out response measurement of bone screws and porous-surfaced posts. *Journal of Biomechanics,* 27(10)**,** 1249-1258.

Sivanandam, S. N., Sumathi, S. and Deepa, S.N. (2007) *Introduction to fuzzy logic using MATLAB.* Berlin: Springer Verlag.

Sivananthan, S., Arif, M. and Choon, D. S. (2003) Small stem Exeter total hip replacement: clinical and radiological follow-up over a minimum of 2.5 years. *Journal Orthopedic Surgery,* 11(2)**,** 148-153.

Sivarasu, S., Beulah, P. and Mathew, L. (2011) Novel approach for designing a low weight hip implant used in total hip arthroplasty adopting skeletal design techniques. *Artificial Organs,* 35(6)**,** 663-666.

Siwach, R. C. and Dahiya, S. (2003) Anthropometric study of proximal femur geometry and its clinical application. *Indian Journal Orthopedic,* 37, 247-251.

Sporer, S. M., Obar, R. J. and Bernini, P. M. (2004) Primary total hip arthroplasty using a modular proximally coated prosthesis in patients older than 70: two to eight year results. *Journal of Arthroplasty,* 19(2)**,** 197-203.

Spotorno, L. and Romagnoli, S. (1991) *The CLS uncemented total hip replacement system.* Berne: Protek.

Stem, E. S., O'Connor, M. I., Kransdorf, M. J. and Crook, J. (2006) Computed tomography analysis of acetabular anteversion and abduction. *Skeletal Radiology,* 35, 385-389.

Stulberg, S. D., Stulberg, B. N. and Wixson, R. L. (1989) The rationale, design characteristics, and preliminary results of a primary custom total hip prosthesis. *Clinical Orthopedic Related Research,* 249, 79-96.

Tai, C. L., Chen, W. P., Lee, M. S., Lee, P. C. and Shih, C. H. (2004) Comparison of Stress Shielding between straight and curved stems in cementless total hip arthroplasty – An in vitro experimental study. *Journal of Medical and Biological Engineering,* 24(4)**,** 177-181.

Tallroth, K. and Lepisto, J. (2006) Computed tomography measurement of acetabular dimensions: Normal values for correction of dysplasia. *Acta Orthopedic,* 77(4)**,** 598-602.

Tkach, D., Huang, H. and Kuiken, T.A. (2010) Study of stability of time-domain features for electromyographic pattern recognition. *Journal of NeuroEngineering and Rehabilitation,* 7, 21-33.

Tonnis, D. (1976) Normal values of the hip joint for evaluation of X-rays in children and adults. *Clinical Orthopedic Related Research,* 119, 39-47.

Tonnis, D. (1987) *Congenital dysplasia and dislocation of the hip in children and adults.* New York: Springer.

Traina, F., Clerico, M. D., Biondi, F., Pilla, F., Tassinari, E. and Toni, A. (2009) Sex differences in hip morphology: is stem modularity effective for total hip replacement? *Journal of Bone and Joint Surgery America,* 91, 121-128.

Umer, M., Sepah, Y. J., Khan, A., Wazir, A., Ahmed, M. and Jawad, M. U. (2010) Morphology of the proximal femur in a Pakistani population. *Journal of Orthopaedic Surgery* 18(3)**,** 279-281.

Umer, M., Thambyah, A., Tan, W. T. J. and Das De, S. (2006) Acetabular morphometry for determining hip dysplasia in the Singaporean population. *Journal of Orthopaedic Surgery,* 14, 27-31.

Verdonschot, N., Huiskes, R. and Freeman M. A. R. (1993) Pre-clinical testing of hip prosthesis designs: a comparison of finite element calculations and laboratory tests. *Part H: Journal of Engineering in Medicine,* 207, 149-154.

Verdonschot, N. and Huiskes, R. (1996) Mechanical effects of stem cement interface characteristics in total hip replacement. *Clinical Orthopedic Related Research,* 329, 326-336.

Viceconti, M., Brusi, G., Pancanti, A. and Cristofolini, L. (2006) Primary stability of an anatomical cementless hip stem: A statistical analysis. *Journal of Biomechanics,* 39(7)**,** 1169-1179.

Viceconti, M., Muccini, R., Bernakiewicz, M., Baleani, M. and Cristofolini, L. (2000) Large-sliding contact elements accurately predict levels of bone-implant micromotion relevant to osseointegration. *Journal of Biomechanics,* 33, 1611-1618.

Visser, J. D., Jonkers, A. and Hillen, B. (1982) Hip joint measurement with computerised tomography. *Journal Pediatric Orthopedic,* 2, 143-146.

Wagner, H. (1978) *Experience with spherical acetabular osteotomy for the correction of the dysplastic acetabulum.* New York: Springer.

Wagner, H. and Wagner, M. (2000) Cone prosthesis for the hip joint. *Archive Orthopedic Trauma Surgery,* 120, 88-95.

Walker, P. S., Culligan, S. G., Hua, J., Muirhead-Allwood, S. K. and Bentley, G. (2000) Stability and bone preservation in custom designed revision hip stems. *Clinical Orthopedic,* 373, 164-173.

Walker, P. S., Culligan, S. G., Hua, J., Muirhead-Allwood, S. K. and Bently, G. (1999) The effect of a lateral flare feature on uncemented hip stems. *Hip International,* 9, 71-80.

Walker, P. S., Schneeweis, D., Murphy, S. and Nelson, P. (1987) Strains and micromotions of press-fit femoral stem prostheses. *Journal of Biomechanics,* 20, 693-702.

Wiberg, G. (1939) Studies on dysplastic acetabula and congenital subluxation of the hip joint with the special reference to the complication of osteoarthritis. *Acta Chemica Scandinavica,* 83, 58.

Widmer, K. H. and Majewski, M. (2005) The impact of the CCD-angle on range of motion and cup positioning in total hip arthroplasty. *Clinical Biomechanics (Bristol, Avon).* 20(7)**,** 723-728.

Williamson, O. W. (1999) Measuring the success of joint replacement surgery. *Medical Journal Australia,* 171, 229-230.

Wu, T. F., Lin, C. J. and Weng, R. C. (2004) Probability estimates for multiclass classification by pairwise coupling. *Journal Machine Learning Research,* 5, 975-1005.

Yamada, H., Yoshihara, Y., Henmi, O., Morita, M., Shiromoto, Y., Kawano, T., Kanaji, A., Ando, K., Nakagawa, M., Kosaki, N. and Fukaya, E. (2009) Cementless total hip replacement: past, present, and future. *Journal Orthopedic Science,* 14, 228-241.

Yeung, Y., Chiu, K. Y., Yau, W. P., Tang, W. M., Cheung, W. Y. and Ng, T. P. (2006) Assessment of the proximal femoral morphology using plain radiograph—can it predict the bone quality? *Journal of Arthroplasty,* 21(4)**,** 508-513.

Yoon, K. S., Kim, J., Lee, J. H., Kang, S. B., Seong, N. H. and Koo, K. H. (2007) A randomized clinical trial of cementless femoral stems with and without hydroxyapatite/tricalcium-phosphate coating. An 8- to 12-year follow-up study. *Journal of Arthroplasty,* 22(4)**,** 504-508.

Yosibash, Z., Katza, A. and Milgrom, C. (2013) Toward verified and validated FE simulations of a femur with a cemented hip prosthesis. *Medical Engineering and Physics,* 35, 978- 987.

Zhou, S. M., Gan, J.Q. and Sepulveda, F. (2008) Classifying mental tasks based on features of higher-order statistics from EEG signals in brain-computer interface. *Information Sciences*, 178(6), 1629-1640.

Zwartele, R. E., Witjes, S., Doets, H. C., Stijnen, T. and Poll, R. G. (2012) Cementless total hip arthroplasty in rheumatoid arthritis: a systematic review of the literature. *Hip Arthroplasty,* 132, 535-546.

Zweymuller, K. and Semlitsch, M. (1982) Concept and material properties of a cementless hip prosthesis system with Al_2O_3 ceramic ball heads and wrought Ti-6Al-4V stems. *Archcives Orthopedic Trauma Surgery,* 100, 229-236.