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A Disposable Compliant-Forceps for HIV Patients

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The objective of this project was to develop a disposable compliant forceps for HIV patients. Three-dimensional compliant forceps was modeled and analyzed using a commercial FE software i.e., I-DEAS (Integrated Design Engineering and Analysis Software). This forceps's handle was subjected to a load case from 5 to 25 N, corresponding to loads applied to rigid-body forceps. Pseudo-Rigid-Body method was used as a methodology and the Finite Element Method (FEM) was used to validate this compliant mechanism. The suitable material for this disposable forceps had been chosen i.e., Polypropylene Co-Polymer.

Key words: Compliant mechanisms, disposable forceps, finite element method

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INTRODUCTION

Human Immunodeficiency Virus (HIV) is the virus that associated with AIDS (Acquired Immune Deficiency Syndrome). This retrovirus target CD4 cells in the body, eventually leading to their destruction. However, from AIDS manual glossary, HIV infection is driven by viral replication rather than by immune system destruction. Since the first case of HIV/AIDS was identified in 1986 in Malaysia, the number of infected individuals has increase steadily each year, so that, by the end of 2002, the cumulative number of people living with HIV/AIDS was 57,835 (51,256 with HIV and 6,579 with AIDS), with 5,676 AIDS deaths (Huang and Hussein, 2004).

The uncured disease, AIDS, has shocked the global especially in the medical world. It is not just made the scientists and doctors working-hard towards it antidote, but also to the engineers, who must design and develop a new disposable tools/products specially for them who are HIV-positive. It is very important to produce the disposable products because of the virus spread by sharing or re-used something that is exposed to this human immunodeficiency virus. So, it is important to dispose anything that has been used by the HIV patient. One of the devices that almost everyday exposed to this virus is a forceps as shown in Fig. 1.

Forceps is used everyday at the every hospital in this world. It becomes a very important tool either for open surgery or physical nursing. So, it is important to develop a disposable forceps that is easier to get rid compared to the conventional forceps. Besides that, it will reduce the productivity cost of the device.

Nowadays, almost all of the conventional forceps are made from stainless steel. It has two rigid segments that are pinned at the middle. Hence, the production cost of the conventional forceps is higher than the disposable one. It is very costly and difficult to dispose something that made of the stainless steel. The objective of this study is to design a disposable forceps. It designed based on compliant mechanism's concept and it could solve the problems that cannot be solved with conventional forceps.

Fig. 1: Conventional forceps (Fullam, 2003)

MATERIALS AND METHODS

Joints: The Q-Joints method is one of the methods that been used to replace a conventional pin-joint. This type of joint is suitable to approximate the device that has pin-joint especially at the middle of the two ends. The Q-Joints obtained its name from their quadrilateral shape. There were two types of Q-Joints, but one that is applied here is Deltoid Q-Joint (Howell, 2001).

This joint is classified as a Deltoid Q-Joint as each of their rigid segments that is in quadrilateral the adjacent to a segment of an equal length as shown in Fig. 2. The symmetry of the joint allows it to be modeled as two slide-crank mechanisms, as shown in Fig. 3 (Howell, 2001).

Where:

r_1 = Distance from k_1 to k_3 (mm)
r_2 = Link k_1 and k_2 (mm)
r_3 = Link k_2 and k_3 (mm)
θ_2 = Segment r_2 angle (degree)
θ_3 = Segment r_3 angle (degree)

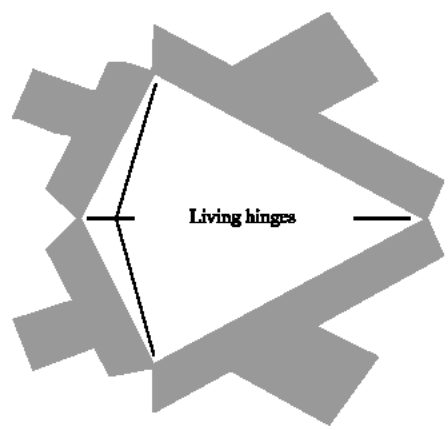

Fig. 2: Deltoid Q-Joint (Howell, 2001)

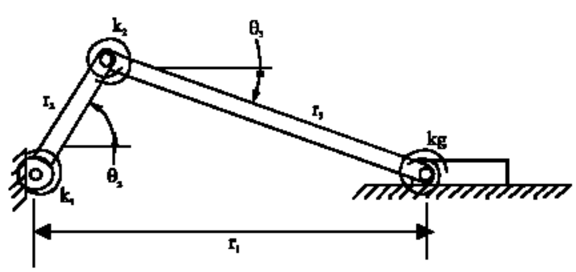

Fig. 3: Slide-crank mechanism. (http://research.et.byu.edu/llhwww/)

The change in an angle between the two opposite rigid segments (segment r_2 and segment r_3) may be determined from the equation for a rigid-link slider-crank mechanism, or from the law of sine (Howell, 2001).

$$r_2 \sin\theta_2 = r_3 \sin\theta_3 \quad (1)$$

Meanwhile, translational offsets may be calculated from the equation below.

$$\theta_3' = \sin^{-1}\frac{r_4 - r_2 \sin\theta_2}{r_3} \quad (2)$$

Where;

$$\theta_3' = 360 - \theta_3 \quad (3)$$

$$r_1 = r_2 \cos\theta_2 + r_3 \cos\theta_3' \quad (4)$$

If the slider is an input and $r_4 = 0$, the law of cosine is used to determine the crank angle.

$$\theta_2 = \cos^{-1}\frac{r_1^2 + r_2^2 - r_3^2}{2r_1r_2} \quad (5)$$

The calculation parameter that used to make the Deltoid Q-Joint in this design was shown below. Eq. 1 was used to calculate θ_3.

$$r_2 \sin\theta_2 = r_3 \sin\theta_3$$
$$10\sin 35° = 16\sin\theta_3$$
$$\theta_3 = \sin^{-1}\left[\frac{10\sin 35°}{16}\right]$$
$$\theta_3 = 21°$$

Material selection: The most important thing in producing this compliant forceps is to select the suitable raw material. The condition and working environments must be known because this thing will become the important guideline in choosing materials. Hence the failure of the design could be avoided (Howell, 2001). Besides that, the chemical reaction of the material should be known too. In order to develop this compliant forceps, plastic is the best material to use because it is very easy to dispose compared to the stainless steel. In addition, plastic is much easier to machining and to form in any shape without any problems. The material that was selected for the analysis is Polypropylene Co-Polymer (Table 1).

Table 1: The material property of Polypropylene Co-Polymer

Characteristic	Material Polypropylene Co-Polymer
Modules elastic	1.4 GPa
Yield stress	31.0-37.2 MPa
Melting point	150-164°C

Proposed design: As mentioned earlier in this study, this compliant-forceps is designed as a single piece and used the Deltoid Q-Joint (Fig. 4). There were two types of analysis that used on this compliant-forceps. The first analysis is Pseudo-Rigid-Body and the second analysis is Finite Element Method (FEM). The FEM was done by using I-DEAS (Integrated Design Engineering Analysis Software) software. The focus of the analysis is at the point that is critical for failure. Five different loads were applied beginning from 5 N until 25 N at the increment of 5 N. Actually, the load that is usually applied on a forceps handle is about 20 N (Patkin, 1985). The results from the both of analysis were compared.

Pseudo-rigid-body method: Based on Fig. 5, we know that point A will receive the maximum load. Load, F from

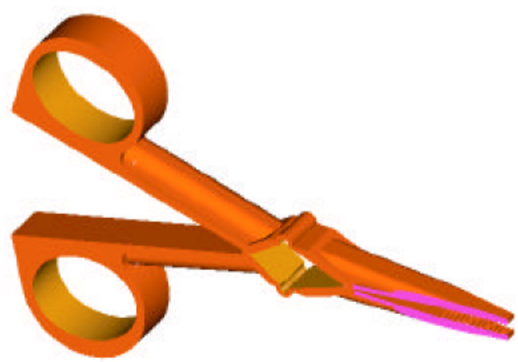

Fig. 4: Compliant-forceps

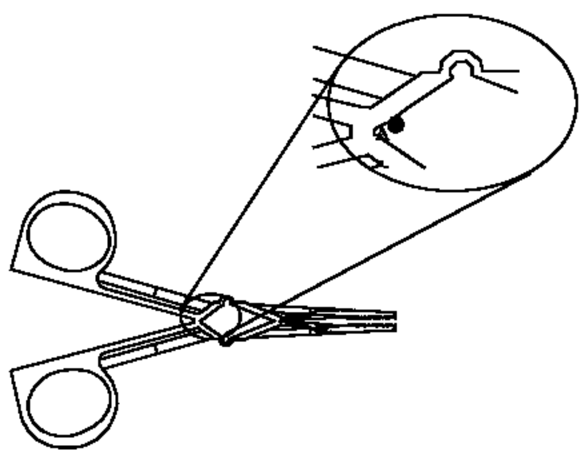

Fig. 5: A is the point where the analysis focused on

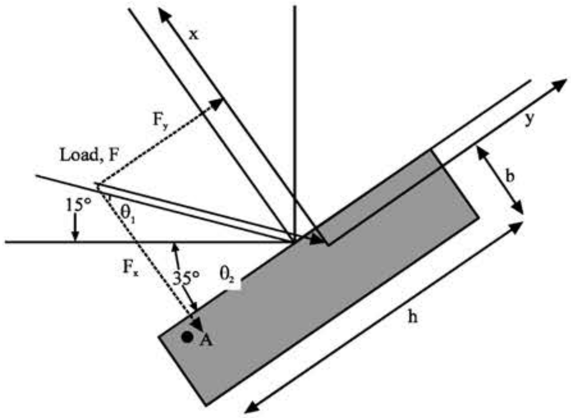

Fig. 6: The force, F is resolved as F_x and F_y on one of the Deltoid Q-Joint segment

handle was transferred to Deltoid Q-Joint at $\theta_1 = 15°$. To simplify the calculation, load, F was resolved to vector-x and vector-y (Fig. 6).

$$F_x = -F\sin(\theta_1 + \theta_2) \tag{6}$$

(negative = compression)

$$F_y = F\cos(\theta_1 + \theta_2) \tag{7}$$

The loads applied were acting on the surface of the Deltoid Q-Joint, so that, average loads can be assumed at the centroid. So, moment could be calculate.

$$M_x = F_x\left(\frac{h}{2}\right) \tag{8}$$

$M_y = 0$ because load, F_y was act perpendicular with point A.

The stress was calculated using Eq. (9).

$$\sigma_x = \frac{M_x \bar{y}}{I_x} \tag{9}$$

$\sigma_y = 0$ because $M_y = 0$

The moment of inertia, I was calculated by using Eq. (10) and (11),

$$I_x = \frac{bh^3}{12} \tag{10}$$

$$I_y = \frac{hb^3}{12} \tag{11}$$

So that, the maximum stress, σ_{max} will find as:

$$\sigma_{max} = \sigma_x + \sigma_y \tag{12}$$

Table 2: The results using Pseudo-Rigid-Body method

Load, F (N)	Load on vector x, F_x (N)	Load on vector y, F_y (N)	Moment on vector x, M_x (N mm)	Maximum stress, σ_{max} (mN mm^{-2})
5	3.830	3.214	19.15	5.74×10^2
10	7.660	6.428	38.30	1.15×10^3
15	11.491	9.642	57.46	1.72×10^3
20	15.321	12.856	76.61	2.30×10^3
25	19.151	16.070	95.76	2.87×10^3

Table 3: The result of Finite Element method

	Polypropylene Co-Polymer Stress, σ_{max} (mN mm^{-2})	
Load, F (N)	Min	Max
5	1.19×10^{-8}	4.15×10^2
10	2.36×10^{-8}	8.27×10^2
15	3.57×10^{-8}	1.25×10^3
20	4.76×10^{-8}	1.66×10^3
25	5.94×10^{-8}	2.08×10^3

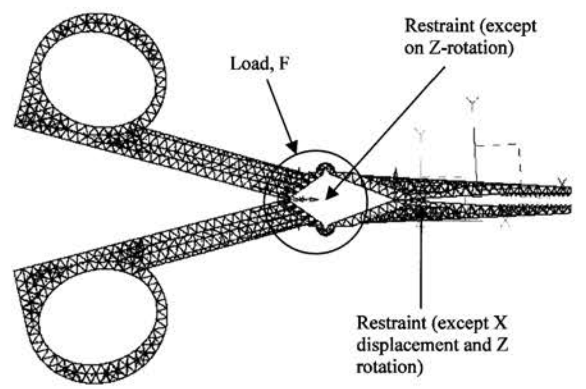

Fig. 7: Finite element method analysis on compliant-forceps

Table 2 shows the results that calculated using Pseudo-Rigid-Body method for each load applied such as load on vector x, F_x, load on vector y, F_y, moment on vector x, M_x and maximum stress, σ_{max}.

Finite element method: In order to analyze using finite element method, forceps need to go through steps such as meshing, boundary condition and model solution. Figure 7 shows the forceps that being meshed with Tetrahedral-4-nodes element. The element length used is 3 mm. The total numbers of nodes generated were 2151 nodes and total elements generated were 6493 elements. The load, F was subjected to the Deltoid-Q joint at 15°. The Deltoid-Q joint was restrained on all of its displacement and rotation except on Z-rotation. Meanwhile at the opposite side, it was restrained all moveable part except on X-displacement and Z-rotation to allow it to rotate and to move along X-direction.

Table 3 shows the minimum and maximum stress for Polypropylene Co-Polymer that taken from finite element method analysis result from I-DEAS software.

RESULTS AND DISCUSSION

Stress analysis results: Based on the Table 4 and Fig. 8, we can calculate the percentage differences between the result from pseudo-rigid-body model and finite element method. At load 5 N, the difference was 27.7% for Polypropylene Co-Polymer. Meanwhile, at the maximum load, 25 N, the difference becomes 27.5% for Polypropylene Co-Polymer. From the percentage shown, Polypropylene Co-Polymer has a small percentage of different, either at the minimum or the maximum load case. Table 5 shows the stress on every selected node for Polypropylene Co-Polymer. These 10 points nodes were selected along the deltoid-Q joint.

Table 4: Comparison between the analysis of Pseudo-Rigid-Body and Finite Element method

Load, F (N)	Maximum stress, σ_{max} (mN mm^{-2}) Pseudo-Rigid-Body analysis	Finite Element method analysis polypropylene Co-Polymer
5	5.74×10^2	4.15×10^2
10	1.15×10^3	8.27×10^2
15	1.72×10^3	1.25×10^3
20	2.30×10^3	1.66×10^3
25	2.87×10^3	2.08×10^3

Table 5: Stress values for each load on different node distance for Polypropylene Co-Polymer

Node distance	Stress (mN mm^{-2}) 5 N	10 N	15 N	20 N	25 N
0	361.9	721.4	1086.0	1448.0	1809.0
2.26	223.7	447.6	671.1	894.9	1119.0
4.33	182.2	363.4	546.6	728.8	911.0
6.40	120.5	240.7	361.4	481.9	602.4
8.47	50.8	101.8	152.5	203.3	254.2
9.96	114.8	227.5	344.4	459.1	573.9
11.97	101.1	200.1	303.3	404.4	505.5
13.72	22.2	45.3	66.8	89.0	111.3
15.47	72.8	143.5	218.5	291.3	364.2
17.47	55.2	109.1	165.8	221.0	276.3

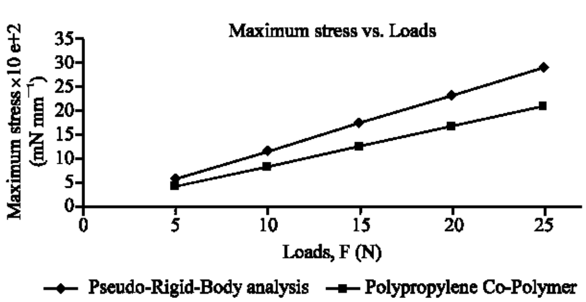

Fig. 8: Comparison between Pseudo-Rigid-Body analysis and finite element method for three types of materials

Figure 9 has shown the graph of stress vs. node distance for load 5 to 25 N. The nodes were selected at the Deltoid-Q Joint, where the maximum stress occurred. From the graph, the stress was decreasing as the node distance increases.

Design comparison: Compliant mechanism could reduce the count of part or segment for any product that applied this method in their design. On the other hand, compliant mechanism's product can operate just like the conventional product itself. That means, the application of the compliant mechanism onto this forceps design make it simple compared to the conventional forceps. The result from application deltoid Q-joint on this forceps make it come out with a single part forceps compared to the conventional forceps, i.e., two parts and one pin joint.

Nowadays, almost all forceps that supplied to the hospital is made from stainless steel. It is a really huge different with the compliant-forceps because it raw material is a polymer i.e., Polypropylene Co-Polymer. In addition, Polypropylene Co-Polymer provides the excellent resistance to organic solvents, degreasing agents and electrolytic attack. It has lower impact strength, but its working temperatures and tensile strength are superior to low or high density polyethylene. It is light in weight, resistant to staining and has a low moisture absorption rate. It has excellent resistance to acids and alkalines (Boedeker, 2004).

For a forceps that designed and manufactured by using the compliant mechanism method, it can reduce the cost of manufacturing the product. This is because; the price of the Polypropylene Co-Polymer is cheaper than Stainless steel. It is about \$US kg^{-1} 2.15-10.00 (Callister, 1999). It is not only saving the manufacturing cost, but it also the shipping cost and the maintenance/ disposable cost could be reduced as well.

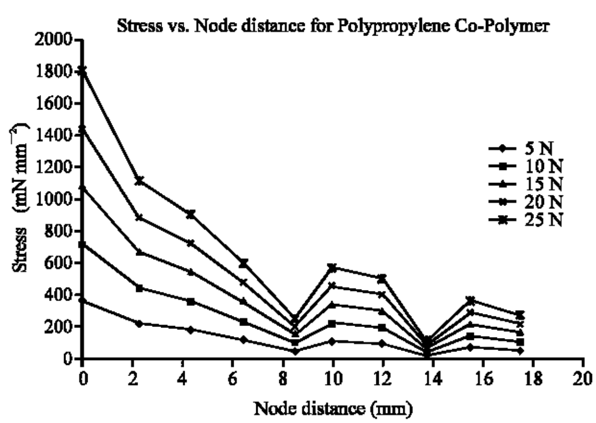

Fig. 9: Stress value vs. node distance for Polypropylene Co-Polymer

The compliant-forceps is very easy to get rid off because it is fully plastic. So, the melting point of it is lower than the stainless steel. The melting point for a Polypropylene Co-Polymer is about 150-164°C (Eastpoint-Oltein, 2003).

In addition, this compliant forceps is much easier to sterile because it has no gap between parts just like the conventional forceps. So that, the sterilize process is easier and cheaper.

CONCLUSIONS

The application of the compliant mechanism on forceps design helps the disposal task and at the same time reduces in cost. Based on the analysis, Polypropylene Co-Polymer was selected to be a material with maximum stress withstand the force is 2.08×10^{3} mN mm^{-2} (2.08×10^{6} N m^{-2}) at 25 N.

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