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Mechanical behavior investigation for hip joint with inclination angle influence by manufacturing and design simulator instrument machine

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Abstract
The topic of the hip joint has always been of interest to the researchers, which is of a great importance to people who suffer from pain in this joint. This study is focused on the factors that have an effective role in the failure or prolongation of the lifespan of the joint. One of the most important influencing factors is the angle of inclination of the implanted cup within the pelvic bone, as it plays a prominent role in reducing or increasing friction, wear, deformation and stresses between the contacted surface that are located between the femoral head and acetabulum cavity. For the purpose of identifying the plastic deformation, strains and stresses resulting from the applying of a static load on the joint, a special device was manufactured for this purpose to simulate the natural movement of the human body, where it was very necessary to find a practical method to simulate the movement of the joint. This simulator instrument is used with the same original biomaterials that produce the hip joint components to make the results as real as possible. The principle of the simulator instrument is based on supplying pressure by a hydraulic system to produce a vertical load on the polyethylene liner and then measuring the produced strains on the liner during specified angles of motion with the three angles of inclination individually. Besides that these results are obtained also by numerical mathematical estimations for comparison and validation. Where, the investigation included study three different values for angle of inclination ($35^o, 45^o$ and 55^o degrees) studied and discussed during three phases of the gait cycle ($-10^o, 0^o$ and 30^o degrees). Finally, The experimental and numerical results showed that, when ($\theta = 35^o, 45^o$ and 55^o) the convergence strain rates approximately (13.5%) for all values of angle α. Also, it is seen the strain values at ($\theta = 35^o$) are higher than strain values at other angle due to effects of edge loading.

Keywords: Hip joints; Inclination angle; Simulation hip joint; Biomechanical; Hip phase angle.

1. Introduction
The hip joint is considered as the biggest and strongest joint in the human body, it has an especial place; where the femur (ball) and pelvic bones (socket) are contacted with each other's. This configuration gives the hip joint the stability and ability to endure the heavy loads. Beside that this distinctive formation contributes the body to move in a wide range during its daily activities of walking, running, sitting and other activities. Fig. 1, [1], shows the composition of the hip joints and as indicated, the head of the femur

is a convex shape covered with a thin cartilage while the acetabulum in the pelvic bone is a concave spherical shape and covered with a thin cartilage also. Separating the two parts by a fluid, which works as a lubricant, this fluid called Synovial Fluid (SF). The two cartilages and synovial fluid are working together to reduce the function and giving the freedom and comfort during the movement in all three directions. Besides that the hip joint is designed to bear the heavy loads and sudden loads.
There are several cases that accelerate to the failure of the hip joint. Damage of the cartilage and the decreasing in synovial fluid leads to increase the friction between the contacted bones. In addition, there are several diseases that affect this region, which lead to failure of the hip joint such as rheumatoid arthritis and osteoarthritis that cause degradation of the articular cartilage and affect the operation of the lubrication which try to limit the range of motion. As a result, failure of the hip joint and the resulted pain are led to the urgent need to replace the natural hip joint with another prosthetic by performing surgery, then, two types are,

1. Total Hip Replacement (THR), as shown in Fig. 2.
2. Hip Joint Resurfacing (HJR), as shown in Fig. 3.

More than a century, the artificial hip joint is used, but over the past five decades the studies were interested to achieve a better design for the hip joint as much as possible. The total hip arthroplasty (THR) is an ideal solution for the patient who suffers from failure and pain in this joint. Besides that, after all these years of theoretical and experimental studies, (THR) is considered from the successful operations worldwide.

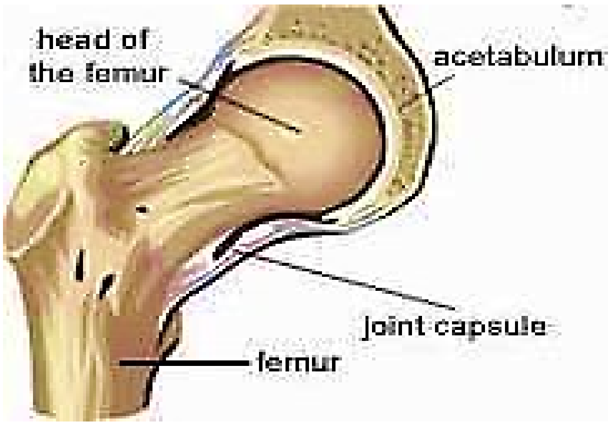


Figure 1. The Natural Hip Joint.

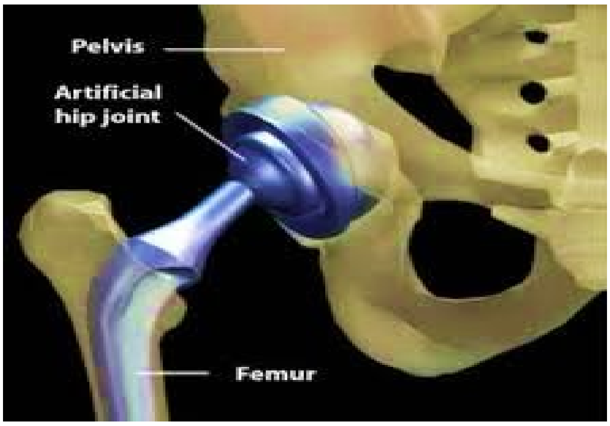


Figure 2. Total Hip Replacements (THR).

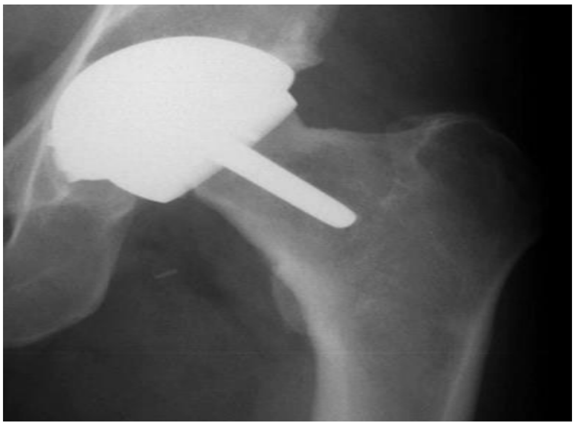


Figure 3. Hip Joint Resurfacing (HJR).

Therefore, several types of total hip replacement which are used in the production of hip joints as follows,

1. Metal on metal hip joint (MoM), there are several types of metals which are used in the production of hip joints as follows, stainless steel, titanium-aluminum-vanadium, and, cobalt-chromium-molybdenum. The studies showed good characteristics that made (MoM) has a longer period of use,

like a high durability and a low rate of wear. But there are side effects for utilizing this type, like the debris which are produced due to the friction in the contact surfaces between the ball and the socket and the small particles of metallic debris (in Nanometer) which enter the blood circulation and cause toxic, [2].

2. Metal on polyethylene hip joint (MoP), its acceptable specifications such as shock absorption and cheaper cost than other types which were used in the production of the artificial hip joints. In addition, the resulted friction in the contact surfaces is very low, [3].
3. Ceramic on polyethylene hip joint (CoP), its durability and high compatibility with the human body. Besides that, there are low wear and friction rates between the contact surfaces of the hip joint which are used ceramic head on polyethylene cup compared with the hip joint which are used metal head on polyethylene cup. Several kinds of ceramics are used in the total hip joint, for a long time pure alumina (Al2O3) has used for femoral head due to its excellent biocompatibility and high corrosion and wear resistance. Another kind of ceramics, zirconia (ZrO2), is used in the orthopedic field due to its higher fracture toughness, great resistance to the wear and the friction occurred in the contact surface and more compatibility when it compared with alumina, [4].
4. Ceramic on ceramic hip joint (CoC), this type of hip joint arthroplasty is used due to the higher mechanical properties of ceramics. Zirconium oxide (ZrO2) and aluminum oxide (Al2O3) are the most wide types of ceramics that are used on both bearing surfaces. Ceramics are considered as brittle materials, no ductility and a limited bending strength so; there is a risk of fracture of ceramic head and sometimes the implants break suddenly without warning. An increase in body weight, a high activity level and an entrapment of a foreign body between the taper and the ball played a role to fail the hip joint. However, ceramic is still used widely for its high specifications as a low rate of wear and friction, [5].

Therefore, many types of materials are used in the manufacturing of the artificial hip joint. The most important characteristic of these materials is its compatibility nature with the human body. These materials were used as an alternative to the anatomical parts affected in the physiological system, so they must be of high rigidity, high resistance to corrosion and wear, low rate of friction and non-toxic. Then, the following types and characterizations for materials are used,

1. Metals, the Metals are the first materials used in the manufacture of hip joints due to its durability and high resistance to wear and friction. The problem with the use of metal in the stem industry is that, the stiffness of the metal is greater than the stiffness of the bone five to six times, which leads to increased stress on the femoral bone, [6]. There are, the following types can be using for the hip joint materials, as, stainless steel alloys, titanium alloys, and, cobalt-chromium alloys.
2. Polymers, Polymers are commonly utilized in (THR) articulating bearing surfaces and also are worked as bone cement surface to stabilize the implant within bone cavity Due to the low friction rates, preference has been given to the use of the polymer in these areas. Polymers are utilized also for its best mechanical properties and cheap cost. There are two kinds of polymers, as, PMMA (is used as bone cement to join the components of the implants), and, UHMWPE (is used in a wide range due to its high stability and the excellent mechanical properties), [7].
3. Ceramics, Ceramics had been used in the manufacture of hip joints in recent years instead of polyethylene and sometimes instead of metal. Ceramics have a good biocompatibility and stability Due to its high stiffness and resistance to corrosion and wear. All of these superior mechanical properties have given ceramics the advantage in the manufacturing of the joints compared with (MoM) or (MoP) hip joint replacement. There, Two types of ceramics will mention, as, Alumina (Al2O3), is utilized in the production of (THR) due to its high resistance to wear and also for its high compatibility, and, Zirconia (ZrO2), is an oxide ceramic with high resistance to friction, wear, corrosion and chemical inertness, [8].

Then, in general, the materials are used for biomechanical application must be have multi characterizations, as, biocompatibility, stability, high resistance to wear and friction, high rigidity, and other properties. Therefore, many researchers investigated the modified for its materials to get best materials with good characterizations. Then, due to important for hip joint replacement, then, Many studies discussed this topic, most of them had attempted to understand the reasons that lead to failure of the hip joint and to study the stresses and changing forces that exposed to it during daily activities of the healthy person and compared with the person who underwent replacement of the joint. Some of previous researches and studies will display as,

Firstly, at 1994, F. Eckstein et. al, [9], used five configurations with different geometry for a ball and socket; these models were similar to the natural hip joint. In this research, the authors estimated the stress distribution and the Von Mises stresses of multiple values of applied loads and at a specified depth to the edge of the socket. They used a program that deals with a variable contact stresses, the results showed that the stress distribution depended on the head diameter size where there is an increase in loads, the stress at the edge is less than at the stress at the depth of the socket.
Then, at 1999, C. Bajer et. al, [10], explained the reasons that led to the prosthesis loosening. They used a numerical simulation to estimate the stress concentration in the implanted stem in the thigh bone, where it was considered as one of the important mechanical factors. This study showed that, changes of the material rigidity and stem form could decrease external stresses by (10 to 20%).
At, 2002, M. M. Mack et. al, [11], explained the edge contact that occurred in (CoC) hip joint when there is a micro-separation between the ball and socket. In this study the researchers used a finite element in three –dimensional model and they noticed the effect of the radial clearance between the femoral head and the cup on the contact stresses and edge loading. Beside that a fillet radius of (2.5mm) of the cup edge worked to reduce edge loading on the cup mouth.
Then, at 2003, O. Colonius et. al, [12], studied the friction that produced in the hip joint and they recognized the amount and type of the resulting wear by using a simulation system for the applied forces on the cup and implanted stem. This study developed a new method of recognizing the steps of wear by using specified track which are pointed on the polyethylene cup during the movement. These points gave a guide to the critical cases than others and also explained the pressure distribution on the hip. After this, at 2005, S. M. Oliveira, [13], utilized two ways to calculate the changes of the surface roughness when there is a mechanical contact between the articulate surfaces. The first way depends on the mathematical models that are used to estimate the pressure distribution, plastic deformation and effect of the rough surface. The second type depends on experimental method, where the statistical surface parameters are too important for foreseeing the wear and plastic deformation. Load is applied in a glass disc on a three different specimens and by using a camera to capture the changes in the roughness profile, the results of the two methods are coherent and similar.
A. Anderson at 2007, [14], developed a new study about modeling the parts that are more prone to failure in hip joint prosthesis. The author used the finite element method (FEM) to create a model that simulates the size of the pelvis bone with a developed entire hip joint. The accuracy for the modeling is too important, the thickness of the cartilage and the cortical bone are necessary to be used for this purpose by phantom based on imaging studies. Therefore the results of (FEM) are compared with the experimental results. Then, at 2012, M. Al Hajjar, [15], discussed two types of mal-positioning that are occurred in the hip joint prosthesis which cause edge loading. The first type is rotational mal-positioning, and the second type is translational mal-positioning. The author is focused to understand the wear mechanics and factors which lead to failure of the hip joint, by utilizing different sizes of (MoM) and (CoC) bearing under different values of edge loading and determining the effects of the two types of mal-positioning which lead to increase wear.
At, 2014, L. C. Brezeanue, [16], discussed and presented a comparison between the Hertzian theory and the finite element method (FEM) results of the contact tension that occurred between two bodies. Two contacted spherical bodies with different radius and a spherical body with a specified radius rests on a flat plane. The results gave a similarity and convergence between the values of the equivalent Von Mises stress, the principal stresses and the shearing stress. Both the results of the numerical calculation (FEM) and Hertzian theory of the two models applied gave a validation. After this, at 2015, J. Girard, [17], encountered the effect of the femoral head diameter size in the joint replacement process, as it had a significant effect throughout the period of use, reduction of friction, avoid dislocation and exclude chronic pain after implantation. In this paper two types of hip joint replacement were studied; Ceramic-on-Ceramic (CoC) and Metal-on-Metal (MoM) replacements, it found that no more difference between these two types. The author showed three ranges of head diameter sizes: small diameter (22 to 28mm), medium diameter (28 to 36mm) and large diameter (more than 36mm).
Finally, at 2017, M. Wang et. al, [18], studied a mathematical expression to estimate the contact stresses between the articulate surfaces and they used also the numerical calculation by using (FEM) for the same purpose. That facility is very necessary when designing the hip joint and to avoid the risks that may be exposed to it as much as possible. Finally, M. Al-Waily et. al., [19], investigated the effect for gait cycle and inclination angle on the stress distribution by using numerical modeling for hip joint, with used for

finite element technique. Where, the investigation included analysis for the stress at the ball and cup for hip joint made of the different materials.
All the previous studies discussed the reasons that led to failure the hip joint individually form; where they were about diameter size, effect of the clearance, effect of the cup thickness, supplying load with one specified angle of inclination through the gait cycle and the effect of the lubrication regimes on the contact surface. Most of these studied concerned on the numerical or mathematical sides and there is no comparison with the practical results in details. This study aims to identify the effect of the edge loading which occurred in the hip joint when supplying a vertical force on the joint at different angles that correspond to the real angles during the gait cycle with different angle of the cup inclination. The experimental method ,by manufacturing a simulator instrument to measure the strains that are exposed to the cup during a movement at different angles (phases).

2. Numerical Work

The numerical methods which are used to estimate the mechanical behavior for structure with approximate solution, [20-23]. There, multi programs which using to analysis the mechanical behavior for system by using numerical technique, [24-28]. Thus, during several decades and with the great technological development, the need to use numerical programs in all important and necessary calculations is increased related to all aspects of scientific, medical, engineering and all different sciences. In this research will deal with one of these types of method which is the finite element method (FEM). Numerical methods, such as finite element method, are used to provide acceptable approximate solutions, [29-33]. Therefore, its methods which are can be using to estimate the deformations and stresses in the hip joint application. In general, it is based on three procedures, make a formulation for the problem, a discretization for the finite element and finally arrangement the solution of the equations that arise for each finite element. After the high technological development in the productions of computers, these procedures became easier to accomplish with the relative modeling of the problem. The FEM is based on an important principle which is, a body is divided into smaller bodies, the finite elements, which approximately form the total model of the body. These elements are interconnected at common points, the nodal points or nodes, or boundary lines, or surfaces. This process is called discretization or mesh generation, which provides us with a mesh of finite elements, [34-38]. Thus, with this method we form and solve the equations for every finite element which are combined to find the solution for the entire body instead of solving the whole complicated problem for the body.
More than one commercial software package that is programmed to give us more accurate estimations to the reality in a variety of structural and solid mechanics problems, in this study, Solid-Works package is used for drawing and simulation of the hip joint. As previously mentioned, in this study the Solid-Works program will be used for two purposes in this research, the first purpose is for drawing a modular model of (MoP) according to the standards and global designs of the manufacturers of the total hip replacement (THR). The other lower part is the stem which is implanted in the thigh bone. Table 1, illustrated the sizes of the articulated parts (the ball and socket) of the main specified cases in this study. Where there are fixed dimensions, the thickness t of the socket $6\ \mathrm{mm}$ and the radial clearance R_C between the ball and socket is $0.04\ \mathrm{mm}$, thus, our study dealt with model shown in Fig. 4. Incorporate the mechanical properties of the components which are used in the design. All the mechanical properties are mentioned previously in Table 2. Will mention to the materials in an individual table as shown in Table 3, [39].
It is very important in this study to consider the same mesh pattern for the contacted area between the ball and socket (the outer head surface and the inner liner surface) to ensure the placed nodes in the articulating surfaces do not interface with the target area. FE model comprised approximately $(113{,}541)$ six-node triangular solid elements, including $(52{,}680)$ elements for the liner and $(60{,}861)$ elements for the femoral head and the stem together where are considered as one body with element sizes less than $2\ \mathrm{mm}$. To avoid nodal penetration problem; designing of a polar mesh is selected, Fig. 5 shows liner and ball mesh type. Due to the worst mechanical behavior of polyethylene, therefore it is necessary to study polyethylene in individually case as it done in this study. Fig. 6 shows the stability of the deformation value for the liner where it stabled at $(35.2\ \mathrm{micron})$ when degree of freedom was $(207{,}213)$ and at the same number of elements were mentioned before. The results of the mechanical behavior for hip joints will be calculated automatically by the program according to the data and the conditions mentioned above. Also make a comparison with the other results from the experimental estimations.

Table 1. Dimensions of the Liner Socket and Ball.

Cases	Inner-Socket Diameter (mm)	Outer-Socket Diameter (mm)	Ball Diameter (mm)
1	28.08	40.08	28
2	32.08	44.08	32
3	36.08	48.08	36

Table 2. Mechanical Properties of Biomaterials Artificial Hip Joints Materials.

Material	Characterizations					
	σ_{st}	σ_y	ε_f	H_v	E	σ_f
3161 SS (Annealed) Wrought	650	280	45	190	211	280
Co-Cr Alloy	1540	1050	9	450	541	490
Cast Co-Cr Alloy	690	290	8	300	241	300
Titanium	710	270	30	-	121	300
Ti-6Al-4V	1000	970	12	-	121	-
Human Bone	137.3	-	1.49	26.3	30	-

σ_{st}: Tensile Strength (MPa), σ_y: Yield Strength (MPa), σ_f: Fatigue Limit (MPa), ε_f: Elongation at Fracture, H_v: Vickers Hardness, E: Young's Modulus (GPa)

Table 3. Mechanical Properties of the Socket and the Ball Materials.

Components	Materials	E	ν
Cup	UHMWPE	0.975	0.46
Head	Cobalt-Chromium Alloy	225	0.3

E: Young's Modulus (GPa), ν: Poisson's Ratio

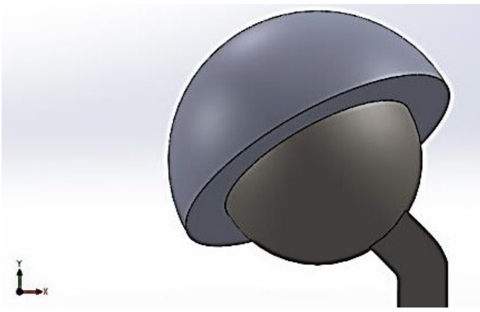


Figure 4. Hip Joints Model.

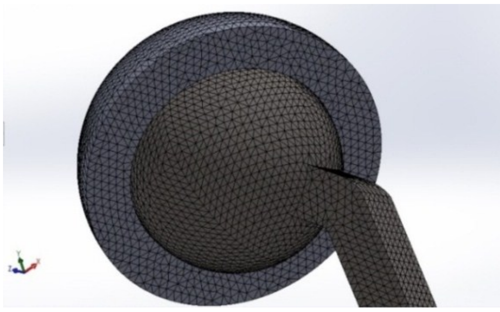


Figure 5. The Ball and Liner Socket Mesh Element.

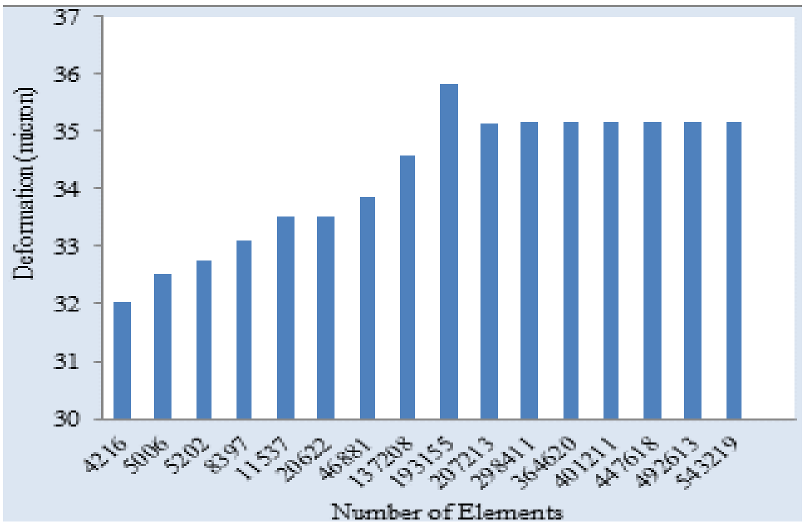
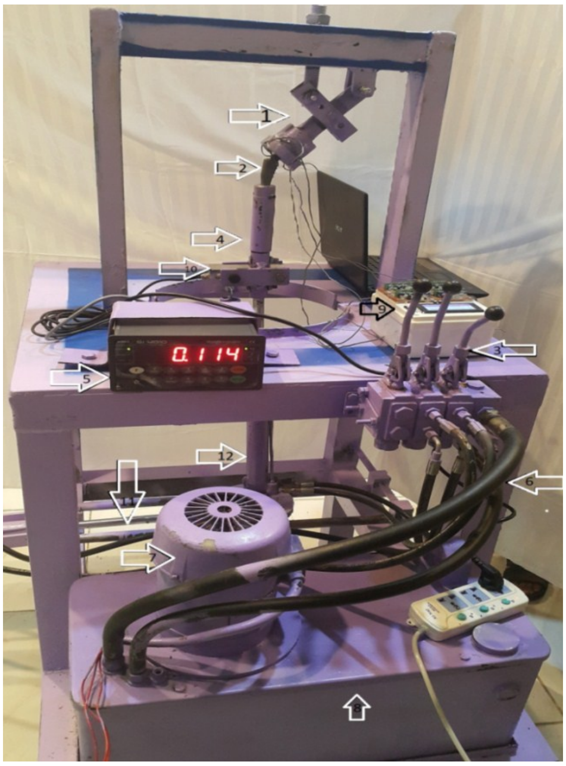


Figure 6. Degree of Freedom Stability with Number of Mesh Elements.

3. Experimental Investigation Technique

A special device has been designed and manufactured to simulate the normal movement of the human body and estimate the produced strains on the polyethylene liner within certain leg angles $(-10^{o}, 0^{o}$ and $30^{o})$ as these three phases represent variable transitions during normal walking. Static load 3000 N is supplied in the same direction of the leg movement and affected on the contact area between the implanted acetabular cup, which is implanted at different inclination angles $(35^{o}, 45^{o}$ and $55^{o})$, and the ball at the top of the iron leg. This load is produced by a hydraulic system which supplied a pressure that pushes the iron leg towards the liner. A load cell is placed up the iron leg to measure the load that supplied on the liner. However, there are four implanted strain gauges on the polyethylene thickness to measure the resulting strains in (x and z directions). The Experimental rig (simulator) consists of several items (instruments) and all of these items are installed on a cube iron- structure shape, as, height 170 mm, width 90 mm, and, depth 90 mm.
Simulator instrument, as shown in Fig. 7.a, consists of multi parts, and, Fig. 7.b, illustrates all the components of the simulator instrument. A modular of (THR), with the same biomaterial as mentioned as, Titanium stem 150 mm, Cobalt-Chromium head 28 mm, and UHMWPE liner ≥ 28 mm, as shown in Fig. 8, is inserted into the iron leg where its head is in touch with the cup. Connecting all the components of the simulator instrument in the correct form, it is necessary to do a test for the simulator in more than angle at least twice. After testing, will choose three specified positions for the iron leg as explained previously which were $(-10^{o}, 0^{o}$ and $30^{o})$ and numbered them as 1, 2 and 3, respectively, where every single position is placed and controlled manually by the horizontal hydraulic piston.



a. Structure

Part	Components
1	Cup Jig
2	Modular THR
3	Manual Control
4	Iron Leg
5	Strain Gauge Indicator
6	Hydraulic Pipes
7	Hydraulic Pump
8	Hydraulic Tank
9	Strain Gauge Data Logger
10	Load Cell
11	Horizontal Hydraulic Piston
12	Vertical Hydraulic Piston

b. Simulator Components

Figure 7. Simulator Instrument.

Also to choose angle of the liner inclination, that possible by placed the cup jig in a specified angle, here, these angles are limited $(35^{o}, 45^{o}$ and $55^{o})$. All previous positions, 1, 2 and 3, will use individually with these cup angles. Supplying a hydraulic pressure by the vertical piston, which is in touch with the polyethylene liner, there is a load cell is fixed on a small plate between the iron leg and the modular stem. By increasing the supplied pressure by a manual hydraulic control, the head (ball) of the modular (THR) tries to produce contact pressure on the polyethylene liner, until the indicator screen reads a force value equals to 3000 N, at this force value the vertical piston will stop. Four strain gauges are implanted in the thickness of the polyethylene liner in two directions (x and z axis), where strain gauges (A,C) are measured the produced strains in (x-axes) and (B,D) in (z-axes) respectively, as shown in Fig. 9. These sensors are connected by lead wires to a Strain Gauge Data Logger (SGDL) which converts the coming signals from the sensors to digital values appeared on the (SGDL) screen. These values are corrected by a gauge factor of (3.3667) and divided by 10^6 to be the results in micron. Same procedures are repeated with all angles of inclinations to estimate that produced strains due to supplied static load of (3000N). Then, after calculating results, must be comparison for its results with other numerical results are calculated, [40-46].

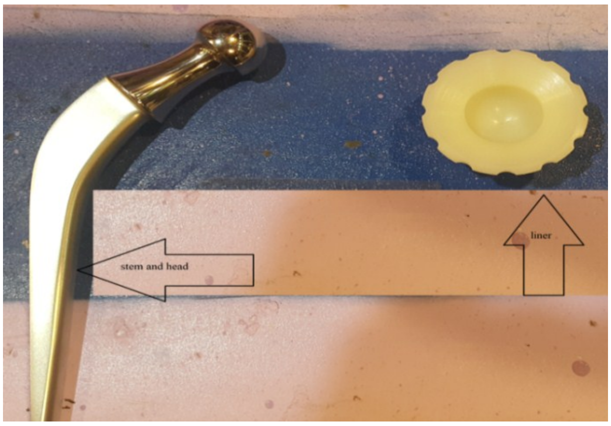


Figure 8. Modular (THR).

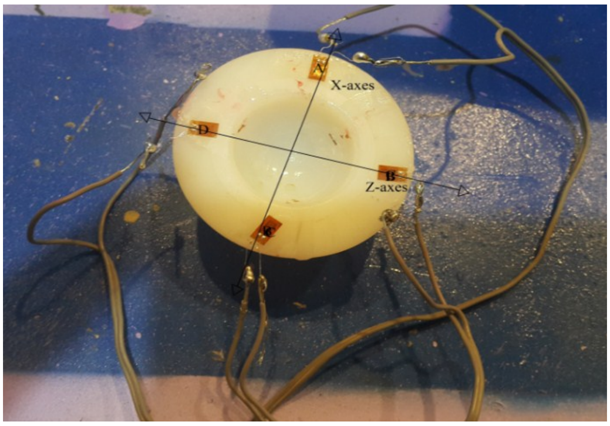


Figure 9. Strain Gauges Directions (x and y-axis).

4. Results and Discussion

The results are including review the results that are obtained from the numerical and experimental techniques and make a comparison among these results, with various hip parameters effect. The studied include estimation the stresses and the equivalent plastic strain of liner of the hip joint, with a vertical force of (3000N) was applied to the liner. By using the simulator that manufactured for estimation the plastic strains in the polyethylene liner at the same specifications that of case one, shown in Table 1. Where, the comparison was among the numerical values of the plastic strains in (x and z axis) directions due to these values are more interest to study. Because the liner is not constrained in y-axis while is fixed in the two other axes (x and z axis).

For experimental estimations, the simulator (which was manufactured) is used for this purpose. Three sensors (strain gauges) are implanted in the liner and at the same time three implanted points inserted in the mesh for numerical estimations. Both the sensors and the points are with radial degree of 120^o between every sensor and other. Figs. 9 and 10, show the position of the sensors in the liner. For the validation the results of sensors (A, B, C and D), both the experimental and numerical measurements values are compared.

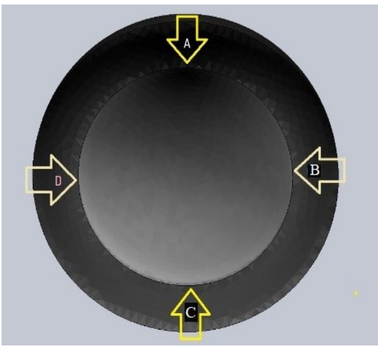


Figure 10. Sensors Positions on the Polyethylene Liner by Solid-Works.

There, the comparison between experimental and numerical strain results of hip joint with different phase and inclination angle, for hip joint with materials properties presented in Table 2, and dimension for case 1 presented in Table 1. Then, its comparison are presenting in Fig. 11. a to h, which are figure showed the convergence between the experimental and numerical estimations are rated between (10.5-12.7%) between the four sensors (A, B, C and D) at various inclination and phase angle effect. Sensors (A and B) are closer than sensors (C and D) to the area of contact, therefore their values are greater. Many reasons are

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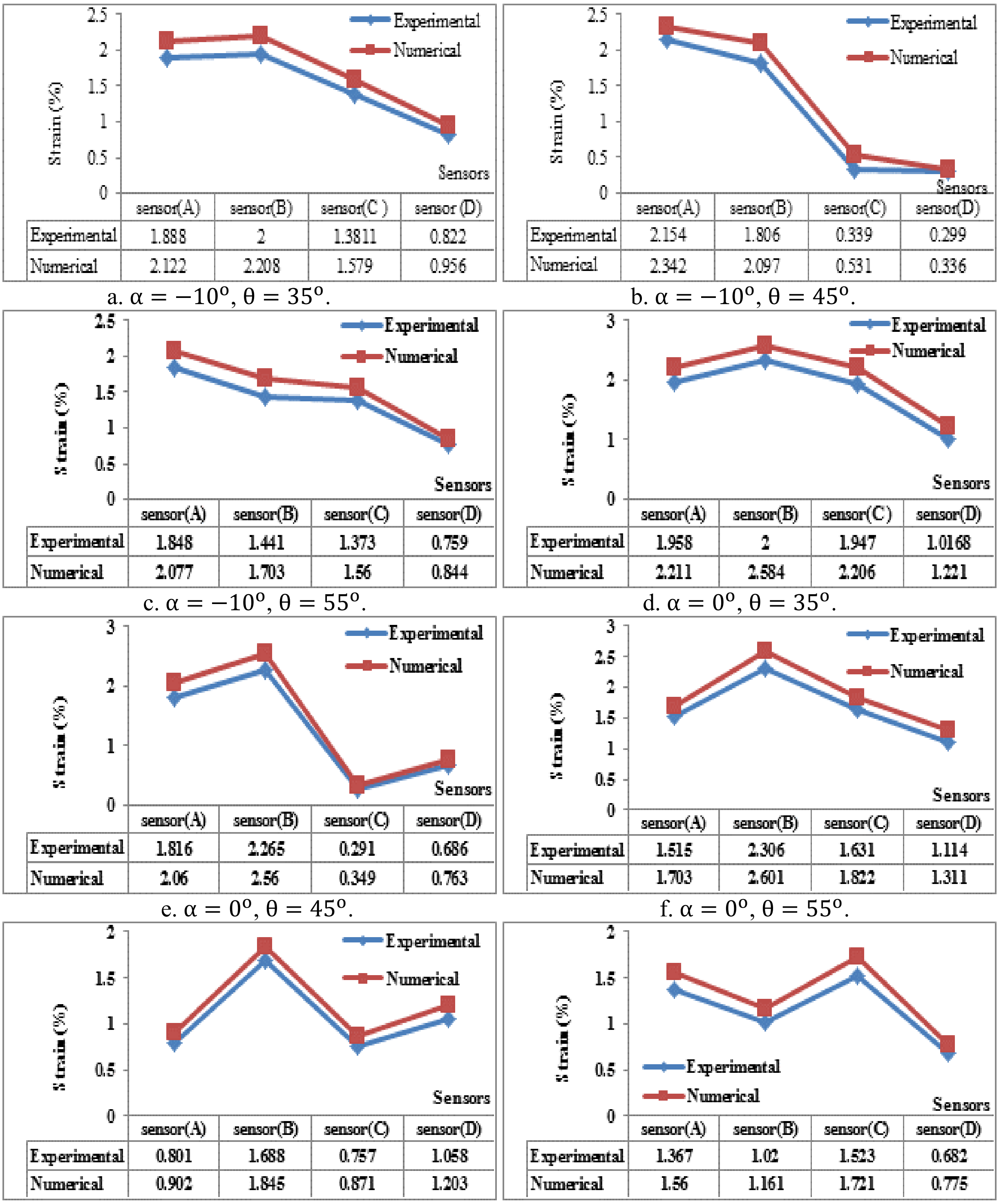
responsible and have a great role on the differences between the two methods and it can be observed that; the experimental values are less than numerical values. As mentioned previously, the figures will illustrate all the numerical and experimental strain values and give an imagination about the behavior of the results for all values of the inclination and phases angles with a specified liner diameter size of (28.08 mm).



	sensor(A)	sensor(B)	sensor(C)	sensor (D)
Experimental	1.888	2	1.3811	0.822
Numerical	2.122	2.208	1.579	0.956

a. $\alpha = -10^o, \theta = 35^o$.

	sensor(A)	sensor(B)	sensor(C)	sensor(D)
Experimental	2.154	1.806	0.339	0.299
Numerical	2.342	2.097	0.531	0.336

b. $\alpha = -10^o, \theta = 45^o$.

	sensor(A)	sensor(B)	sensor(C)	sensor(D)
Experimental	1.848	1.441	1.373	0.759
Numerical	2.077	1.703	1.56	0.844

c. $\alpha = -10^o, \theta = 55^o$.

	sensor(A)	sensor(B)	sensor(C)	sensor(D)
Experimental	1.958	2	1.947	1.0168
Numerical	2.211	2.584	2.206	1.221

d. $\alpha = 0^o, \theta = 35^o$.

	sensor(A)	sensor(B)	sensor(C)	sensor(D)
Experimental	1.816	2.265	0.291	0.686
Numerical	2.06	2.56	0.349	0.763

e. $\alpha = 0^o, \theta = 45^o$.

	sensor(A)	sensor(B)	sensor(C)	sensor(D)
Experimental	1.515	2.306	1.631	1.114
Numerical	1.703	2.601	1.822	1.311

f. $\alpha = 0^o, \theta = 55^o$.

	sensor(A)	sensor(B)	sensor(C)	sensor(D)
Experimental	0.801	1.688	0.757	1.058
Numerical	0.902	1.845	0.871	1.203

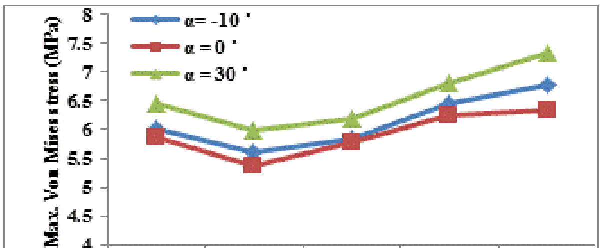
g. $\alpha = 30^o, \theta = 45^o$.

	sensor(A)	sensor(B)	sensor(C)	sensor(D)
Experimental	1.367	1.02	1.523	0.682
Numerical	1.56	1.161	1.721	0.775

h. $\alpha = 30^o, \theta = 55^o$.

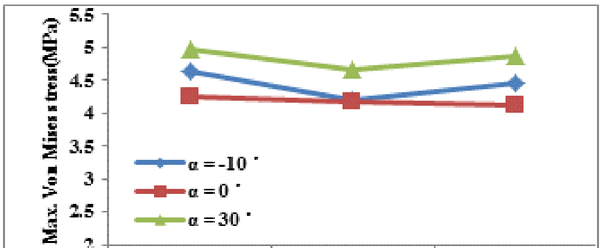
Figure 11. Comparison for Experimental and Numerical Strain Results ($\times 10^{-1}$) for Hip Joint, with Various Phase and Linear Inclination Angle Effect.

Therefore, after comparison the results are calculated by two techniques, presenting investigation for various angle effect on stress behavior for hip joint. The load was applied vertically in different angles of motion α through the gait cycle to the finite element model with every specified angle of inclination θ. It is cleared that, the maximum Von Mises stresses of the liner are changed when (α) changed. There, the maximum Von Mises stresses firstly decreased by approximately $(7-8\%)$ when θ increased from $(35^{o}$ to $45^{o})$ and then increased about $(4, 13.5$ and $18\%)$ when θ increased up to $(55^{o}$ to $75^{o})$, respectively. Thus, Fig. 12 illustrated the variations of the maximum Von Mises stresses, with various hip cases shown in Table 1, for angle of inclination. These figures and rates are shown an important behavior of the liner, at $(\alpha = 0^{o})$ all the results are less than the two other positions of motion $(\alpha = -10^{o}$ and $30^{o})$ due to the edge loading is not concentrated and also the leg is stroked the ground lightly than other two positions. Also, it is clear that, the behavior for cases one, two and three are same. Wherein the maximum values are at angle $(\theta = 35^{o})$ and minimum values at $(\theta = 45^{o})$ besides that changes of motion angles have the same effects on the results.



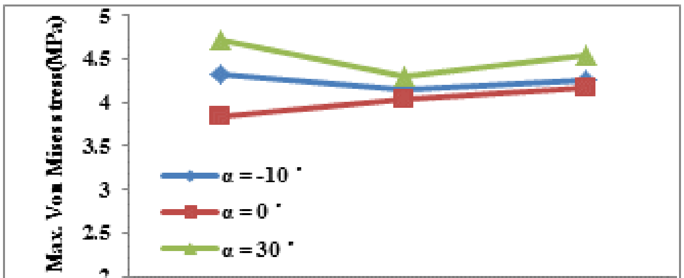
	θ = 35 °	θ = 45 °	θ = 55 °	θ = 65 °	θ = 75 °
α= -10 °	6.0234	5.6034	5.8334	6.452	6.791
α = 0 °	5.8816	5.3816	5.787	6.253	6.332
α = 30 °	6.4644	5.9918	6.1767	6.822	7.336

a. Case-1.



	θ = 35°	θ = 45°	θ = 55°
α = -10 °	4.6326	4.2047	4.459
α = 0 °	4.2471	4.1673	4.1231
α = 30 °	4.959	4.672	4.8787

b. Case-2.



	θ = 35 °	θ = 45 °	θ = 55 °
α = -10 °	4.3275	4.1427	4.2691
α = 0 °	3.8505	4.0296	4.1615
α = 30 °	4.7306	4.3083	4.552

c. Case-3.

Figure 12. Maximum Von-Mises Stresses (MPa) for Hip Joint System with Different Phase and Inclinations Angle Effect, and Various Hip Cases.

5. Conclusion

After the estimation of the stresses and strains in the polyethylene liner by both Numerical (Solid-Works program) and experimental methods (simulator instrument). All these methods gave a prediction about the important reasons which are responsible in a way or other on the activity and lifespan of the hip joint.

There are several important points can be noted from the previous results and discussions:

1. There is a clear effect of the angle in which the cup is implanted into the acetabulum. Where the current study showed that the amount of stresses and strains when the angle is equal to 35^{o} are higher than when the angle is equal to $(45^{o}$ or $55^{o})$. In addition, when the angle of the inclination increases to more than 55^{o} all the results are higher than it at 35^{o}. This supports proves that safe zone of the angle of inclination ranges between $(45^{o}-55^{o})$.
2. Edge loading begins to appear prominently when the angle of the inclination greater than 55^{o} degrees where the effect of the force is closer to the rim of the liner, therefore, edge loading must be avoided.

3. In some phases of the gait cycle, the joint is exposed to more stress than other. Three different phases were studied and the results showed that the start of the movement (heel strike) is more severe and dangerous than other phases, so the patient should be careful when starting the movement.
4. The comparison for experimental and numerical results are given a good agreement for percentage error, about (12.7%), between results are evaluated by two techniques. Then, from comparison for results can be accordant on the experimental techniques, with simulator instrument, to evaluate the mechanical behavior for hip joints system.

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