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Finite Element Analysis of Elbow Arthroplasty

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***Abstract*— This article provides an information of the biomedical engineering modeling and approach of the elbow arthroplasty process. In this investigation also gives the conceptual design of the total replacement elbow joint which was allows the formulation and analyzing. The complete assembly of elbow model was designed in Creo parametric and analysis done using ANSYS tool, which was gives the results of proposed design and compare between existing and proposed work. Throughout the paper concluded the proposed design was gives the maximum efficient work in suitable material which is cobalt chromium alloys after analysis and comparison in good literature.**

***Keywords*— Elbow arthroplasty, finite element analysis, titanium, cobalt chromium, Von-Mises stresses.**
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I. INTRODUCTION

The elbow implant is used on patients with arm joint pain and disabilities. Samples of conditions inflicting the arthritis and Rheumatoid Arthritis and Osteoarthritis. Arthritis could also be pathologic at intervals that the animal tissue settled in between the humerus and therefore the radius and ulna, that surrounds the joint becomes inflamed and thickened [1]. This may cause harm to the tissue and eventually, pain. Degenerative arthritis joint disease is most generally referred as "wear and tear" arthritis. This disorder happens due to repetitive movement of the joint, inflicting the animal tissue (cartilage) artefact the two bones forming the hinge movement to wear away. because of the animal tissue (cartilage) becomes dilatant, the humerus and radius and ulna would possibly rub against each other, inflicting pain to the elbow.

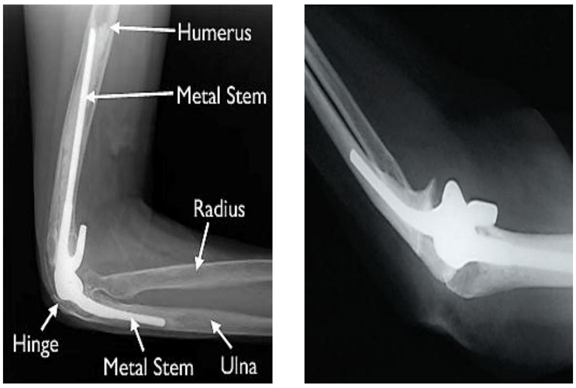

Figure 1 elbow implant X-ray images

A. Link Segment Model

Link section analysis could also be started with a bottom level approach where ground reaction forces functioning on the feet is entered the model first or a top-down approach where forces functioning on the hands area unit accustomed drive the analysis [3]. Link section models are of two types:

a) Static link section model

b) Dynamic link section model

Link section model for the force analysis within the body once a load of specific amount is upraised within the bending condition [3]. The Figure 2 shows the detail link section model drawing of the physique in bend position.

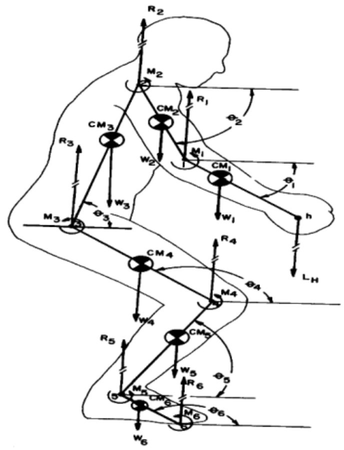

Figure 2 Human body link segment model

II. MATERIALS

For materials to be thought-about a biomaterial it ought to be ready to safely degree dependably replaces or perform in living tissue with an applicable physiological response [5]. In other words, the materials ought to be biocompatible. There are four teams of artificial biomaterials: polymers, metals, ceramics, and composites [5].

A. Alumina

The single crystal corundum is hard and powerful but is simply too brittle to be used as articulating part. Like most ceramics, the strength of crystalline corundum is improved by decreasing consistency and grain size [5]. Aluminium oxide implant ought to have a flexural strength and modulus of elasticity of 380GPa to meet ASTM standards F603-78 [5].

B. Stainless Steel

The most common form of stainless-steel used for implants is 316L (ASTM F138, F139) [7]. The inclusion of 2.25-3wt.% molybdenum improves salt water corrosion resistance, whereas the drop-in carbon content from 0.08-0.03wt.% maximum improves chloride resolution corrosion resistance.

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C. Cobalt-Chromium Alloys

The two cobalt-chromium alloys most often need to manufacture implants are CoCrMo (ASTM F75) and CoNiCrMo (ASTM F562). CoCrMo is castable and commonly used in implant applications, whereas CoNiCrMo is hot solid and regularly used to the stem of joint replacements in legs. The properties of CoCrMo ar usually improved by hot isostatic pressing [7]. The addition of chemical element provides the alloy higher strength by preventative grain growth. Despite these variations, however, the trade designation of Vitallium (or within the Great Britain, "Stellite") is often applied erroneously to every alloy. The cobalt-based alloys show a useful balance between mechanical properties and biocompatibility, every type being somewhat superior to stainless-steel in strength and corrosion resistance, however, dearer to manufacture.

D. Titanium Alloys

Pure (98.9-99.6%) titanium has four completely different grades, correlating to an increase in impurity content [7]. These impurities, like oxygen, carbon, and nitrogen, greatly influence the mechanical properties of titanium through opening primary solid solution strengthening. Nitrogen offers concerning double the strengthening impact per atom, however oxygen content varies the foremost between the grades, rising from 0.18% (grade 1) to 0.40% (grade 4). Hydrogen impurities will harm the malleability of the metallic element through the formation of hydrides [8]. Because of this, the most quantity of hydrogen allowed in titanium element is 0.015wt%. Cold working has been shown to increase the fatigue strength of titanium element [7]. The fatigue strength of pure titanium element is much inferior to alloyed titanium element, it is shown in Table 2.

TABLE 1 BLOOD COMPATIBILITY PROPERTIES OF BIOMATERIALS.

S. No.	Properties	Stiffness	Strength	Corrosion resistance	Blood compatibility
1.	Stainless steel	Best	Better	Good	Good
2.	Co-Cr alloys	Better	Good	Better	Better
3.	Ti-alloys	Good	Best	Best	Best
4.	Polyester	Good	High	High	Moderate
5.	Polytetrafluoroethylene	High	High	High	Low
6.	Polyurethanes	Better	Medium	Medium	Good

TABLE 2 PROPERTIES OF IMPLANT MATERIALS.

Materials	ASTM designation	Condition	Young's modulus (GPa)	Yield Strength (MPa)	Tensile Strength (MPa)	Fatigue endurance limit (at 107cycles, R=-1) (MPa)
Stainless Steel	F745	Annealed	190	221	483	221-280
	F55, F56, F138, F139	Annealed	190	331	586	241-276
		30% Cold worked	190	792	930	310-448
		Cold forged	190	1213	1351	820
Co-Cr alloys	F75	As-cast/ Annealed	210	448-517	655-889	207-310
		Powder metallurgy product, hot isostatically pressed	253	841	1277	725-950
	F562	Hot forged	232	965-1000	1206	500
		Cold worked, aged	232	1500	1795	689-793
						(axial tension R = 0.05, 30 Hz)
Ti alloys	F67	30% Cold-Worked Grade 4	110	485	760	300
	F136	Forged Annealed	116	896	965	620
		Forged, heat treated	116	1034	1103	620-689

III. METHODOLOGY

Elbow, vary of motion of an elbow joint is within the vary from full extension to full flexion. In this section, some mathematical model can be defined for elbow mechanism.

A. Lever Mechanism in Human Body

Levers are one amongst the essential tools that were probably employed in prehistoric times. Levers were 1st diagrammatic concerning 260 BC by the standard Greek person Archimedes (287-212 BC). A lever could be a mechanical device that creates work easier for use; it involves moving a load around a pivot employing a force. Several of our basic tools use levers, together with scissors, pliers, hammer claws, nutcrackers, and tongs.

Their lever mechanism is classified into three class they are following [18]:

- The lever Class One, the pivot (fulcrum) is between the effort (force) and the weight.
- The Lever Class Second, the weight is between the pivot and the effort (force) and
- The Lever Class Three, the effort is between the pivot and the weight or load.

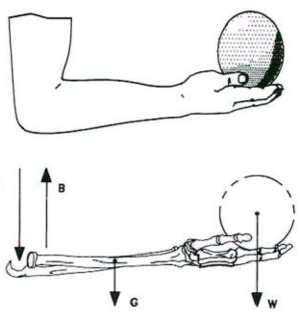

Figure 3 Free body diagram of elbow

B. Equations of Arm Mechanism

From the free body diagram in Figure 5, several equations were derived to calculate all four forces to be put in finite element analysis. The derived equations were;

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Moments about Elbow joint = 0,

$$(B \times D_1) - (G \times D_2) - (W \times D_3) = 0 \quad \text{-----------------(1)}$$

$D_1, D_2, \& D_3$ are perpendicular measured distances from the elbow joint.

After the force acted by the biceps was calculated, the sum of the moment in the 'y-axis' direction will be taken as zero.

Sum of moments on 'y-axis' = 0,

$$-R + B - G - W = 0 \quad \text{------------------(2)}$$

G is the weight of the forearm with an account of the gravitational force, acting vertically downwards. B is the force acted by the biceps, W is the weight of the object and R is the reaction force of the joint.

C. Modelling and Analysis

The models have created in Creo Parametric software tool. Figure 4 has been shows that the existing modeling, proposed model has been modeled by changing existing design and surface geometry of model from sharp edge to smooth edges as shown in Figure 5.

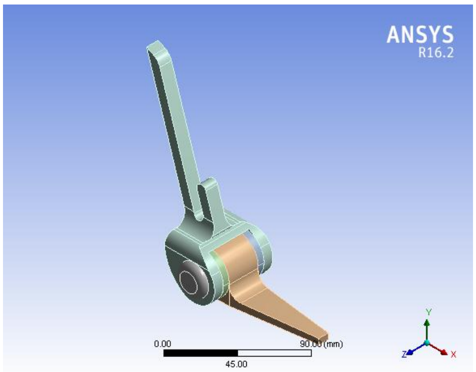


Figure 4 Total replacement joint existing model

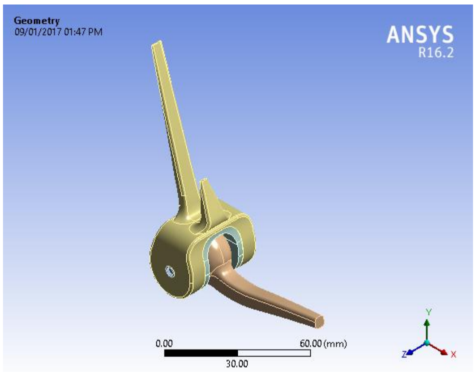


Figure 5 Total replacement joint proposed model

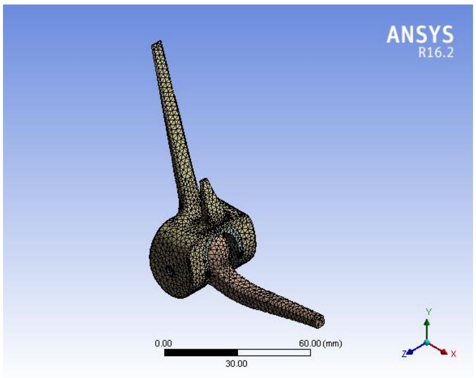


Figure 6 Meshing view of proposed model

D. Boundary Conditions

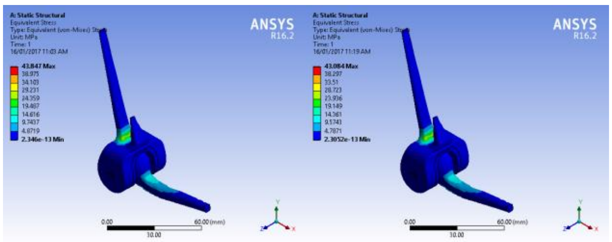
All four forces were calculated and compiled for boundary conditions as shown in TABLE 3, shows the forces applied for all three materials [21].

TABLE 3 FORCES APPLIED TO THE ALL MATERIALS ELBOW MODAL [21].

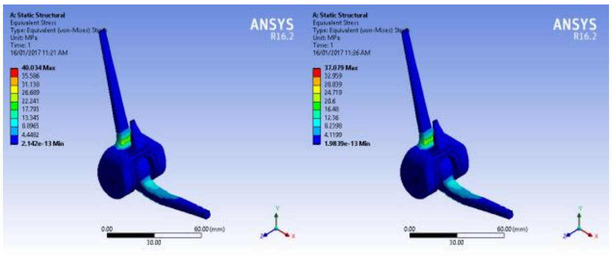
Conditions	Force, N			
	G	W	B	R
0.1kg, **30°**	6.867	0.981	50.458	34.762
0.1kg, **90°**	6.867	0.981	25.229	17.381
0.1kg, **130°**	6.867	0.981	32.934	22689
0.5kg, **30°**	6.867	4.905	95.309	71765
0.5kg, **90°**	6.867	4.905	47.654	35.882
0.5kg, **130°**	6.867	4.905	62.209	46.481
1.5kg, **30°**	6.867	14.715	207.437	164273
1.5kg, **90°**	6.867	14.715	103.719	82137
1.5kg, **130°**	6.867	14.715	135.395	107.222
2.5kg, **30°**	6.867	24.525	319.566	256.391
2.5kg, **90°**	6.867	24.525	159.783	128.391
2.5g, **130°**	6.867	24.525	208.582	167.602

IV. RESULTS AND DISCUSSIONS

For this investigation, the criterions were viewed from the ANSYS 16.2, that are gives the Equivalent (von-Mises) Stress and a Principal Stress as shown in Figure 7 & 8. The various results from ANSYS 16.2 exploitation whole completely different cases.

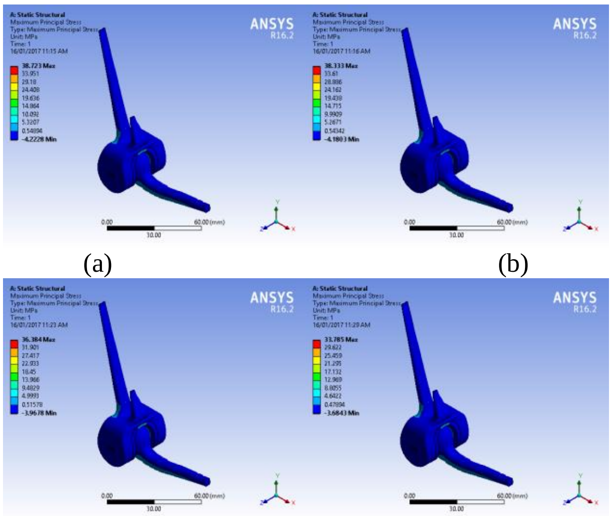


(a) (b)



(c) (d)

Figure 7 Von-Mises Stress in proposed elbow joint for different materials (a) Copper (B) Stainless Steel (c) Titanium and (d) Cobalt chromium alloy



(a) (b)

(c) (d)

Figure 8 Von-Mises Stress in proposed elbow joint for different materials (a) Copper (B) Stainless Steel (c) Titanium and (d) Cobalt chromium alloy

TABLE 4 RESULT OF VON-MISES STRESS FOR EXISTING MODEL

S. No.	Material	Khoo et. al. (Exist Model)	Validation	% Error
1	Copper	45.755	45.1	1.4315
2	Stainless Steel	45.04	44.838	0.4485
3	Titanium	42.365	42.085	0.6609

The Table 4 indicates that the validation results between existing and Khoo et. al., work.

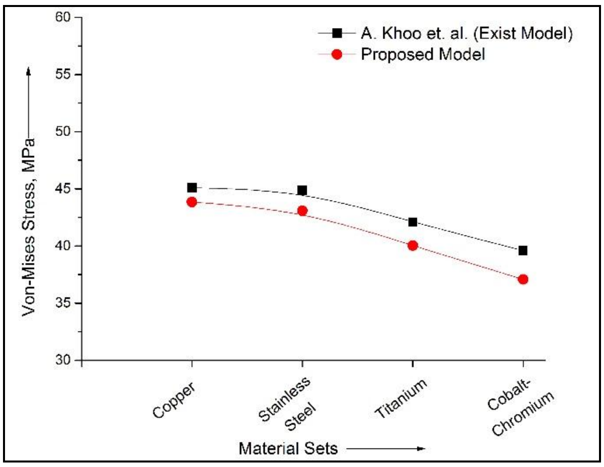


Figure 9 Comparison of von mises stress between existing model and proposed model for all materials

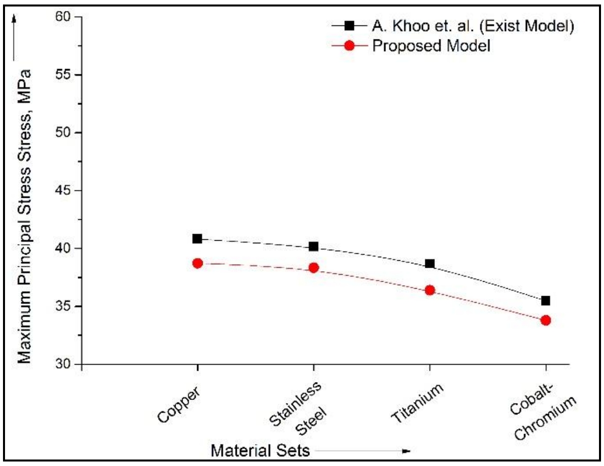


Figure 10 Comparison max principal stress between existing model and proposed model for all materials

Figure 9 and 10, shows a comparison between existing model and proposed model for the different materials, such as copper, stainless steel, titanium and cobalt chromium. Proposed model gives 12.477% less von mises stress and 14.030% less maximum principal stress generation as compare to existing model respectively.

TABLE 5 COMPARISON BETWEEN EXISTING WORK WITH PROPOSED WORK

Stress	Titanium (Khoo et. al. (Existing work)	Cobalt-Chromium with Proposed Model (Proposed work)	% Difference
Von-Mises	42.365	37.079	12.477
Max Principal	39.299	33.785	14.030

V. CONCLUSION

In this article, the applications of the biomaterial cobalt chromium metal for elbow arthroplasty implant has been proposed for higher performance. The proposed model performs the less von-mises stress generation as compare to existing implant. The comparisons of the each existing [7] and proposed model (present work) simulated results for identical environmental setups. Table 1, shown that relative differences between the commonly used metallic alloys or polymers as biomaterials, which clarify that the cobalt chromium has a better blood compatibility for the human body. The von mises and maximum principal stress percentage error between the existing work and the proposed work are 12.477% and 14.030% respectively is shown in Table 5, which is under design safe. Due to modification of design and surface conditions, the weight of proposed model was less as compare to existing and cost are also reduced, therefore the cobalt chromium is suitable for proposed design and existing design. By using cobalt chromium which will also result in a minimal principal stress on the implant.

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