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Biped Hip Simulator for Human Walking Cycles

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Abstract: Recently there is an increasing number of people who underwent hip implant surgery based on the statistics by the World Health Organization (WHO). Based on the report by WHO, most hip implant cases are due to hip damages or injuries, in particular caused by rheumatoid arthritis or osteoarthritis which lead to replacement of artificial hips. Consequently, the development of hip simulator has received massive attention from researchers. To date, artificial hip is used in testing load and wear before implanting it into human body to replace damaged hip joints. This study aims at reviewing hip simulators and proposes a new design of biped hip simulator that includes the initial design, specifications, advantages and also limitation.

Key words: World health organization, injuries, osteoarthritis, implanting, biped hip simulator

INTRODUCTION

Hip simulator also known as hip testing machine is a machine for testing joint replacement that imitate the loads and motions of a human hip joint during walking, stair climbing and others. Basically, the hip simulator is used to test hip implant that has been developed before implanting it into a human body to replace the damaged hip joint especially caused by rheumatoid arthritis or osteoarthritis (Kiguchi *et al*., 2008, 2009, 2012; Tuke *et al*., 2010).

Rheumatoid arthritis is a type of inflammatory disorder that commonly affects the lining of human joint that causes painful swelling and joint deformity as well as bone erosion (Snekhalatha *et al*., 2012). While, osteoarthritis occurs when protective cartilage at ends of a bone wears down and usually causes damage on any joints of human body, especially in hips and knees (Varady *et al.,* 2015). Generally, there is no specific cure for both disorders as it depends on the condition of the affected joints. Usually, if the joint area is seriously affected, a surgery or joint replacement will take place. Currently, there is an increasing number of people who underwent hip implant surgeries due to both disorders according to the statistics by the World Health Organization (WHO) that require artificial hip replacement (Loving *et al.,* 2013; Fabry *et al.,* 2013).

A hip joint is a synovial joint or known as diarthrosis located between acetabulum in a pelvis and a femoral head which is wrapped in a capsule that contains a biological lubricant known as synovial fluid. The fluid acts as a shock absorber to minimize friction and wear on contact surface of the hip implant in order to lengthen the lifespan (Mattei *et al*., 2011). The aim of this study is to review on the human hip joint and hip simulator that includes its technologies and limitations. In addition, this study proposes a new design of biped hip simulators that includes an initial design, specifications and limitation.

TECHNOLOGY

Available hip simulator: Basically, there are a lot of hip simulators that have been developed as shown in Fig.1 (Galanis and Manolakos, 2011). Hip simulators differ in their sophistication level and plays a crucial role in the pre-clinical validation of biomaterials used for hip implants (Galanis and Manolakos, 2011). As shown in Fig. 1a, the AMTI hip simulator developed by William H.Harris, that was able to simulate the hip motion with the simultaneous loaded applied and provides rotation about 3 axes that able to test for friction or wear (Bragdon *et al*., 2003). While, the HUT-4 hip simulator in Fig. 1b is a simulator by the Helsinki University that built in 12 stations and the prosthesis is mounted in the self-centering and anatomical position. The pneumatic system is used in the load actuator along direction of the neck axis (Saikko, 2015; Saikko and Shen, 2010). The Mark II Durham hip simulator by Durham University in Fig. 1c is a simulator with five station that the joints are mounted anatomically and subjected to two-axis motion of dynamic loading cycle independently (Smith and Unsworth, 2001).

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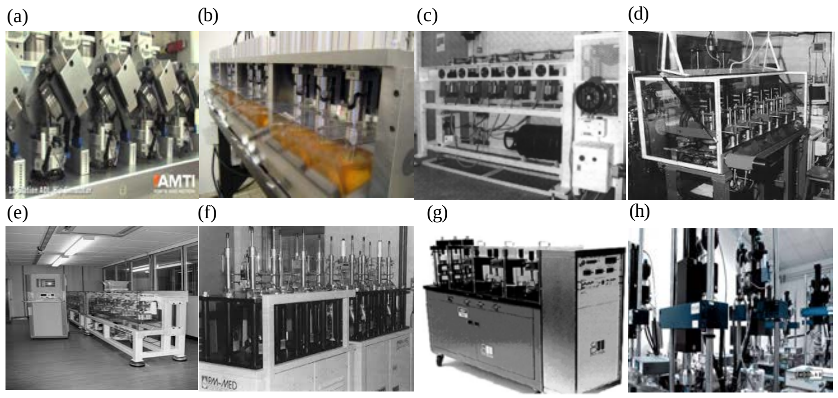

Fig. 1: Hip simulator by: a) AMTI; b) HUT-4; c) Mark II; d) Leeds PA II; e) ProSim Limited; f) MATCO with model EW08 MMED; g) Shore Western (SW); h) Endo Lab

Table 1: The available hip simulator specifications

Authors	Simulator	Station	Classification	Motion simulated	Design
Bragdon (2003)	AMTI	12	3-axis	FE (±25°), AA (±9°),IN-EX (±20°)	Anatomical
Saikko (2005)	HUT-4	12	2-axis	FE (46°), AA (12°)	Anatomical
Smith (2001)	Mark II Durham	5	2-axis	FE (+30°/-15°), IN-EX (±10°)	Anatomical
Nevelos (2001)	Leed PA II	6	2-axis	FE (+30°/-15°), IN-EX (±10°)	Anatomical
Barbour (2000)	PROSIM Limited	10	2-axis	BI-AX (±30°)	Anatomical
Affatato (2006)	Shore Western (SW)	12	2-axis	BI-AX (±30°)	Non-anatomical
Kaddick (2001)	EndoLab	8	3-axis	FE (+25°/-18°), AA (+7°/-4°),IN-EX (+2°/-11°)	Anatomical
McKellop,2004	MATCO, EW08 MMED	16	2-axis	FE (±22.5°), AA (±22.5°)	Non-anatomical

Another simulator that possesses similar design to Mark II Durham is a Leeds PA II hip simulator by the University of Leeds as shown in Fig. 1d, that built with six stations and the motion can be controlled independently about 2 axes to generate multi-directional motion and the joint is mounted in the anatomical position while the load is applied in the vertical axis (Gao *et al*., 2009).

Figure 1e shows the ProSim Limited hip joint simulator by the University of Leeds with 10 stations that the motion and load kinematics follow the Paul's studies that provides the motion of Biaxial rocking (BI-AX). The cup is mounted in anatomical position at each station (Dowson *et al.,* 2004; Goldsmith and Dowson, 1999). While, as shown in Fig. 1f, the MATCO hip simulator with model EW08 MMED that configured in two banks that consist of eight channels each. The heads and cups are not mounted as the anatomical position. Besides that, there is anothe r simulator that also configured non-anatomical which is 12 station Shore Western as shown in Fig. 1g. Generally, in each station, the head's alignment is provided by a ball bearing on the head holder and able to simulate the motion of Biaxial rocking (BI-AX) and the implant are not mounted in anatomical position (Liao *et al.,* 2003). The EndoLab hip simulator in Fig. 1h that built in 6 stations plus 2 reference station that able to test for the hip implant and can simulate the motions in 3 axes which are Flexion-Extension (FE), Abduction-Adduction (AA) and Internal-External rotations (IN-EX) (Affatato *et al*., 2006). Basically, most of the simulator provides can be defined by the user in terms of motions and load control using a computer generated.

Limitation: Mostly, the available hip simulators are built in single sided and were arranged in either series or parallel that cannot imitate closely human hip joint as it only developed to test the hip implant before the hip surgery takes place. Furthermore, the available hip simulators cannot be used to test the effect of the both sides of the hip implant to the patients especially for both hips replacement as there are slightly different effect of contact force and wear on both right and left hip joints.

NEW PROPOSED OF THE HIP SIMULATOR DESIGN

Introduction of the proposed biped hip simulator design: The idea of designing and developing a new hip simulator for both right and left hip joint which is biped hip simulator is came out from the limitation of the current design as it is more practical in terms of functions as it can imitate closely the human hip motions and can be used to test the effect of wear and contact force on the hip implant. This is because, the effect of wear and contact force on both right and left hip joint during human typical daily life activities are slightly different. The effect of dominant and non-dominant limb in each person are different either young or elderly people. This is because, a person tends to use extra energy on their dominant side

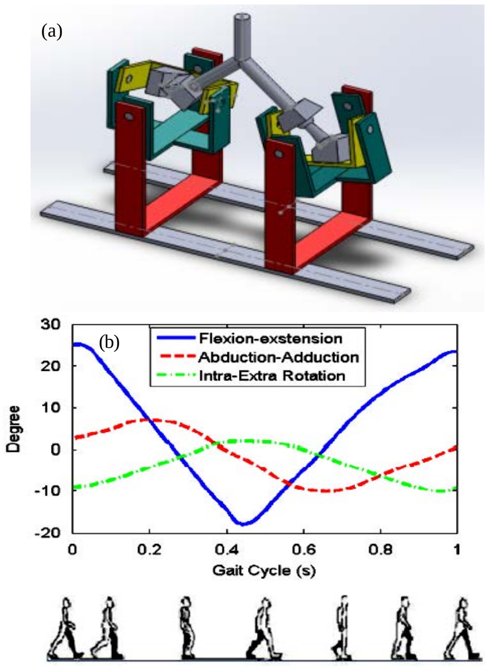

Fig. 2: a) Initial design of biped hip simulator; b) Hip angles of normal walking cycles

in their routine activities and can be seen significantly when they used their dominant side to do rough activities such as playing football, hiking and other. A lot of studies have been done by the researchers to prove that the effect of the dominant and non-dominant limb to the human hip joint (Carpes *et al*., 2010; Rice and Seely, 2010; Seeley *et al*., 2008; Menz *et al*., 2003; Moreira *et al*., 2013; Hsiao-Wecksler *et al*., 2010; Sadeghi *et al*., 2000; Paroczai *et al*., 2006). A study by Parocza *et al*. (2006) proved that there are differences between dominant and non-dominant side for young and elderly people either male or female during human normal walking. The results show the differences in step length, step width and also swing phase.

New proposed biped hip simulator design, advantages and limitation: Generally, the new proposed biped hip simulator is based on the 6 Degrees of Freedom (DOF) that the motions involve are flexion, extension, adduction, abduction, internal and external rotation due to the facts that hip joint can move in three different planes which are sagittal, fronta and transverse plane (Saputra *et al*., 2013). There are a few factors considered to develop the biped hip simulator for both right and left hip joint (double sided) which are the problems to be solved or improvement to be made, limitations of the new design,

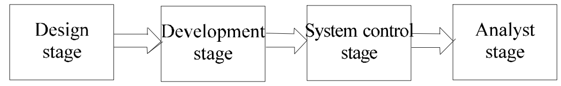

Fig. 3: Stages of developing biped hip simulator design

materials to be used, the size and shape and also the cost to develop the hip simulator. As shown in Fig. 2a and b are the proposed idea of the new design of the hip simulator and the hip angles for human normal walking during the gait cycles in steady state based on the ISO standard 14242-1 (Oliveira *et al*., 2011). Generally, the new proposed hip simulator design is based on the standard and only applicable or considered the human normal walking cycles during the gait cycles.

Basically, the new biped hip simulator design is able to be used to test wear rate and load applied. The simulators joint is mounted anatomically and the range of motions provides are flexion-extension (0°-120°/0°-30°), abduction-adduction (0°-45°/0°-30°) and internal-external rotation (0°-40°/0°-40°) with 3 axes. Besides, the maximum load applied for the simulator is up to 3 kN based on the Paul's studies. That means the simulator is able to support ±300 kg in weight. Generally, the biped hip simulator design is according to the ISO standard 14242-1 (Oliveira *et al*., 2011).

The process of developing the biped hip simulator is divided into several stages which are design stage using SolidWorks Software, development stage, system control stage using microcontroller and analyst stage as shown in Fig. 3. The analyst that will be involved are slide track analysis, performance analysis and others (Calonius and Saikko, 2002; Saikko and Calonius, 2002). From the initial design, there are a few advantages can be seen especially in terms of functionality, cost, size and weight. This is because, the new designs will be built in compact space that lead to minimize the size and weight of the simulator that lead to reduce the cost of the development of the biped hip simulator. However, there are no such things that are perfect in this world as well as the new proposed design of biped hip simulator. This is because, the design is only can be used to test the hip implant for walking condition although it can be used to test for wear rate and load applied on hip implant before implant surgery takes place.

CONCLUSION

This study summarizes the commonly known hip simulators and proposed a new biped hip simulator to improve the limitation of existing single-sided that came out with series or parallel arrangement which cannot imitate closely the loads and motions of a human hip joint. The new design of biped hip simulator can be used to investigate the effect of dominant and non-dominant limb in each person especially young or elderly people either male or female. However, the proposed design is only applicable for human walking condition during the gait cycle only. Therefore, the future research will consider the other motions such as running, jumping and any other gestures that performed by human.

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