

## **Biomechanical Wear Tests in a Novel Hip Joint Simulator** **Yeni Kalça Eklem Simülatöründe Biyomekanik Aşınma Testleri**

<sup>1</sup>R. Bugra Husemoglu, <sup>2</sup>Orkun Halac, <sup>2</sup>Onur Hapa, <sup>1</sup>Fatih Ertem, <sup>2</sup>Ahmet Karakasli,  
<sup>2</sup>Hasan Havitcioglu

<sup>1</sup>Dokuz Eylul University, Institute of Health Sciences, Department of Biomechanics, Izmir, Turkey

<sup>2</sup>Dokuz Eylul University, Faculty of Medicine, Department of Orthopedics and Traumatology,  
Izmir, Turkey

**Abstract:** The work in this paper involves the study of the biomechanical wear tests and joint kinematics analysis. Such analyses are very useful to investigate the mobility and natural functionality as well as the motion variation due to replacement implant. The simulator can be used in implant design. The simulator is developed to provide rotation of mobility with the intention of using it for different joints loaded under body activities. Modeling the human joint as rotation is a challenge because of the complexity of linking the motion drivers of the simulator with the constrained joint motion of the joint to be simulated which inevitably involves constraining of simulator motion. In this study, a joint simulation platform has been developed. Microcontroller, relay module, DC motor and power regulators are used in building the platform. The motion of the bottom plate of a joint simulation platform is controlled by a rotational axes control system connected to one actuator independently. The actuator is used to obtain the required load and displacement. This work is performed to study the mobility, wear and load analysis of the artificial hip joint. The presented platform can be used for joint simulation, implant testing, joint kinematics, laxity analysis, load transmission. The proposed simulator has been tested for validation of the human hip implant insert. The worn surfaces were observed by scanning electron microscopy (SEM). It is shown that the wear rates obtained in this work are closer to clinical studies than to similar hip joints simulator studies.

**Keywords:** Joint simulator, hip simulator, wear testing.

Husemoglu RB, Halac O, Hapa O, Ertem F, Karakasli A, Havitcioglu H, 2019. Biomechanical Wear Tests in a Novel Hip Joint Simulator, *Journal of Medical Innovation and Technology*

**Özet:** Bu makaledeki çalışma, biyomekanik aşınma testleri ve eklem kinematiği analizini içerir. Bu tür analizler, hareketliliği ve doğal işlevselliği ve ayrıca yerine yerleştirilen implant nedeniyle hareket değişimini araştırmak için faydalıdır. Simülatör implant tasarımında kullanılabilir. Simülatör, hareketliliğin rotasyonunu, vücut aktiviteleri altında yüklenen farklı eklemler için kullanılması amacıyla rotasyonel hareket için geliştirilmiştir. İnsan eklemine dönme ekseninde modellenmesi, simülatörün hareket sürücülerini, kaçınılmaz olarak simülatör hareketinin sınırlandırılmasını içeren, simüle edilecek eklem kısıtlanmış eklem hareketi ile bağlamanın karmaşıklığı nedeniyle bir zorluktur. Bu çalışmada ortak bir simülasyon platformu geliştirilmiştir. Platformun yapımında mikrodenetleyici, röle modülü, DC motor ve güç regülatörleri kullanılmaktadır. Ortak simülasyon platformunun alt plakasının hareketi, bir aktüatöre bağımsız olarak bağlanan dönme eksenleri kontrol sistemi tarafından kontrol edilir. Aktüatör, gereken yükü ve yer değiştirmeyi elde etmek için kullanılır. Bu çalışma, yapay kalça eklemine mobilite, aşınma ve yük analizini incelemek için gerçekleştirilmiştir. Sunulan platform eklem simülasyonu, implant testi, eklem kinematiği, gevşeme analizi, yük iletimi için kullanılabilir. Önerilen simülatör, insan kalça implant insertinin doğrulanması için test edilmiştir. Aşınmış yüzeyler taramalı elektron mikroskobu ile gözlemlenmiştir. Bu çalışmada elde edilen aşınma oranlarının klinik çalışmalara benzer kalça eklemleri simülatör çalışmalarından daha yakın olduğu gösterilmiştir.

**Anahtar Kelimeler:** Eklem simülatörü, kalça simülatörü, aşınma testi.

Hüsemoğlu RB, Halaç O, Hapa O, Ertem F, Karakaşlı A, Havitçioğlu H, 2019. Yeni Kalça Eklem Simülatöründe Biyomekanik Aşınma Testleri, *Medikal İnovasyon ve Teknoloji Dergisi*

**ORCID ID of the authors:** R.B.H 0000-0003-1979-160X, O.H 0000-0002-2288-6979, O.H0000-0001-8154-658X,  
F.E0000-0002-4464-716X, A.K 0000-0002-5887-3678 H.H 0000-0001-8169-3539

Yazışma Adresi / Correspondence Address

R. Buğra Hüsemoğlu

mail: [bugrahusem@gmail.com](mailto:bugrahusem@gmail.com)

## 1. Introduction

The natural joint has to be replaced with artificial materials, there is a change in the tribological situation due to the inability of the actual materials used to produce an artificial permanent lubricating film. For this reason, the materials used to articulating components in an artificial joint are always subject to wear. Additionally, there is no ideal bearing material that currently fulfills all the requirements of total joint replacement design. Nowadays, the penetration rates of the femoral heads into the acetabular cups are so low that there should not be any problem associated with the design or functionality of the implant. However, wear particles from the UHMWPE accumulator, in particular, cause osteolysis due to the particle-initiated foreign body reaction and consequently require revision [1].

Joint simulators were developed for predicting the in vivo wear rates of total joint replacements by means of laboratory tests. In these tests the motion, load, lubrication, environment and geometries of the articulation are more similar to those found clinically than in screening wear test devices [2].

The objective of this work was to study mobility, wear and load analysis of the human joints. A hip joint simulator was designed and built for these studies. The worn surfaces were observed by optical and scanning electron microscopy.

## 2. Materials and Methods

### Hardware

#### Microcontroller

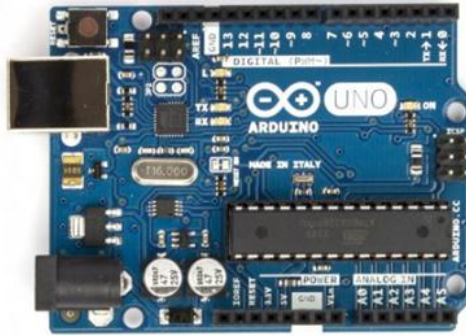
The development platform Arduino was used to implement the hip simulator presented in Fig. 4. Arduino is an open-source platform composed of two parts: Arduino board, which is the physical component (hardware), and Arduino IDE, which is the software used to develop programs that will run in the board. In this study, we used the Arduino Uno board [20]. This board has a microcontroller based on the processor Atmel atmega328p. The board specifications showed in Table. 1. The board is adequate to support the microcontroller. It is necessary to connect it to a computer with a micro-USB cable or power it with a AC-to-DC adapter or battery to get started.

**Table 1.**  
Microcontroller Specifications

<b>Microcontroller:</b>	<b>ATmega328p (8-bit)</b>
<b>SRAM:</b>	2KB
<b>Flash Memory:</b>	32KB
<b>Clock Speed:</b>	16MHz
<b>Analog Pin:</b>	6 Adet
<b>Digital Pin:</b>	14 (6 PWM)

Arduino IDE (Integrated Development Environment) is the software that allows the development of programs that will run on the Arduino board. Developed by the same team that maintains the hardware, the IDE follows the same open-source principle, all source code (developed in Java language) is available for

download on the official site. The Arduino IDE supports the languages C and C++ using special rules of code structuring. The executable code is converted into a text file in hexadecimal encoding that is loaded into the Arduino board by a loader program in the board's firmware. The board used is displayed in Fig. 1.



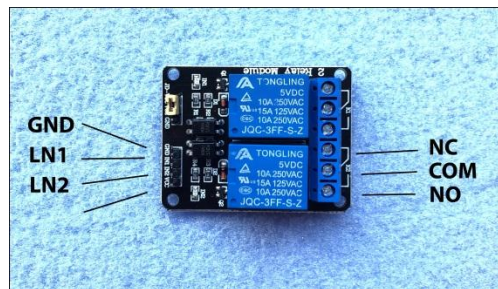
**Figure 1.**  
The Arduino Uno Board

**Relay Module**

The relay is an electrically operated switch that can switch the current on and off and can be controlled, switched on and off with low voltages such as 5V provided by the Arduino pins.

This relay module has two channels. There are other models with one, four and eight channels.

This module must be powered by 5V, which is suitable for use with an Arduino. There are other relay modules running at 3.3V, which are ideal for ESP32, ESP8266 and other microcontrollers. The relay board and connections used is displayed in Fig. 2. The six pins on the left side of the relay module connect high-voltage and the right side pin connects the low-voltage component (Arduino pins).



**Figure 2.**  
The relay board and connections

**12V Connection:** On the high-voltage side, there are two connectors, each with three sockets: common (COM), normally closed (NC), and normally open (NO).

**Relay Output:** The first Pin set consists of the following.

- COM: common pin
- NC (Normally Closed): the normally closed configuration is used when you want the relay to be switched off by default.
- NO (Normally Open): the normally open configuration works in reverse: the relay is always on.

The right set consists of VCC and GND module to energize and input 1 (IN 1) and input 2 (IN2), respectively, to control the base and top relays.

The second set of pins consists of GND, VCC and JD-VCC pins. The JD-VCC pin supplies power to the relay's electromagnet.

- GND: Grounding
- IN1: controls the first relay (Processor Digital Pin)
- IN2: controls the second relay
- VCC: 5V energy

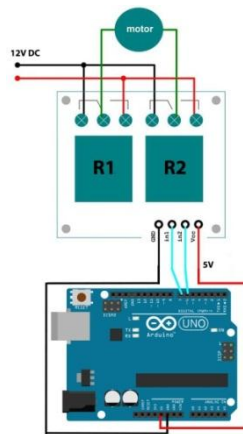
**Pin Wiring:** The low-voltage side consists of four pins and three pins.

### Electronic Circuit Design

Biomechanical testing includes a microprocessor, relay module, motor (12V) and belt pulley system. This system was established and loop simulation of hip replacement was performed. The electrical circuit of biomechanics setup is displayed in Figure 3.

### Mechanical Parts

We produced a mechanical part for hip simulator. Customizable T5 gear and motor mount produced via 3D printer. T5-1000 belt used for belt-driven mechanic system. Also sigma profiles (30x30mm) used for rigid setup frame. One circular ball was used for belt tension during movement. The simulator is shown in Figure 4.



**Figure 3.**  
The electrical circuit of biomechanics setup



**Figure 4.**  
Biomechanical Joint Wear Simulator Test Setup

### Test Procedure

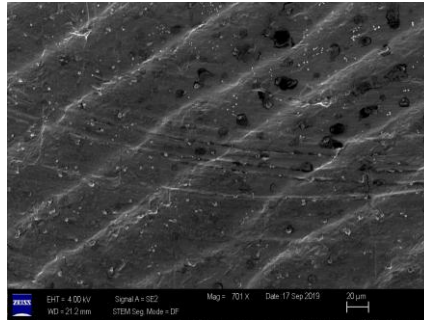
Standard total hip replacement medium femoral head, polyethylene insert and stem were used for hip joint simulator test. The universal axial testing device (Shimadzu AG-IS 5 KN, Kyoto, Japan) was used for axial loading. Stainless steel femoral stem was used as femoral stem. Tests were carried out at 1000 N

load with 30 degree flexion and extension movement compared to neutral and 10000 cycle movements were performed. All wear tests were performed using 0.9% NaCl solution was used as lubricant. The worn surfaces were observed by scanning electron microscopy (SEM).

### 3. Results

The hip joint rotation tester worked properly under 1000 N axial load. Prosthetic insert and femoral head specimens were observed to be eroded in macro size. Following the macro

observation, polyethylene surface wear was investigated by scanning electron microscope (SEM). The effects of machining marks, loading and wear on the surfaces are observed in figure 5.



**Figure 5.**  
Polyethylene hip insert surface wear

### 4. Discussion

Afifi and Jacob developed a 4-year acetabulum wear rate in 100 patients with X-ray films with the knowledge of a template developed by the Orthopedic Surgery Research and Trial Foundation[3].

Salvati et al broken and replaced two polyethylene acetabulum examined. The authors found wear above laboratory tests. In the first case, acetabulum was broken 4.5 years after the operation. In the high wear zone, the depth of the wear pit was found to be 1.4 mm. In the second case, the acetabulum was broken 6,5 years later and the depth of the wear pit was 2.6 mm. Both acetabulum were eroded to 0.5 mm / year unlike the experiments. If we say that both acetabulum is made of low-molecular polyethylene, we will explain the causes of fracture and excessive wear [4].

The influence of femoral scratching on polyethylene wear has been widely investigated on various devices and has resulted in many discrepancies being observed. Initially, linear pin-on-disc wear machines reported a significant increase in polyethylene wear with increased counterface roughness, showing up to a 30-fold increase in wear [5], [6], [7].

However, more recently, multi-directional simulator studies under serum lubrication have shown a less marked effect of increased femoral roughening[8],[9]. This reduced influence of counterface roughening is in good agreement

with clinical studies [10], [11], with many retrieval investigations showing at best a poor relationship between roughness and polyethylene wear.

Previous studies have confirmed that the influence of femoral roughness is significantly reduced when using hip joint simulation, compared to reciprocating wear test machines [8], [9].

The results are also similar to those studies using hip simulators with multiple loading axes and a more representative in vivo contact locus, thus indicating that simplified wear machines are capable of accurately predicting polyethylene wear performance. Different wear tests can be performed by angling femoral stem with the hip joint test simulator used in the study.

Furthermore, in order to simulate the movement of the hip joint, in addition to axial load and rotational movement, the movement planes need to be increased. This is the limited aspect of the study. This biomechanical setup can also be used for testing other body joints similar to the hip joint.

### 5. Conclusions

This hip simulator study has shown that the influence of femoral roughness on the wear of polyethylene, becomes greater under increased with patient activity demonstrating that roughness may be a more influential factor than

previously ascribed. It is shown that the wear rates obtained in this work are closer to clinical studies than to similar hip joints simulator studies. Thorough studies would be necessary to validate the tribological performance and their adaptability in biomedicine. These results should be compared further with clinical data to determine if differences exist in the rate of

implant loosening or defined osteolysis between different prosthetic designs.

### Acknowledgment

The authors thanks to Defne Ozturk (Izmir Biomedicine and Genome Center, Dokuz Eylul University, Izmir, Turkey) for technical support in SEM.

### REFERENCES

1. L. C. Mejia and T. J. Brierley, "A hip wear simulator for the evaluation of biomaterials in hip arthroplasty components," *Biomed. Mater. Eng.*, 1994.
2. I. C. Clarke, V. Good, L. Anissian, and A. Gustafson, "Charnley wear model for validation of hip simulatorsball diameter versus polytetrafluoroethylene and polyethylene wear," *Proc. Inst. Mech. Eng. Part H J. Eng. Med.*, 1997.
3. H. A. C. AFIFI, K. F., JACOB, "Verschleißmessungen bei Hüft-Totalendoprothesen mit Polyethylenpfanne (RCH-100) und hartverchromten Protasul-10 Kopf," *Orthop.*, vol. 119, pp. 157-162, 1981.
4. E. A. Salvati, T. M. Wright, A. H. Burstein, and B. Jacobs, "Fracture of polyethylene acetabular cups. Report of two cases," *J. Bone Joint Surg. Am.*, vol. 61, no. 8, pp. 1239-42, Dec. 1979.
5. H. Minakawa, M. H. Stone, B. M. Wroblewski, J. G. Lancaster, E. Ingham, and J. Fisher, "Quantification of third-body damage and its effect on UHMWPE wear with different types of femoral head," *J. Bone Jt. Surg. - Ser. B*, vol. 80, no. 5, pp. 894-899, Sep. 1998.
6. J. G. Lancaster, D. Dowson, G. H. Isaac, and J. Fisher, "The wear of ultra-high molecular weight polyethylene sliding on metallic and ceramic counterfaces representative of current femoral surfaces in joint replacement," *Proc. Inst. Mech. Eng. Part H J. Eng. Med.*, vol. 211, no. 1, pp. 17-24, 1997.
7. D. Dowson, M. M. El-Hady Diab, B. J. Gillis, and J. R. Atkinson, "INFLUENCE OF COUNTERFACE TOPOGRAPHY ON THE WEAR OF ULTRA HIGH MOLECULAR WEIGHT POLYETHYLENE UNDER WET OR DRY CONDITIONS," in *ACS Symposium Series*, 1985, pp.171-187.
8. H. McKellop, F. W. Shen, W. DiMaio, and J. G. Lancaster, "Wear of gamma-crosslinked polyethylene acetabular cups against roughened femoral balls," *Clin. Orthop. Relat. Res.*, no. 369, pp. 73-82, Dec. 1999.
9. A. Wang, V. K. Polineni, C. Stark, and J. H. Dumbleton, "Effect of femoral head surface roughness on the wear of ultrahigh molecular weight polyethylene acetabular cups," *J. Arthroplasty*, vol. 13, no. 6, pp. 615-620, 1998.
10. R. M. Hall, P. Siney, A. Unsworth, and B. M. Wroblewski, "The effect of surface topography of retrieved femoral heads on the wear of UHMWPE sockets," *Med. Eng. Phys.*, vol. 19, no. 8, pp.711-719, Oct. 1997.
11. R. M. Hall and A. Unsworth, "Wear in retrieved Charnley acetabular sockets," *Proc. Inst. Mech. Eng. Part H J. Eng. Med.*, vol. 210, no. 3, pp. 197-207, 1996.