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Gait Asymmetry in Biped Hip Simulator Design

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Abstract: Gait is a one of the universal motion in daily activities and its analysis becomes one of the important aspects in conveying information about one's physical condition. Normal gait is assumed to be symmetrical but some research reported there are differences in the action of lower extremities although in able-bodied. People who suffer from osteoarthritis will use the hip prosthesis to replace the damage hip joint. Osteoarthritis is a disease which affects the gait cycle of a human. Some of the patients undergoes single replacement of hip joint while the others undergoes both the left and right joint replacement. Asymmetrical gait will actually affect the performance of both right and left hip joint since the wear mechanism were difference between them. The aim of this study was to define asymmetrical gait towards the hip joint and to explore the design concept of biped hip simulator that mimics physiological loading of hip joint replacement. A simulator is designed as to obtain significant result from asymmetrical gait where parameters are assumed to be different.

Key words: Damag, gait, hip, joint, patients

INTRODUCTION

Many researchers assume that normal gait is symmetrical (Gouwanda and Senanayake, 2010; Sant'Anna and Wickstrom, 2010) in order to streamline data collection and gait analysis (Jiang *et al*., 2010; Gregg *et al*., 2012). Besides, kinematic and kinetic variables are also assumed to have no significant difference between dominant and contralateral legs of a healthy person (Van der Harst *et al*., 2007). In some researches, gait asymmetry has been used as an indicator to track patient's walking performance (Illyes and Kiss, 2005) since people with gait asymmetry are assumed to have lower limb disease. Besides that, gait analysis is one of the tools used to study patients with total hip arthroplasties (Schmalzried *et al*., 996; Cuckler *et al*. (2004). Osteoarthritis is one of the disease that affect the gait cycle of human. Patient who undergoes single replacement of hip joint normally will face the asymmetrical gait. However, there were also patient that undergoes replacement for both hip joint. Since, the gait of human was considered as asymmetrical in this study, result of wear mechanism for patient with both hip replacement was important in order to see the different of wear between left and right hip joint. The purpose of this study was to consider the asymmetrical gait in able-bodied. Gait differences for both right and left limbs in able-bodied have been reported frequently (Sadeghi *et al*., 2000). Growing evidence shows that sometimes able-bodied exhibits the behavior of impaired walking (Gregg *et al*., 2012, 2011; Seeley *et al*., 2008; Rodano and Santambrogio, 1987). In the last decades, hip joint prosthetics have been widely used in world's orthopaedic surgery where 400,000 operations were performed every year and >100 designs of orthopedic construction have been proposed (Galanis and Manolakos, 2009, 2011). In addition, Total Hip Replacement (THR) becomes one of the most successful medical operation in orthopaedic surgery which restores diseased hip function affected by osteoarthritis or rheumatoid arthritis (Uddin, 2015). Furthermore, the hip simulator was evolved over the year to test the biomaterials, wear mechanism and dislocation of artificial hip.

The aim of this study is to review the effect of gait asymmetry to hip joint and present hip simulators which are available in the market in terms of its applications and technologies. Furthermore, this study proposes a new design of hip simulator known as biped hip simulator.

GAIT ASYMMETRY ANALYSIS

Many methods were proposed in order to quantify gait asymmetries motion between left and right leg

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Table 1: The results of the angular parameters of healthy elderly and young subjects (Paroczai *et al*., 2006)

		Elderly		Young	
Parameters	Sides/unit (degree)	Female	Male	Female	Male
Hip flexion range	Dominant	52.34±3.56	59.20±3.50	61.64±4.56	64.02±3.56
	Non-dominant	50.12±4.78	54.30±3.30	69.2±3.450	62.76±3.56
Maximum	Dominant	64.23±6.78	69.30±9.10	66.76±4.56	68.62±5.63
	Non-dominant	60.12±4.57	63.67±8.50	64.32±3.12	67.54±5.23
Minimum	Dominant	11.89±3.78	9.91±5.78	5.12±1.34	4.60±1.44
	Non-dominant	10.00±5.08	9.63±3.89	5.32±2.10	4.79±1.45
Pelvic rotation range		8.59±2.96	7.42±1.69	4.46±2.34	6.57±2.01
Maximum		2.91±2.60	6.37±1.30	2.12±1.23	6.57±2.01
Minimum		-5.38±0.35	-1.26±1.15	-2.34±1.23	-1.23±2.23
Pelvic obliquity range		2.65±0.38	3.12±1.87	1.42±0.33	1.75±0.44
Maximum		5.64±1.58	3.97±1.55	4.56±2.34	3.12±1.23
Minimum		2.99±1.19	0.85±0.85	3.14±1.03	1.37±0.76

(Hsiao-Wecksler *et al*., 2010). The hypothesis of functional asymmetries in able-bodied is each leg have different role in term of vertical support, mediolateral control and anterior-posterior propulsion. Fast walking trials by Seeley *et al*. (2008) shows that there are differences between leg roles and proposes that challenging locomotor requires asymmetric strategies. reports by Rodano and Santambrogio (1987) and Carpes *et al*. (2010). Conclude that asymmetry in athletic race walking, running and cycling were caused by ground irregularities, shoes and curved tracks condition. Spatial-temporal and kinematic parameter was used to observe the asymmetrical behavior of lower extremities such as velocity profiles (Law, 1987; Allard *et al*., 1996), step, stride, length, foot placement angle, maximum knee flexion and a range of motion (Gregg *et al*., 2012). As reported by some study gait asymmetry was found in able-bodied subjects which few parameters were examined (Gouwanda and Senanayake, 2010). Damholt and Termansen (1978) asymmetry was discovered in plantar flexor strength and circumference. Furthermore, differences also found in left and right lower limbs of 62 able-bodied subjects for the variation of peak vertical, anterior-posterior and medial-lateral components (Herzog *et al*., 1988). Leg dominance is common explanation for gait asymmetry although there were conflicts exist for this theory as reported by Gundersen *et al*. (1989). Table 1 shows the differences in the angular parameter between elderly people and young people.

PREVIOUS HIP SIMULATOR

One of the simulator developed by Kiguchi *et al*. (2008) shown in Fig. 1a. The simulator can generate 3 Degree of Freedom (DOF) motion: flexion/extension, abduction/adduction and internal/external rotation. By using artificial hip joint which consist of cup and ball joint, the simulator will test the dislocation that involve in hip prosthesis. Other than that, AMTI-Boston hip simulator shown in Fig. 1b simulates hip joint motion with synchronous loading in a physiologic surrounding. It provides rotation in 3 axes: Sagittal plane, frontal plane and the vertical axis. Besides that it also duplicate loading profiles of walking and climbing stairs. The system in simulator operates in four degree of freedom which are load and three motions. In addition, the simulator also assembled with an additional 4 load-soak stations (Affatato *et al*., 2006).

Besides that, 12-station HUT-4 simulator in Fig. 1c has been developed which the hip prosthesis mounted in anatomical position and self-centring. Motion of electromechanical include in this simulator are Flexion-Extension (FE) and Abduction-Adduction (AA) of the femoral head. Mark II Durham hip simulator is a five stations machine where the hip joint are in the anatomical position and followed the dynamic loading cycle with independent two axis motion. Figure 1d show the Mark II Durham simulator and the measured variation of the motion. Another simulator that possess similar design to Mark II Durham is a Leeds PA II simulator shown in Fig. 2e. This simulator is able to control flexion-extension motion and internal-external rotation and the load is applied in vertical axis. Multidirectional motion between femoral head and acetabular cup is generated by using simplified cycle. Amplitude of 90° in internal/external rotation out of phase with the flexion-extension is applied as it generated open elliptical wear path between the components (Affatato *et al*., 2006; Galvin *et al*., 2005). ProSim Limited hip joint simulator in Fig. 1f developed by University of Leeds is a machine with 10 stations arranged in row. The joint mounted at anatomical position which the cup is placed above the femoral head inclined at 35° with respect to horizontal axis (Galvin *et al*., 2005). The design focus on to simplify the kinematics of the machine and to provide practical motion to six degree of freedom system (Goldsmith and Dowson, 1999). MATCO hip simulator (Model EW08 MMED) is a simulator that

Table 2: The available hip simulator specifications

Authors	Simulator	Station	Classification	Motion simulated	Design
Kiguchi *et al.* (2008)	Artificial	1	3-axis	FE (±100°), AA (±15°), IN-EX (±20°)	Non-anatomical
Bragdon *et al.* (2003)	AMTI	12	3-axis	FE (±25°), AA (±9°), IN-EX (±20°)	Anatomical
Saikko	HUT-4	12	2-axis	FE (46°), AA (12°)	Anatomical
Smith	Mark II Durham	5	2-axis	FE (+30°/-15°), IN-EX (±10°)	Anatomical
Nevelos	Leeds PA II	6	2-axis	FE (+30°/-15°), IN-EX (±10°)	Anatomical
Barbour	PROSIM Limited	10	2-axis	BI-AX (±30°)	Anatomical
McKellop	MATCO, EW08 MMED	16	2-axis	FE (±22.5°), AA (±22.5°)	Non-anatomical
Affatato *et al.* (2006)	Shore Western (SW)	12	2-axis	BI-AX (±30°)	Non-anatomical

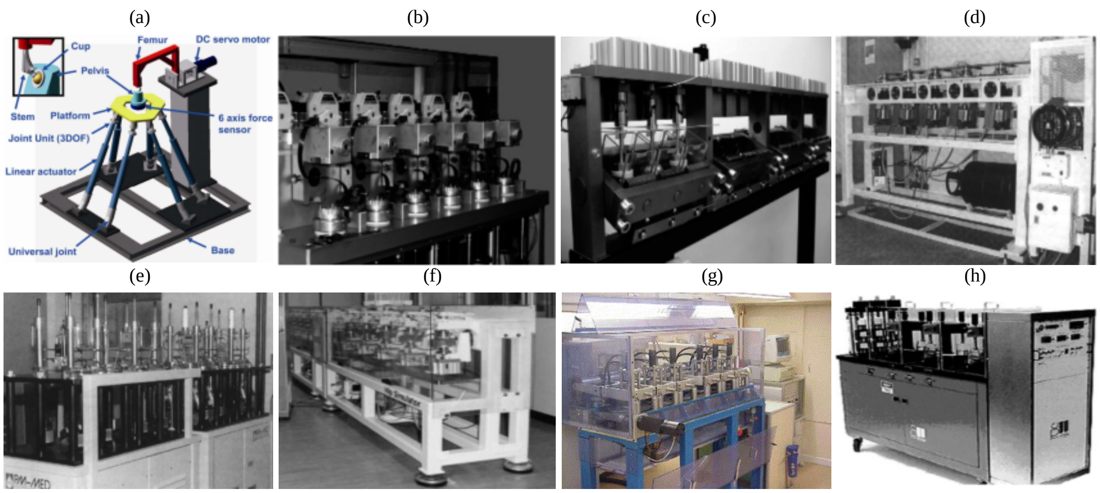

Fig. 1: Previous hip simulator: a) artificial hip joint simulator; b) AMTI hip simulator; c) HUT-4 simulator; d) Mark II Durham simulator; e) leeds PA II simulator; f) ProSim limited simulator; g) MATCO simulator and h) shore Western simulator

perform non-anatomical position for the joint. As shown in Fig. 1g, this simulator configure with two bank of eight channel each and provide symmetrical shift of the cup over a stationary head through a range approximate to 45° (±22. 5) in both sagittal and frontal plane but no rotation in transverse plane (Medley *et al*., 1997).

Besides that, there are another simulator that also configure non-anatomical which is 12 station Shore Western (SW) hip joint simulator shown in Fig. 1h. All implants in each station are mounted in non-anatomical and the ball bearing in the head holder provide the head alignment in the machine. The load has maximum value of 2.0 kN running in frequency of 1.0 Hz (Mizoue *et al*., 2003). Table 2 summarize the hip simulator that has been discussed based on their characteristics.

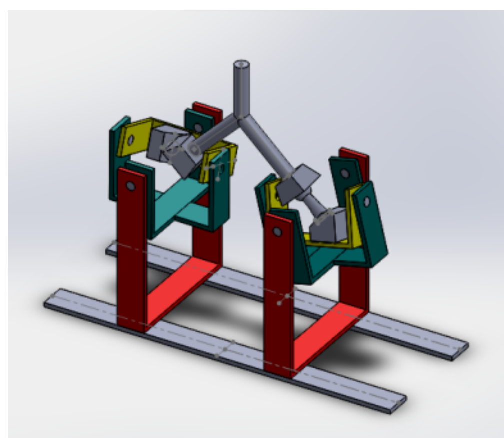

Fig. 2: Biped hip simulator

Biped hip simulator: The main characteristics of the gait asymmetry has been taken into consideration in designing new concept of 3-axis bilateral hip simulator which capable in combining movement and rotation in the three different angles. Figure 2 shows the design of biped hip simulator which consist of right and left part, both assemble with artificial hip and cup. This simulator enable to show direct comparison between left and right artificial hip which are designed to move and rotate in different parameters (flexion-extension, abduction-adduction, internal/external rotation). Different parameters for 3 important angles are set according to analysis of gait asymmetry in Table 1.

The new biped hip simulator design as shown in Fig. 2 is able to be used to test wear rate and load applied. The simulators joint are mounted anatomically and the motions provides is flexion-extension (0°-120-°/0-°30°), abduction-adduction (0°-45°/0°-30°) and internal external rotation (0°-40°/0°-40°) with 3 axis. Besides, the maximum load applied for the simulator is up to 3 kN based on the Paul's studies. That mean, the simulator is able to support ±300 kg in weight. Generally, the biped hip simulator design is according to the ISO standard 14242-1.

CONCLUSION

This study discussed the effect of gait asymmetry on human gait cycles by proposing new design of hip simulator which is biped hip simulator for walking condition. As compare to previous single sided hip simulator, the new design capable to imitate closely the human hip joint as it is built for both right and left hip joint. The simulator can be used to test the hip implant for both right and left simultaneously in terms of wear test and load applied. However, it is limited to the other gait cycle of human such as jumping, squad and sitting that produced similar load at the same time for both hip's left and right. The future research would considers the reliable motion of the hip joint mechanism for any movement produced by human.

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REFERENCES

Affatato, S., W. Leardini and M. Zavalloni, 2006. Hip joint simulators: State of the art. Proceedings of the 11th BIOLOX® Symposium, June 30-July 1, 2006, Rome, Italy, pp: 171-180.

Allard, P., R. Lachance, R. Aissaoui and M. Duhaime, 1996. Simultaneous bilateral 3-D able-bodied gait. Hum. Movement Sci., 15: 327-346.

Bragdon, C.R., M. Jasty, O.K. Muratoglu, D.O. O'Connor and W.H. Harris, 2003. Third-body wear of highly cross-linked polyethylene in a hip simulator. J. Arthroplasty, 18: 553-561.

Carpes, F.P., C.B. Mota and I.E. Faria, 2010. On the bilateral asymmetry during running and cycling-A review considering leg preference. Phys. Therapy Sport, 11: 136-142.

Cuckler, J.M., K.D. Moore, A.V. Lombardi, E. McPherson and R. Emerson, 2004. Large versus small femoral heads in metal-on-metal total hip arthroplasty. J. Arthroplasty, 19: 41-44.

Damholt, V. and N.B. Termansen, 1978. Asymmetry of plantar flexion strength in the foot. Acta Orthopaedica Scandinavica, 49: 215-219.

Galanis, N.I. and D.E. Manolakos, 2009. Investigation of cutting parameters in manufacturing of femoral heads. Proceedings of the World Congress on Engineering, Volume 2, July 1-3, 2009, London, UK., pp: 1606-1611.

Galanis, N.I. and D.E. Manolakos, 2011. Design of a hip joint simulator according to the ISO 14242. Proceedings of the World Congress on Engineering, Volume 3, July 6-8, 2011, London, UK., pp: 2088-2093.

Galvin, A.L., S. Williams, P. Hatto, J. Thompson and G. Isaac *et al*., 2005. Comparison of wear of ultra high molecular weight polyethylene acetabular cups against alumina ceramic and chromium nitride coated femoral heads. Wear, 259: 972-976.

Goldsmith, A.A.J. and D. Dowson, 1999. Development of a ten-station, multi-axis hip joint simulator. Proc. Inst. Mech. Eng. Part H: J. Eng. Med., 213: 311-316.

Gouwanda, D. and S.A. Senanayake, 2010. Identification of gait asymmetry using wireless gyroscopes. Proceedings of the IEEE Asia Pacific Conference on Circuits and Systems, December 6-9, 2010, Kuala Lumpur, Malaysia, pp: 608-611.

Gregg, R.D., Y. Dhaher and K.M. Lynch, 2011. Functional asymmetry in a five-link 3D bipedal walker. Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, August 30-September 3, 2011, Boston, MA., USA., pp: 7820-7823.

Gregg, R.D., Y.Y. Dhaher, A. Degani and K.M. Lynch, 2012. On the mechanics of functional asymmetry in bipedal walking. IEEE Trans. Biomed. Eng., 59: 1310-1318.

Gundersen, L.A., D.R. Valle, A.E. Barr, J.V. Danoff, S.J. Stanhope and L. Snyder-Mackler, 1989. Bilateral analysis of the knee and ankle during gait: an examination of the relationship between lateral dominance and symmetry. Phys. Therapy, 69: 640-650.

Herzog, W., B.M. Nigg and L.J. Read, 1988. Quantifying the effects of spinal manipulations on gait using patients with low back pain. J. Manipulative Physiol. Therapeut., 11: 151-157.

Hsiao-Wecksler, E.T., J.D. Polk, K.S. Rosengren, J.J. Sosnoff and S. Hong, 2010. A review of new analytic techniques for quantifying symmetry in locomotion. Symmetry, 2: 1135-1155.

Illyes, A. and R.M. Kiss, 2005. Gait analysis of patients with osteoarthritis of the hip joint. Facta Universitatis Ser.: Phys. Educ. Sport, 3: 1-9.

Jiang, S., B. Zhang, W. Xu and D. Wei, 2010. Gait symmetry analysis based on affinity propagation clustering. Proceedings of the IEEE 10th International Conference on Computer and Information Technology, June 29-July 1, 2010, Bradford, UK., pp: 1673-1678.

Kiguchi, K., A. Yamashita, M. Sasaki, M. Ueno, T. Kobayashi, M. Mawatari and T. Hotokebuchi, 2008. Control of an artificial-hip-joint simulator to evaluate dislocation. Proceedings of the International Conference on Control, Automation and Systems, October 14-17, 2008, Seoul, South Korea, pp: 1942-1945.

Law, H.T., 1987. Microcomputer-based low-cost method for measurement of spatial and temporal parameters of gait. J. Biomed. Eng., 9: 115-120.

Medley, J.B., J.J. Krygier, J.D. Bobyn, F.W. Chan, A. Lippincott and M. Tanzer, 1997. Kinematics of the MATCO™ hip simulator and issues related to wear testing of metal-metal implants. Proc. Inst. Mech. Eng. Part H: J. Eng. Med., 211: 89-99.

Mizoue, T., K. Yamamoto, T. Masaoka, A. Imakiire, M. Akagi and I.C. Clarke, 2003. Validation of acetabular cup wear volume based on direct and two-dimensional measurements: Hip simulator analysis. J. Orthopaedic Sci., 8: 491-499.

Paroczai, R., Z. Bejek, A. Illyes, L. Kocsis and R.M. Kiss, 2006. Gait parameters of healthy, elderly people. Facta Universitatis-Ser.: Phys. Educ. Sport, 4: 49-58.

Rodano, R. and G.C. Santambrogio, 1987. Quantitative comparison of locomotor performance in different race walkers. Proceedings of the 5th International Symposium on Biomechanics in Sports, (BS'87), Athens, Greece, pp: 122-134.

Sadeghi, H., P. Allard, F. Prince and H. Labelle, 2000. Symmetry and limb dominance in able-bodied gait: A review. Gait Posture, 12: 34-45.

Sant'Anna, A. and N. Wickstrom, 2010. A symbol-based approach to gait analysis from acceleration signals: Identification and detection of gait events and a new measure of gait symmetry. IEEE Trans. Inform. Technol. Biomed., 14: 1180-1187.

Schmalzried, T.P., P.C. Peters, B.T. Maurer, C.R. Bragdon and W.H. Harris, 1996. Long-duration metal-on-metal total hip arthroplasties with low wear of the articulating surfaces. J. Arthroplasty, 11: 322-331.

Seeley, M.K., B.R. Umberger and R. Shapiro, 2008. A test of the functional asymmetry hypothesis in walking. Gait Posture, 28: 24-28.

Uddin, M.S., 2015. Contact of dual mobility implants: Effects of cup wear and inclination. Comput. Methods Biomech. Biomed. Eng., 18: 1611-1621.

Van der Harst, J.J., A. Gokeler and A.L. Hof, 2007. Leg kinematics and kinetics in landing from a single-leg hop for distance. A comparison between dominant and non-dominant leg. Clin. Biomech., 22: 674-680.