DEVELOPMENT OF NECK DUMMY FOR HEAD IMPACT (SOCCER HEADING) EXPERIMENTAL SETUP

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ABSTRACT

Heading a ball during soccer game will not affect to human health. But repeating similar action might cause serious injury especially onto human head. As head is one important part of human body, head need to be protected as well human body will have no further use if there is any damaged system at human brain. Due to this serious risk when perform repetitive ball heading, this study was conducted to assist head impact (soccer heading) experimental setup by developed a significant method in building neck dummy that can perform like real human neck. Using this dummy, accurate value of force impacted by the ball to the head can be measured. Besides, skull dummy that attached to the neck dummy will react as same way with real human head while heading the ball. So that is the purpose of neck dummy in this experimental setup. Besides using complete experimental setup including this neck dummy, risk of repeating ball heading by human can be measured using these dummies and human is unnecessarily needed to perform this kind of action.

ABSTRAK

Menanduk bola semasa perlawanan bola sepak tidak akan memberi kesan kepada kesihatan manusia. Tetapi tandukan yang berulang akan memberi kesan yang serius kepada kepala manusia. Sebagaimana kepala adalah salah satu bahagian yang paling penting pada badan manusia, kepala mestilah dilindungi ataupun badan manusia tidak lagi dapat berfungsi jika ada kerosakan pada otak manusia. Oleh kerana risiko yang tinggi semasa menanduk bola, kajian ini telah dijalankan untuk membantu kajian impak kepala semasa menanduk bola dengan membangunkan kaedah yang sesuai untuk membina model leher manusia. Menggunakan model ini, daya impak ke atas kepala manusia dapat dikaji. Selain itu, model tengkorak akan bertindak balas seperti kepala yang sebenar semasa menanduk bola. Jadi itulah tujuan model leher ini dibina. Mengunakan alatan eksperimen yang cukup, risiko menanduk bola oleh kepala manusia dapat dikaji dan manusia tidak perlulah membuat aksi – aksi tandukan berulang kali.

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene
C0	Cervical vertebrae 0
C1	Cervical vertebrae 1
C2	Cervical vertebrae 2
C3	Cervical vertebrae 3
C4	Cervical vertebrae 4
C5	Cervical vertebrae 5
C6	Cervical vertebrae 6
C7	Cervical vertebrae 7
FBD	Free body diagram
HIC	Head injury criterion
MSNT	Majlis Sukan Negeri Terengganu
ODD	Omni – Directional Dummy
PLA	Polylactic acid
RP	Rapid prototyping

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Soccer is a most popular game on this planet which involved so much method to play it included heading. Soccer is a sport that not identified as high risk for concussions, but several studies have shown that concussion rates in soccer are comparable with and often exceed those of other contact sports. The actual incidence of soccer-related concussion varies in the literature and likely depends on variables such as age, gender, and level of participation. But the fact is it can lead to traumatic brain injury because of this heading. It is proved by some researchers complained that soccer heading impacted force can cause brain injuries to football player (Andrew Rutherford, 2003). A soccer player can be subjected to an average of six to seven incidents of heading the ball per game. So it was suggested that a single heading will not injure the brain but repetitive heading will. Many researched have proven that heading in soccer can bring bad effect such as concussion and tissues deformations (James R. Funk, 2010). Many existing human skull and neck dummy was developed to study in car crash field such as HYBRID dummy. This kind of dummy can only react to small amount of force and cannot be adjustable to study requirement.

This study requirement is to mimic real neck response while heading the ball and force can be up to 1000 N. New design of neck dummy needed to be developed so it can be fit with requirement of study. So by developing this experimental setup we can analyse how much force impacted to football player's head during soccer heading by using appropriate.

The acceleration of head during heading also will be determined by placing accelerometer in brain dummy. Experimental results were compared to computed pressures and it was determined that pressures above 34 psi could cause brain concussions (Warren N. Hardy, 1993). So that is why we put accelerometer in brain and not by attached it to the dummy skull. Development of head impact experimental setup is an analysis of force impacted to human head (soccer heading). To analyse this force, setup of experiment need to be developed first which consist of three components, neck, skull and brain. This dummy needed to have almost same properties with real human parts to get better accuracy of result analysis. Finally some derivations of equation and calculations needed to determine whether force impacted will bring harm to human skull or not.

1.2 OBJECTIVES

1. To develop significant method to build neck dummy based on real human neck reaction during soccer heading.
2. To study real neck response during soccer heading
3. To fabricate neck dummy model.

1.3 SCOPE

Soccer is the only sport where the head is used to redirect motion of a ball. Head injury during soccer is usually the result of either direct contact or contact with the ball while heading the ball. There are few types of impacts that can occur to human head such as car crash and another type of collisions. For this experimental setup, scope is limited to impact of soccer heading which force that supply from moving ball and impacted to football player head by soccer heading. So as stated, some researchers believe that this kind of impact can cause concussion to our brain. Besides, the scope is also to build a replica of human neck. The replica is needed to have same properties with real human body part such as damping, stiffness, and elasticity. Neck replica with or without muscular activities may lead to different result because oscillatory head motion and neck muscle activity continue for up to 0.5 s post impact (Philip E. Riches, 2006). Then for validation of this experiment setup, using necessary formulas we will carry out an experiment to make sure this experimental setup can be use and can provide an accurate result. The important for us to develop neck dummy is to assist existing head dummy that used to determined forces impacted to the head. By develop this dummy, force absorbed will be more close to real one and force distribution can be improved.

This dummy need to result same reading of head acceleration of skull attached onto it. Besides, angle of bending also one of parameter that being look for comparison purposed with real human neck.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The risk of concussion is a function of the maximum linear acceleration of the head, with the probability of sustaining a concussion at 50% at approximately 750 m/s2 acceleration (Michael L. Levy, 2011). At the first of all the study is about HYBRID dummy. Even that dummy used for crash purposed, not heading soccer ball but they use similar apparatus like mine. Noticing that one does not simply create something high-tech dummy with limited resources so it have been simplified it to simpler setup but can give accurate result.

Main challenge to build neck dummy is stiffness and damping coefficients are varies if compared with other literature values under different experimental conditions (Philip E. Riches, 2006). So the exact value of neck stiffness which has no fixed value for example, 350 N/m (Philip E. Riches, 2006). From journal studied, the head–neck stiffness and damping coefficients determined from the model (350 N m rad–1 and 4 N m s rad–1, respectively) (Philip E. Riches, 2006). Beside, from (Astrid Linder. 1999) the muscle substitute was modelled using a flexible tension element belt with an elastic stiffness of 16 N/m.

In order to get accurate result, neck design must have similar properties like real one which muscular properties also need to be included. Currently, few models of these mechanics exist. Previous models of soccer heading have either ignored the contribution of the neck musculature or only concentrate on the force of impact and associated acceleration during the impact, rather than any oscillatory motion of the head (Philip E.

Riches, 2006). For additional information, this setup only build until neck and whole body part is not necessary so the proper way to heading the ball to reduce concussion cannot be determined.

2.2 DUMMY SETUP

The risk of concussion is a function of the maximum linear acceleration of the head, with the probability of sustaining a concussion at 50% at approximately 750 m/s2 acceleration (Jiri Adamec, 2011). So the replica must to be able to react and accelerate at same rate if force impacted to the head. So accuracy of neck stiffness value need is very high consideration. Neck is the hardest part to replicate it. For best result accuracy, the design need to able to perform flexion and extension. What makes it more complicated is the neck's stiffness that varies with force applied onto it (A.C. Bos, 1985). So ODD neck will treated as a benchmark to construct a simple human neck dummy with similar human neck properties.

For real neck original position is at 37° and 190mm radius. So for dummy some consideration must be done such to allow realistic retraction motion, a total range of motion of 100° in extension and 41° in flexion from the initial position was chosen for the mathematical neck model (Astrid Linder. 1999). So this only one example of factor that needed to be considered.

2.3 ANALYSIS SETUP

Previous study have demonstrated that the majority of cases of heading occur at ball velocities of less than 40 mph (65 km/h), or an impulse force between 12.4 and 13.7 N/s, indicating that they are of insufficient force to cause concussion. In addition, heading a soccer ball has less impact than head-to-head contact and is less likely to result in concussion. Heading a ball was found to result in head accelerations of less than 1000 rad/s2 (less than 10g), cause them incapable of reaching the limit of sport-related concussions of 3500–5000 rad/s2 (40–60g) (Michael L. Levy, 2011).

According to the HIRC, a value of HIC = 1400 is associated with a 50% probability of life-threatening brain injury, while the regulated value of HIC = 1000 entails a risk of about 18%. These predictions are limited to contact events for which the HIC integration time does not exceed 15 m/s (N Shewchenko, 2005). So the point is it will use all methodology that necessary to get the value of HIC during soccer heading. In other word, this is the indicator that will show what amount of force impacted to soccer heading and whether it will bring harm to any football player.

2.4 HUMAN NECK REVIEW

Neck is one of important human pat that connect human body with human head. Neck is a strong organ that can support mass of head all the time. Neck also can perform certain reactions and movements.

Flexion, extension, axial rotation and lateral bending are such an action that can perform by human neck. Flexion is movement toward front of body while extension is vice versa. Extension is a movement that allow head to move backward and this reaction is very important in soccer heading. Meanwhile, flexion is the most important reaction during car crash analysis. Rotation and bending is most complex movement to be followed by neck dummy.

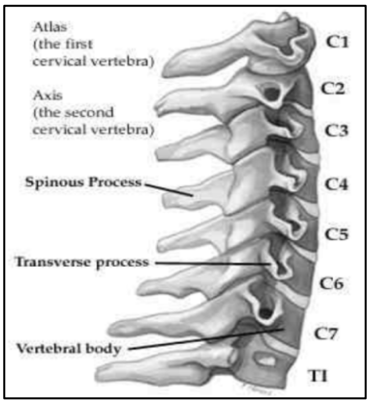

Figure 2.1: Cervical vertebrae

Source: Sarale Luca (2005)

Figure 2.1 show all cervical vertebrae that include in neck part. Starting from c0 until c7 it will made up a structure of 8 cervical vertebrae all of it (Sarale Luca. 2005). T1 is not included as a neck part. These cervical vertebrae if combined will give a length about 12cm in total without bending.

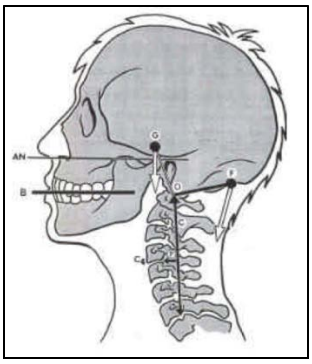

Figure 2.2: Cervical vertebrae with head

Source: Sarale Luca (2005)

Line 'C' in figure 2.2 is what was meant by total length without bending. Figure 2.2 also show that c0 is a cervical vertebra that connected with human head while the bottom one is c7 that connected to human body (Sarale Luca. 2005). Figure 2.3 show how muscle was fitted in onto human neck.

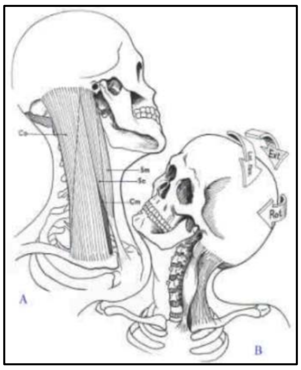

Figure 2.3: Neck muscle

Source: Sarale Luca (2005)

2.5 REVIEW OF ODD NECK

ODD neck is mean Omni-Directional Dummy neck that have been developed by Sarale Luca from Department of Machine and Vehicle Systems, Crash Safety Division, Chalmers University of Technology. This ODD neck development was continued by Diego Astuy Gonzalez at master's level and from same institute.

This neck dummy was developed so it can assist car crash analysis. This dummy can perform flexion, extension and also lateral bending. It was designed to have similar cervical vertebrae parts from c0 until c7. This dummy also was developed with same human neck angle when it is in static condition (Sarale Luca. 2005).

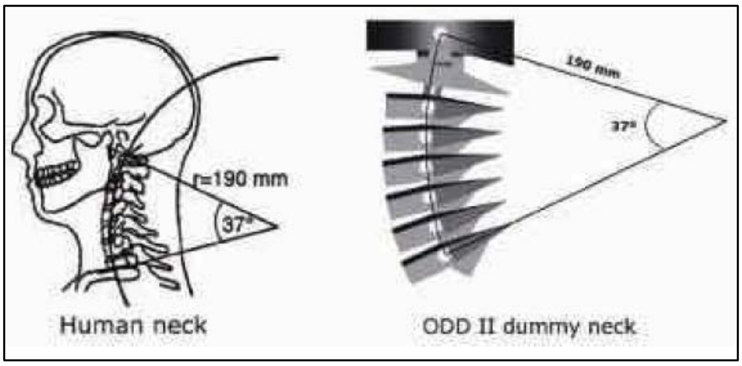

Figure 2.4: Neck angle in static condition

Source: Sarale Luca (2005)

This dummy also use rubber as a substitute of neck muscle and put at each between of cervical vertebrae parts. But rubber used is too soft and not compatible with heading experiment due to high impact force will be used. This dummy also has a complicated setting by use nylon and steel cable to limiting the neck dummy movement (Sarale Luca. 2005).

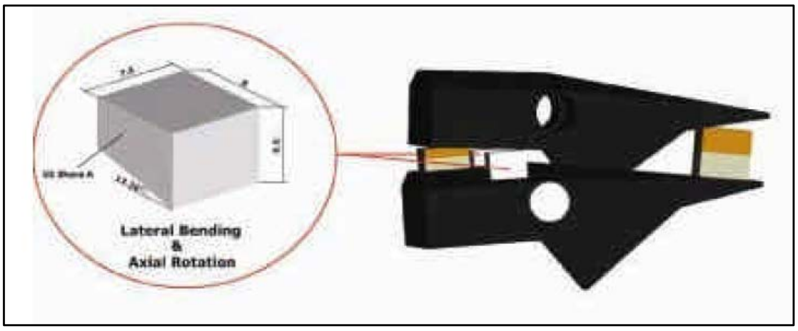

Figure 2.5: Rubber used by ODD neck

Source: Sarale Luca (2005)

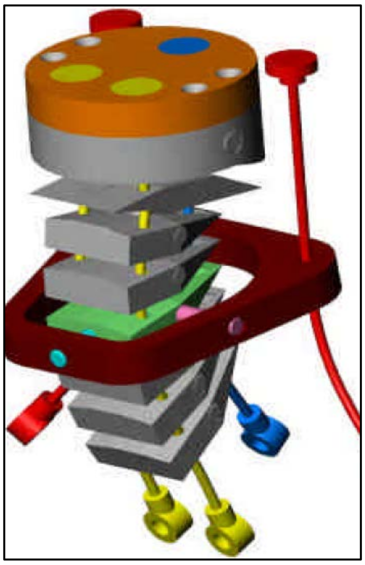

Figure 2.6: Cables in ODD neck

Source: Sarale Luca (2005)

Cables were attached into ODD neck parts by earlier set up. This is to limit the movement of dummy during car crash impact. Limitation movement is due to obtaining same reaction with real neck during car crash (extension and flexion). Besides, cables also used to limit range of lateral bending motion (Sarale Luca. 2005).

2.6 EXISTING DUMMY

According to some literatures, some researchers have developed many types of neck dummy with high technology and simple one. In another word, this is previous studies about constructing neck dummy. Simulations of head-neck reactions also assist us to replicate the dummy easier and with higher detail level. This dummy is constructed with head. But for all dummies, they use different design (Sarale Luca. 2005).

Hybrid III. It was developed for General Motors. This is the most commonly used dummy for both frontal and rear impacts, although it was originally designed for frontal impact This dummy neck has a flexible base component (butyl elastomer) and three vertebrae substitutes in form of rigid aluminium washers. A steel cable runs through the centre of the neck, to give axial strength. The most widely used is 50th percentile which represents an average size and weight of the men population. During a frontal or rear-end test with Hybrid III, the movement of the neck differs from human behaviour. The major difference is the absence of the S-shape (Sarale Luca. 2005).

BIOSID, EUROSID, SID, WORLDSID. They were designed for a deep study of lateral impacts. The SID was the first attempt to study the side impacts developed by National Highway Traffic Safety Administration (NHTSA). BioSID is based on the Hybrid III neck so it doesn’t have any relevant modifications in the neck. EuroSID has been created by European Experimental Vehicles Committee (EECV).There are two versions of this dummy called EuroSID 1 and EuroSID 2. Both of them have a neck made by a composition of metal discs and rubber elements with special joints to head and chest to allow a realistic motion of the head relative to the chest (Sarale Luca. 2005).

Thor. This dummy was developed by National Highway Traffic Safety Administration (NHTSA). It is a frontal impact dummy with a more real frontal response than the Hybrid III, which has been evaluated for rear impacts as well, but it has also been used in lateral and oblique test. It has a multi-directional neck to enable accurate head motion. The neck is made from a series of aluminium discs and rubber pucks which are bonded together and also has compression springs attached to simulate the effects of the musculature. The neck gets the S shape in frontal impact tests. This dummy neck is an improvement compared to the Hybrid III neck (Sarale Luca. 2005).

RID2. The RID2 prototype dummy was originally designed and built within the European Whiplash Project. The dummy was later updated to a commercial version, called RID2, by FTSS. The RID2 is a 2½ D dummy, which means that it is not meant for 3D use, but yet can handle oblique rear impacts. Most of the responses are biofidelic and the RID2 shows the typical s-shape in the neck. However, the dummy showed limited ramping up and lower neck rotations. Furthermore, the dummy was found to be repeatable and reproducible (Sarale Luca. 2005).

BioRID II. This dummy was designed by Chalmers University of Technology. The dummy has a multi-segment spine, representing all the vertebrae in the human body. The dummy shows biofidelic behaviour in most responses, compared to volunteer experiments performed earlier. Also the typical s-shape in the neck, causing head lag, is present in the BioRID II (Sarale Luca. 2005).

2.7 ADVANTAGES AND DISADVANTAGES COLLECTING DATA USING DUMMY

Advantage – when dummies used instead of real athlete, the position of accelerometer can be placed into brain to determine brains' acceleration. Besides, accelerometer also can be put on calculated centre of gravity. Besides, this replica can be used to beyond the degree limit of physical damage which cannot be done on real athlete which will lead to injury.

Disadvantage- so no correct anatomy of human body will be involved such as muscle activity, real position and movement during heading. All this properties need to be add on spring properties.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

From many literatures studied, an initial step is to develop the relevant method to make sure this experimental setup that can lead us to accurate and acceptable result. So to do an analysis for head impact, first of all is plan out an experimental setup. So this setup will consist of head, neck and brain dummy. So head and brain the dummies already build so only neck need to be considered. One more important thing, the neck dummy must be able to be fit into existing head dummy. Dimension to connecting them was calculated. They can be connected by pin joint or just attached by using screw at neck dummy.

So as a summary, it is needed to design a replica with close to human neck stiffness. So the replica can perform flexion and extension. But this design will have limited movement and cannot perform rotation while heading a ball.

3.1.1 Method Proposed

So based on literature studies, most of them used real human such as athlete as their subject test. Most of them also put an accelerometer at a mouth guard or other name such as bite plate but it is refer to the same thing, inside mouth as a fixed point. But for this study dummies will be used instead of real human. All dummies (brain, skull and neck) will be combined together on top of the base prepared. Instruments – for skull, accelerometer will put into the brain. But for neck, high speed camera was used to analyse bending angle of real neck.

Methodology generally divided into 4 parts that is:

1. Experiment for data collections.
2. Solidworks modeling of dummy neck
3. FE analysis of dummy neck model
4. Fabrication of dummy neck

3.2 EXPERIMENT CONDUCTED

To build neck dummy, first data of real human neck response must be collected as a reference for dummy making process. Actually in real soccer heading there is many type of heading skills used at field. Due to objective of the study is to assist skull dummy so it can read same acceleration with real one, muscle activity of neck chose is relaxed and not relaxed. This is because bending angle highly depending on muscle activity of neck and higher muscle activity (not relaxed) will contribute to larger angle of bending.

For relaxed muscle, few series of experiment was held to collect data. The earlier one is by using non – athlete subject to head slow velocity of ball. Bending angle was calculated for every subject and also force impacted by the ball.

Figure 3.1: Relax muscle experimental setup

Figure 3.2 shows how subject ready to heading the ball. Marker was attached at the top of neck to calculate bending angle of the neck. But in order to achieve relaxed muscle of neck activity, there are a few conditions that needed to be applied.

1. Subject cannot resist ball using any movement of head or with any of body posture angle.
2. Ball will be impacted straight to the head and not on projectile motion so subject doesn't need to use any heading skill.

Due to limitation of any equipment such as ball launcher, ball was thrown manually using hand but consistently as straight direction as possible (not in projectile). So for ball velocity, only slow velocity was used that is in range of 2 m/s to 4 m/s.

Figure 3.2: Ball launched manually

Diagram above show how ball constantly threw almost at the same speed, direction and movement to keep the ball speed is same range. Marker was attached at the ball so velocity of ball can be calculated.

But some problem was found in this method where subject's body still tend to move backward to force absorb by the neck during heading. So second series of experiment was conducted to make sure data collected more accurate and right experimental setup can be achieved.

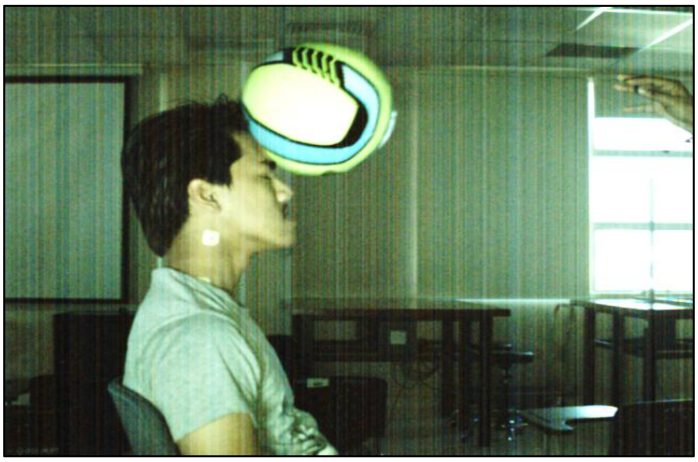

Figure 3.3: Subject seated on chair

Diagram above show how subject was seated on a chair to reduce body movement and same condition was applied in this experiment this time. Constant velocity, neck bending angle, force applied at the head, ball deformation was calculated from this experiment.

For not relax muscle reaction, one special experiment was held using real athlete. Using Majlis Sukan Negeri Terengganu soccer athlete, data was collected. 10 subjects were used with range of age is from 14 – 17 years old. During this experiment, higher velocity of ball was used according to different condition of experiment. Here is a condition that applied.

1. Higher ball velocity will be used and ball direction is in projectile motion.
2. Subject free to use body posture to during ball heading as long ball is heading straight so accurate ball deformation can be analysed.
3. Accelerometer was attached to the subject using bite plat.
4. Relative angle concept was applied.
5. Subject can resist the ball so there will be velocity of ball and also velocity of head.

As mentioned, this condition was applied so that subject tend to perform active muscle activity and resulting angle will be much different due to muscle activity and ball velocity. This experiment also use high speed camera to determine force impacted by the ball at the head, ball velocity and bending angle. Same as previous experiment conducted to collect data for relaxed muscle. This experiment was used a special launcher to throw the ball with constant speed and in projectile motion.

Figure 3.4: High speed camera

Diagram above show high speed camera used during experiment. XCAP software was used to analyse data collected from high speed camera. There are different model of camera and each one need different setting so can produced better image quality.

Figure 3.5: Size 5 ball

Diagram show standard size 5 of ball from Adidas brand was used along in this experiment. The same ball also used in relaxed muscle experiment. Ball used is standard ball of 5 in size and pressure of the ball was constantly check (75 kPa) during experiment so it keep maintain in pressure.

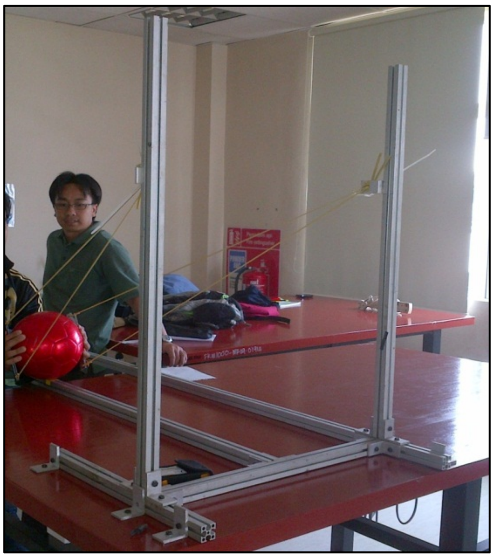

Figure 3.6: Ball launcher

Figure 3.6 show ball launcher that was used in the experiment and in picture was show how crew put ball at the marked limit so it can achieve constant velocity. Velocity of ball is in range of 7 to 9 meter per second. As mentioned this type of launcher will produced ball that move in projectile motion and direction of ball is user defined.

This launcher was screwed onto the table so level of ball is same range with the height of subject. The height level can be adjusted. Noted that the rubber used at this launcher also constantly check from time to time and will be change if detected tend to achieve plastic deformation. That is how constant range of ball velocity was constantly checked. Experiment conducted was allowed subject to perform a free header as long it is in constant movement and ball direction (opposite head direction) and in straight motion if might. So angle of bending cannot be calculated easily because of large range of body movement.

This experiment also use neck marker to detect neck bending. While special part was attached to back of subject for body angle calculation purposed. So there is no problem to calculate neck angle even subject's body freely moving.

Figure 3.7: Steel rod

Diagram showing custom made device so it can be attached at the back of the subject. Main part was produced from steel so it has no bending even subject's body push it hardly. Using flexible band, this body movement marker can be attached at the body and this band can elongate so it can fit any size of subject. No harm was recorded from subject when using this device while heading.

Noted that this device has not effecting the body movement, limitation of body movement, body movement angle, heading skill, free style of body posture and also neck bending angle. So data recorded was not affected by this equipment.

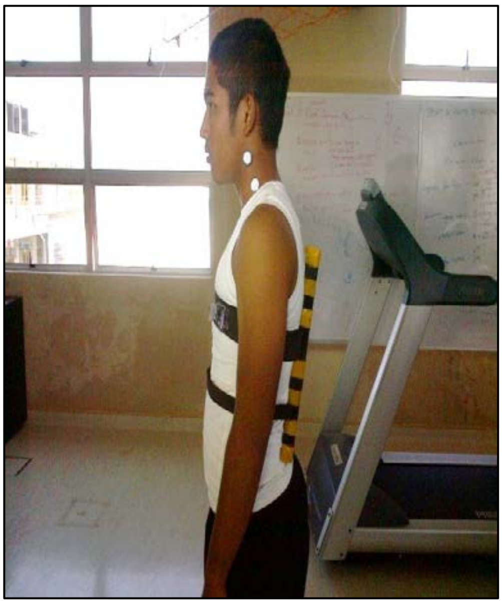

Figure 3.8: Steel rod attached to subject's body

Diagram above has shown how neck marker and steel was attached to the subject body. Actually this setup was inspired by previous study to analyse body movement, but in more complex method. So this setup was simplified so it can fit with study goal and method.

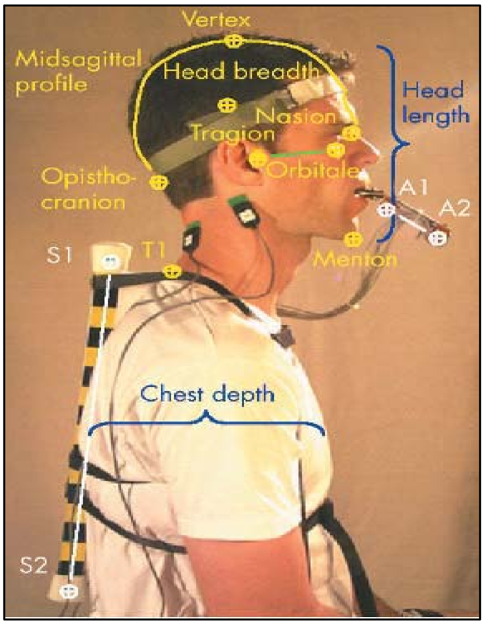

Figure 3.9: Steel rod from previous study

But same calculation method was applied even their setup much more complex and detailed. And noted that during experiment, subject was stand and not sitting on chair to perform free header.

3.2.1 Calculations

In designing experiment to achieve accurate data, calculation was made using data collected from high speed camera such as ball velocity, ball deformation, body angel, neck angle and also head velocity.

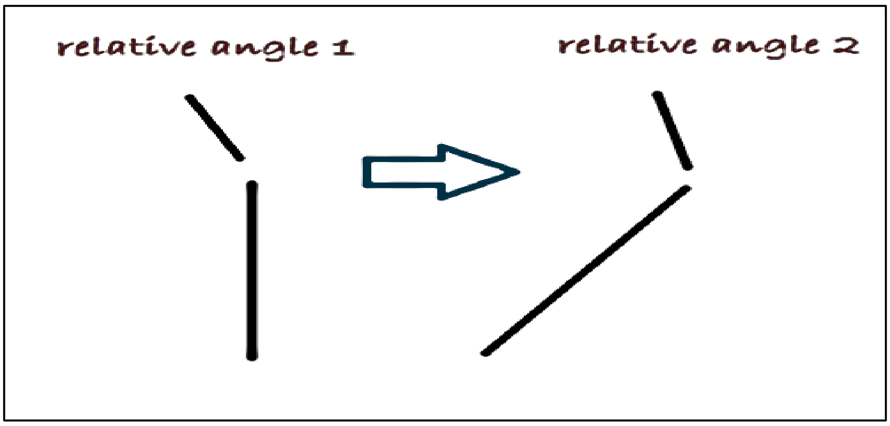

Figure 3.10: Concept of relative angle

There are 2 lines in one diagram. Top line representing neck line while below one represent angle of body. Relative angle 1 is initial body posture while relative angle 2 is final body posture after impact. So the method used to calculate relative angle is by using this way of calculation.

$(\text{angle body} - \text{angle neck})_{initial} - (\text{angle body} - \text{angle neck})_{final} =$ total neck movement angle.

So angle of initial body posture will sum up so it can be bench mark for initial angle of body posture before head receive force from ball impacted. So no matter is how body move, angle of neck bending still can be calculated.

When using computer display to calculate velocity of an object, we are working with pixel. So first of all we need to find pixel ratio with original size of object in real situation. For different computer screen will resulting different pixel density. Pixel setting was the first step need to be done before do any calculation. For pixel calculation example, real ball diameter used is 0.22 m. when displayed in computer, it size is 64 pixel so the pixel ratio is

Diameter ball/diameter in pixel = pixel ratio

0.22/64 = 0.003438

So the ratio of ball displayed in computer is 0.003438 and this ratio might be different for each experimental setup. That is why ball always need to move in straight line only so will no affecting other calculations.

Figure 3.11: Displayed pixel

At “displaying pixel” column, it will display a number representing value of pixel for ball diameter displayed on the screen. Using that value it will converted into pixel ratio later.

After pixel ratio was calculated, next step is calculating ball velocity produced from launcher. Due to ball direction that move in projectile motion and not straight line, velocity for component x and y axis was considered.

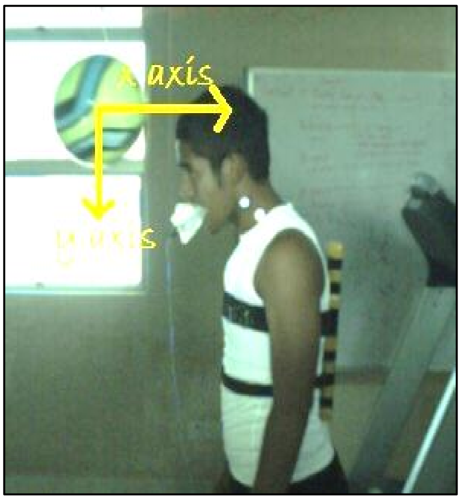

Figure 3.12: Ball movement

To calculate velocity of ball, we need to consider movement of ball in both axis, x and y. ball moving in computer display is same with real situation but time of movement also need to be converted into pixel ratio. Ball velocity was taken 10 frames before ball impacted to the head. Using these 10 frames and reversed, we can see original position of ball within 10 frames before impact. So this is highly depending on value of frame rate per second (fps) that initially setting at the XICAP software. For this MSNT fps setting, 500 fps was used. Which mean the high speed camera captured 500 picture for each second.

frame reversed / fps = time ball travelled for frame reversed

10 / 500 = 0.02 second

So as to calculate velocity, only use formula of (R. C. Hibbeler, 2007):

$$v = d/t \tag{1}$$

But first of all, distance travelled of ball in 10 frames before impacted to the head need to be calculated and it is for both axes. This can be done by mark centre of ball during impact, and make a straight line to the centre of ball at 10 frames before the impact happen.

Figure 3.13: Ball distance travelled

So for end line of A is centre of ball 10 frames before impact and end line of B is centre of ball just before impact was take place. So distance travelled by the ball can be calculated by taking distance of point A and B. Result will be in pixel so it needed to be converted into unit metre first.

To convert it:

Distance in pixel x pixel ratio = Distance in metre

42 x 0.003438 = 0.144375 m

But this is only for x axis. So this is calculation for y axis.

16 x 0.003438 = 0.055 metre

So distance of component x and y was obtained. Then both x and y component's velocity was calculated in metre/second.

X component = 0.144375 / 0.02 = 7.21875 m/s

Y component = 0.055 / 0.22 = 2.75 m/s

So the formula to calculate resultant velocity is (R. C. Hibbeler, 2007):

$$\sqrt{[(v_x)^2 + (v_y)^2]} \quad (2)$$

So for this example of calculation,

$\sqrt{[(7.21875)^2 + (2.75)^2]} = 7.7248205$ m/s

So velocity of ball before impact is 7.7248205 m/s. This calculation is same for both experiment, for relaxed muscle and free style heading experiment. But the difference in velocity calculation is where for free style heading experiment is there is velocity of head before impact and the formula is change and will be:

V resultant = V1 – V2

Since head and ball is in opposite direction, the formula will be (R. C. Hibbeler, 2007):

$$V\ resultant = Vball + Vhead \quad (3)$$

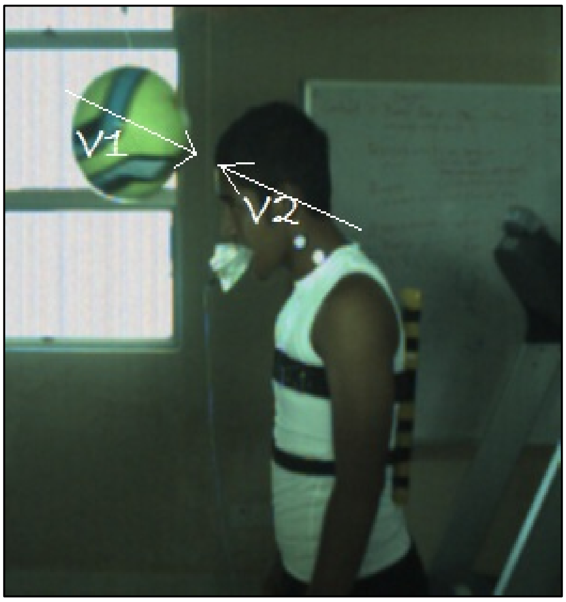

Figure 3.14: Resultant velocity

So to calculate velocity of head is using same method in calculating ball velocity instead to calculate head velocity, ear was used as a marker to be a fixed position of marker before and during heading.

To convert it:

Distance in pixel x pixel ratio = Distance in metre

2 x 0.003438 = 0.0070968 m

But that is only for x axis. So this is calculation for y axis.

1 x 0.003438 = 0.003438 metre

So now we have both distance of component x and y. Then both x and y component's velocity was calculated in metre/second.

X component = 0.0070968 / 0.02 = 0.35484 m/s

Y component = 0.003438 / 0.22 = 0.015627 m/s

So the formula to calculate resultant velocity is:

$$\sqrt{[(v_x)^2 + (v_y)^2]} \quad (4)$$

So for this example of calculation,

$\sqrt{[(0.35484)^2 + (0.015627)^2]} = 0.3552$ m/s

So velocity of head before impact is 0.3552 m/s.

So the resultant velocity is Vhead + Vball :
0.3552 + 7.7248205 = 8.08 m/s.

After that, another parameter that needed to be calculated is deformation of the ball. Deformation of the ball can be analysed from high speed camera where only for clear image only or otherwise result is not accurate.

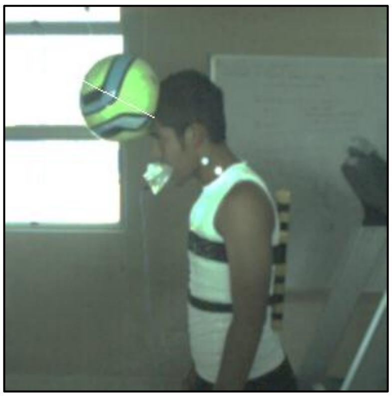

Figure 3.15: Ball deformation

Image of straight line on the ball show how new diameter of ball is calculated. This new diameter is due to deformation occurred during impact and the value is slightly smaller compare to original diameter.

This deformation need to be considered to fill formula of impact force. Deformation is most hard variable to calculate due to various posture of subject. Only clear image was selected to be analysed or otherwise wrong value will be obtained whether smaller or larger. But if larger diameter obtained is obviously it not logic and totally wrong. Formula to get value of deformation is:

Diameter ball original (pixel) – diameter ball final (pixel) = Length of deformation (pixel)

And pixel value need to be converted into metre value by times pixel ratio value.

8.55 x 0.003438 = 0.0293949 m.

And finally is sample calculation to calculate angle of neck bending due to heading the ball.

(angle body – angle neck) initial - (angle body – angle neck) final = total neck movement angle.

(239.04 – 275.49) – (236.31 – 277.34) = -4.67. So angle of neck bending is 4.67 degree from its original position.

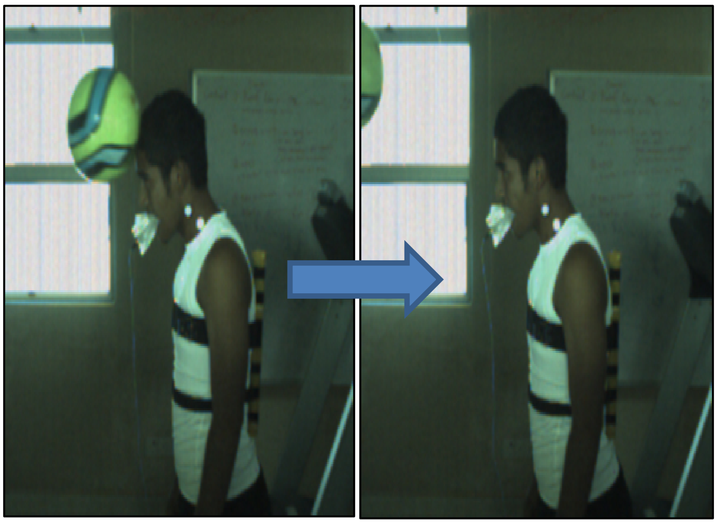

Figure 3.16: Neck bending

Diagram show the difference of neck position after and before impact. This image sequence was taken from same subject and same trial. With naked eyes we hardly can see bending of neck after impact but with assist of proper instrument we can solve the angle accurately. Separated experiment was conducted to determine stiffness and damping coefficient of soccer ball using drop ball experiment.

1. Soccer ball, dropped from different heights (0.5, 1.0, 1.5, 2.0, 2.3 m)
2. Velocity of ball before/after impact, ball deformation, contact time were measured using high-speed cam.
3. Coefficient of restitution was calculated for each trial.
4. Ball stiffness and damping coefficient were determined using equation of:

$$k = \frac{m}{(\Delta T)^2}[\pi^2 + (\ln e)^2] \quad (5)$$

$$c = -\frac{2m}{\Delta T}\ln e \quad (6)$$

So the formula used to find the correlation of amount of force impacted from ball to the head (R. C. Hibbeler, 2007) and resulting angle of bending of neck is:

$$\text{Force} = kx + c\dot{x} \tag{7}$$

k = 36833 N/m

X = ball deformation

C = 15.17 Ns/m

$\dot{x}$ = relative velocity

Velocity

$V_r = V_b - V_h$

Sample of calculation of force is

F = (36833 x 0.0293949) + (15 x 8.08) = 1203.9 N

Based on this sample of calculation, 1203.9 N of force applied from impact during ball heading, it will resulting 4.67 degree of neck bending. But this value of angle may differ according to subject. But many trials were conducted so accurate result distribution can be obtained.

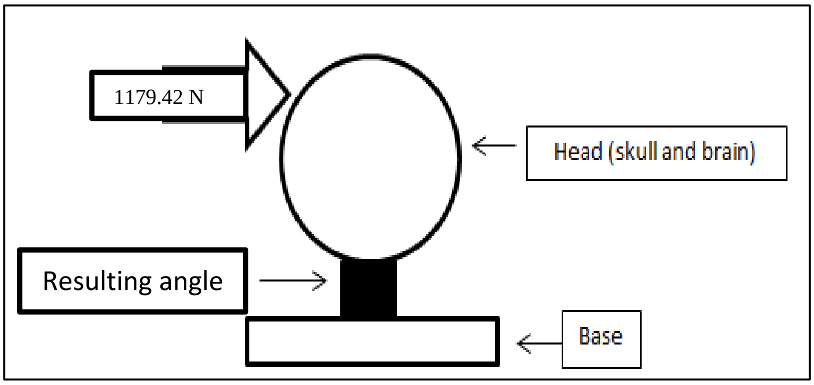

Figure 3.17: Force impacted on head

So there is some calculations that involved in analysing of real human neck reaction to force impacted by the ball. One of problem when dealing with pixel is it is hard to put calculation in very accurate value but the value was analysed with best method and carefully recorded.

3.2.2 Analysing Data

In order to record an accurate data, not all trials can be used as a sample to calculate the parameters. The analysed could be further but wrong result will be obtained. Here is list of wrong posture and image that make image cannot be analysed.

1. Incorrect heading skill (2 types)
2. Neck marker was blocked by hand
3. Incomplete ball image
4. Short duration of video
5. Detached of neck marker

Figure 3.18: Wrong posture 1

Previous picture show how subject heading the ball with a wrong posture. Ball and head almost be in 1 axis (x). Study goal is to calculate angle of bending but not change of length of neck during impact.

Figure 3.19: Wrong posture 2

When subject block their neck marker with their hand, no angle of bending can be recorded. It is same case when neck marker was detached from neck during collecting the result.

Figure 3.20: Wrong posture 3

One of wrong heading method has been recorded. This type of heading will not helping much in analysing force value and angle of bending.

Figure 3.21: Wrong posture 4

Wrong direction of ball direction will lead to wrong value of ball deformation because camera cannot record full deformation that happen on the head.

Figure 3.22: Wrong posture 5

Picture show an example of image that have not include full image of ball. If ball is not displayed clearly in the image, pixel ratio cannot be determined and same goes to another calculations. This error occur if ball does not displayed well all along trial that is from beginning trial until subject finish heading the ball.

3.3 SOLIDWORKS MODELLING

Before fabricating any model, 3D modelling must be done first. To accomplish 3D modelling, solidwork version 2011 version 64 bits software was used to make a 3D model of neck. The idea to modelling dummy was inspired by previous study of Omni – Directional Dummy neck (ODD neck). This ODD neck is an oversea master level studies. And it is required more than one thesis to fabricate this ODD neck. One of the thesis was for modelling and another one for fabricating.

The idea to make a same model with ODD neck is not relevant due to the ODD neck purposed itself. ODD was produced to imitate neck movement and also car crash impact but not something with bigger force participate such as head impact analysis from ball heading which the force can be up to more 1000 N.

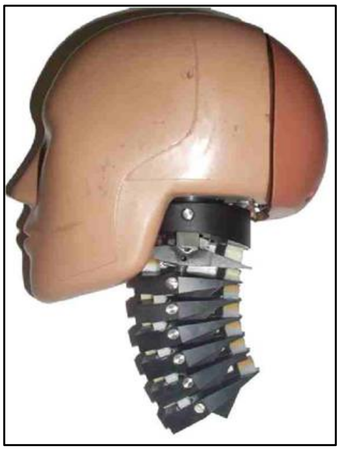

Figure 3.23: ODD neck

Source: Sarale Luca (2005)

Diagram show the product of final parts of ODD neck model. It can be connected to head dummy also. It is fabricated using hard plastic and not aluminium as HYBRID dummy was produced.

This ODD neck model is so special. It can perform lateral bending, flexion, extension and also rotation. But in consideration of study goal, our model needed to be only able to perform flexion and extension. But extension reaction is most critical movement that need to be perform as same as possible with real human neck while heading the ball. Same reaction means is same angle of bending. For early method proposed is to use cantilever beam concept to calculate angle bending of neck. But no material suitability was found to proceed with this method. So ODD neck take place as a bench mark to achieve this study objective.

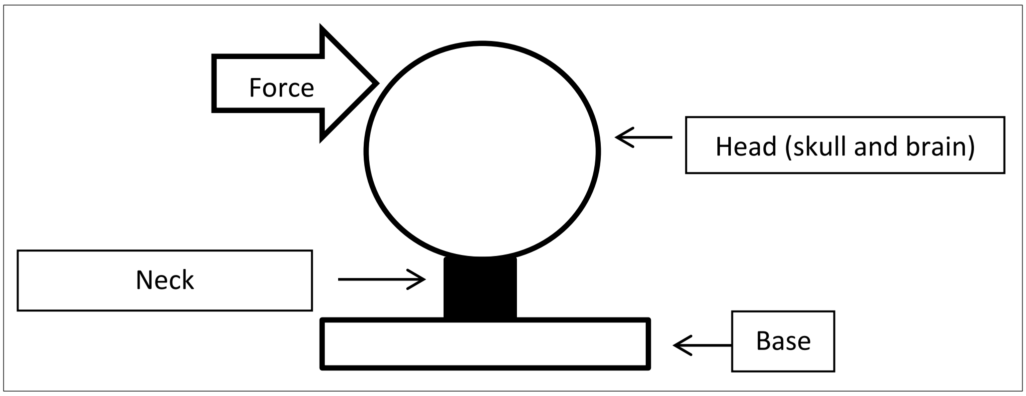

Figure 3.24: Free body diagram

Diagram above show free body diagram of head and neck during impact force where force will impact at the head (forehead) and will affect straight to the neck bending.so base will function to support all structures from collapse. For head part, skull dummy was used. Neck will be constructed with similar human properties, and the base will be made up from simple material (steel) and must be able to support all dummies from collapse during impact test. Glue will be used to tighten neck replica onto wood and it is must be in accurate size to be fit with current skull. Also screw will be used to joined neck replica and the skull part. So all connection will be tested first so it can bear all repetitive force impacted the skull. Polyurethane and polymer were chose because for previous study because it can perform very similar reaction with real neck properties. The literature showed that materials can achieve reaction same like real human value but only for car crash experiment.

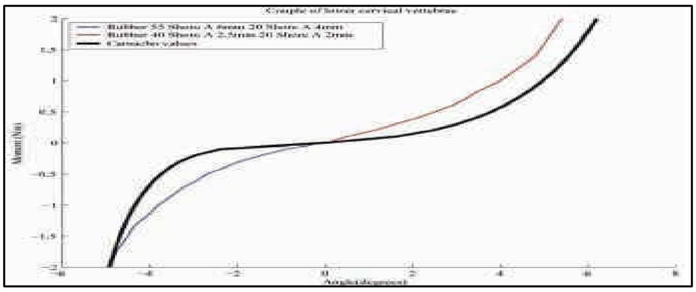

Figure 3.25: Comparison ODD reactions with Panjabi data

Source: Sarale Luca (2005)

Figure 3.26: ODD drawing

Source: Sarale Luca (2005)

Actually it is unnecessary to build whole part of ODD neck. Simple design would not be a problem because the study target just to measure angle of bending by the neck, not the whole reaction of the neck.

ODD neck has been designed to include 8 same cervical vertebrae as real neck human have. The name of those cervical vertebrae was c0, c1, c2, c3, c4, c5, c6, c7, c8. C0 is top vertebrae that connected to the head while c7 is lowest vertebrae that connected to the human body. Design of c2 – c7 is almost same.

So the task here now is to redesign ODD neck so it can be more simple to fabricate and can achieved the study objectives. But in same time, new design needed to be as same as human neck having 8 cervical vertebrae.

Modelling the model is not easy task. If odd have imitate even and original posture of angle of neck during unloading time, new model does not need to follow that. Straight shape of model still acceptable because of the most sophisticated dummy, HYBRID was designed in straight design with no angle.

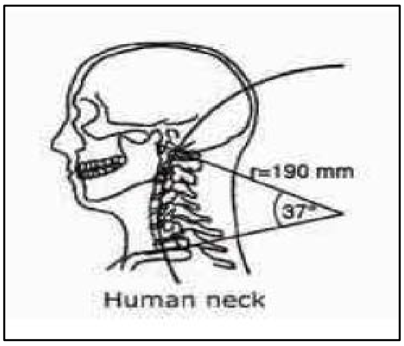

Figure 3.27: Neck angle

Source: Sarale Luca (2005)

Diagram show main angle dimension followed by ODD neck designer. With radius of 19 cm and angle of 37 degree, simple calculation of $s = r\theta$ will how us that human neck is about 12 cm in straight line. So the design must be 12 cm in height, have 8 parts representing cervical vertebrae, the gap between parts represent disk in real neck structure and perform as a muscle and cylindrical shape was chose due to shape of real neck and have an enough space to put rubber that will represent muscle.

Initially, according material availability, main material was ABS and steel as a pin joint and rubber as a muscle. The most important part is rubber that will indicate how much bending will occur. Main part (ABS) needed to capable to withstand large amount of force so it will not crack when supporting head dummy during head impact testing.

Pin joint will be chose from readily material selection such as mild steel screw. What most important is there is no friction between pin joint and the ABS part. After some sketching and designing, figure below is drawn using Solidwork software and this can be treated as final drawing before fabricate the real one. It contained 8 parts of cervical vertebrae, 7 pin joints and 14 parts of rubber. Base part is not included in the fabrication because already built. Black part is a ABS part which is earlier material was chose. Yellow one is rubber and white part is a pin joint.

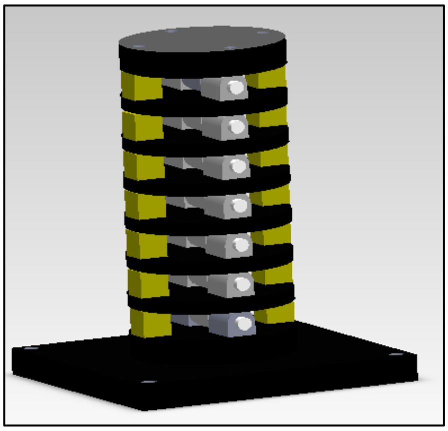

Figure 3.28: Dummy drawing

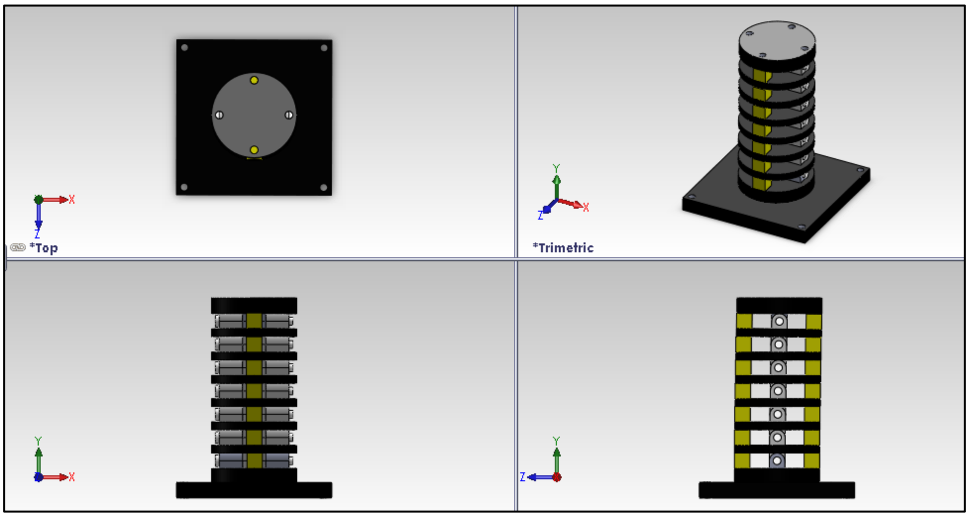

Figure 3.29: Isometric view of dummy

Together of them are capable to perform extension and flexion reaction. Properties of rubber itself will determine how much structure will bend after being applied some force.

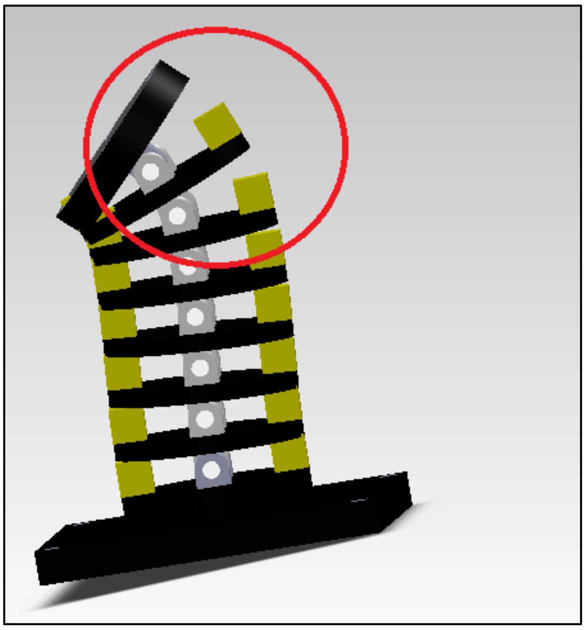

Figure 3.30: Dummy movement

In solidwork modelling, this structure can perform reaction as above diagram (in red circle). Obviously for flexion – reaction part, rubber will only attached to 1 surface only which is surface that follow gravity law, bottom one. This is because the design is extension reaction only will be affected by rubber at one side only, not for both side. Besides, it is for make fabrication process easier.

As mentioned, base part is not included in the fabrication process. But base is needed to support neck structure so it will not collapse together with head dummy. Besides, base was design to not have any movement even head receiving large force and for easier calculation of neck bending angle.

But there is also limitation for this model movement. That is it cannot perform lateral bending and rotation as normal human head can perform. But as mentioned before, it is okay as long as neck can imitate same reaction during ball heading.

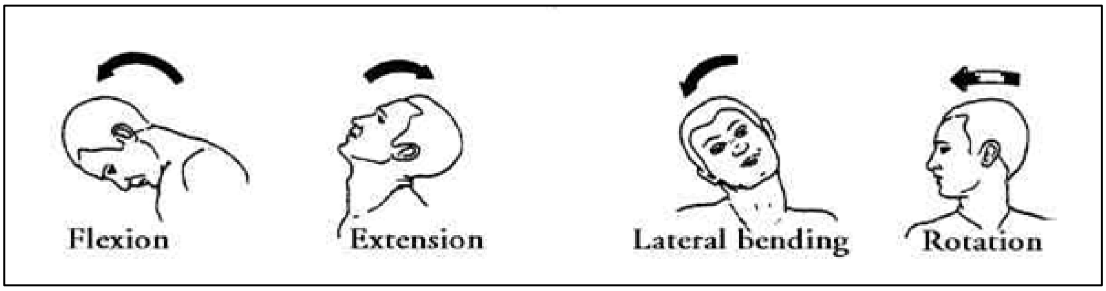

Figure 3.31: Human neck bending

Source: Sarale Luca (2005)

Diagram above show how flexion, extension, lateral bending and rotation being performed by normal human neck and head. But ODD neck can perform all of the above reaction and some modification needed so it also can perform rotation. It can perform lateral bending because it have steel cable in it so it can limit the movement of the neck and make sure ODD neck move in a right range of movement.

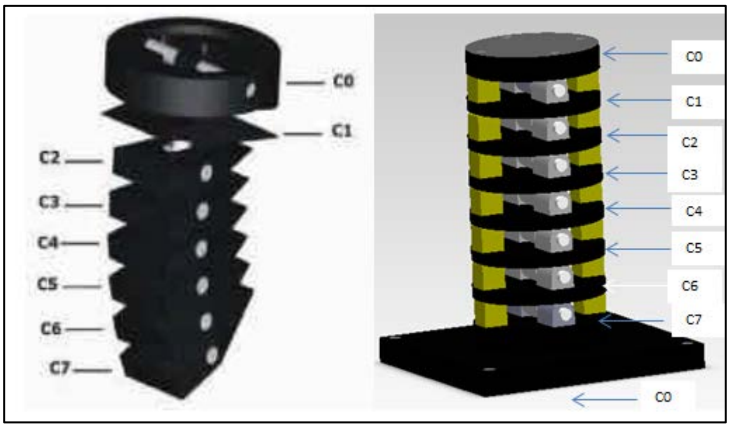

Figure 3.32: Dummy comparison

So here is detailed explanation about each part of the drawing. Even though these structures have 30 parts, but it has many similar structures. For every structure have its own method to connect with each other.

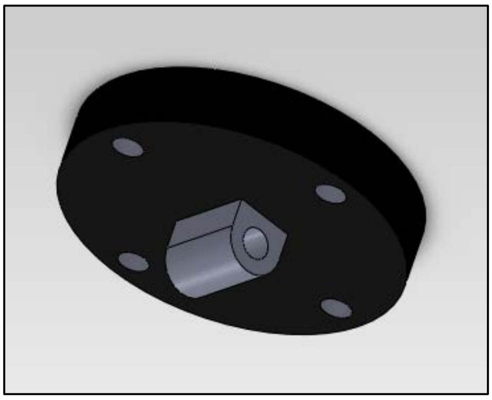

Figure 3.33: C0 part

This is top part (c0). This part has 4 holes with diameter of 5 mm each one. This is due to same hole at the skull and need to be fit to each other to connect them. The diameter of the main circle shape is 52 mm and the grey one is connector to c1. This connector is similar to each connector at each part. Connector is 10 mm height and 5mm diameter of hole on it to put pin joint through it.

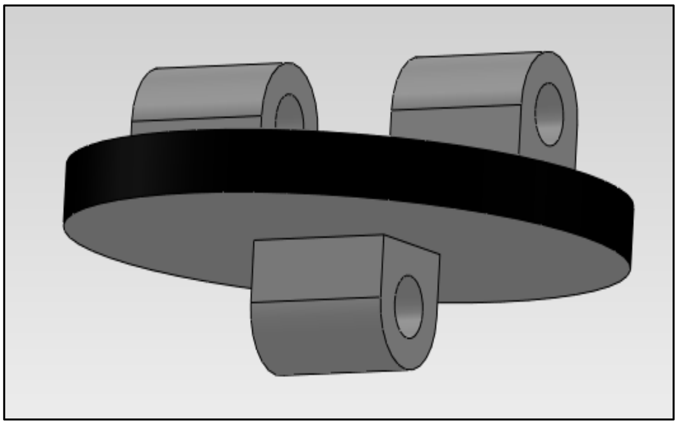

Figure 3.34: C1 – C6 part

Previous picture a similar structures of c1, c2, c3, c4, c5 and c6. With 10 mm as circle diameter thickness, it is also same with c0 and c7 parts. Below part is same like c0 part but above surface is little bit difference. With same dimension of connector at below surface, upper surface have 2 of it so it can hold single connector from above (c0). It is same way of connector joint for c1 with c2, c2 with c3, c3 with c4, c4 with c5, c5 with c6 and also c6 with c7.

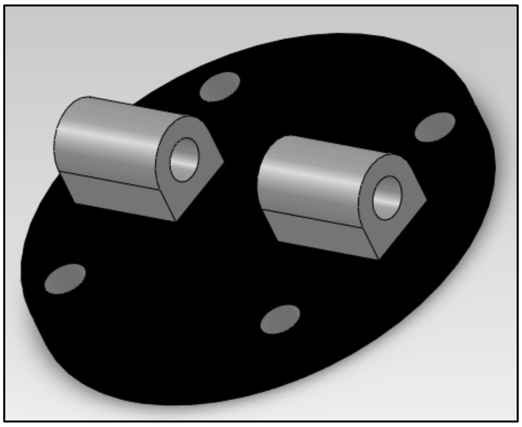

Figure 3.35: C7 part

Above diagram is bottom part that is c7. This c7 also have 4 holes at main circle part and function to connect neck dummy with the base. Thickness also 10mm and connector part also have same dimension.

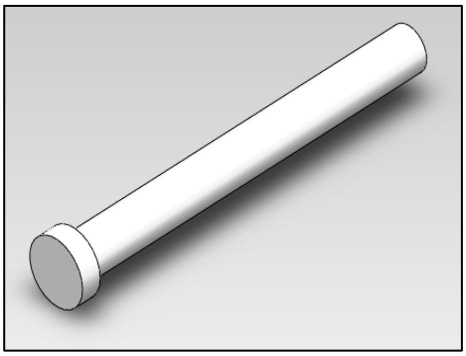

Figure 3.36: Pin joint

Previous figure show the pin joint between each part and will be put through each connector. So it will be 7 pieces of it. The diameter of rod is 5mm and length of 50 mm. The other end will be tightened with nut and thread. The properties must be strong enough to hold all parts from collapse.

Material selection was aluminium in the drawing but steel in the fabrication. This is not a big deal because it will not affect the bending angle. As mentioned it only needed to be smooth.

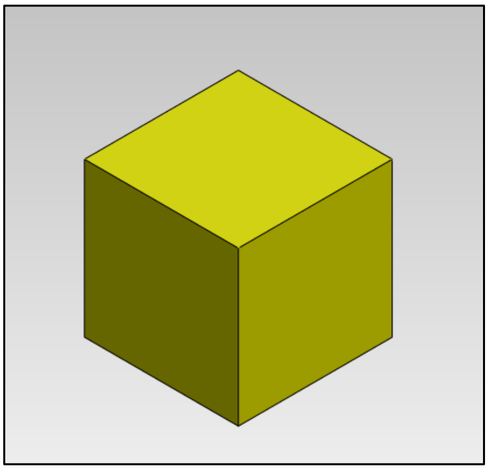

Figure 3.37: Rubber part

Figure above is rubber. There are various type of rubber available and each one having different properties such as Young's Moudulus. Each value of Young Modulus will affect to the bending of the neck. The dimension is 10 mm x 10 mm x 10 mm. in the design, there are 14 similar rubber parts as above. Each one will put in between each wood part.

This rubber part is only part that can be change to get different result of bending. Besides, we need different type of rubber to represent relaxed muscle and active muscle of the neck. In other word, this rubber will be a manipulated variable and very suitable for "try an error method" in determining suitable rubber type.

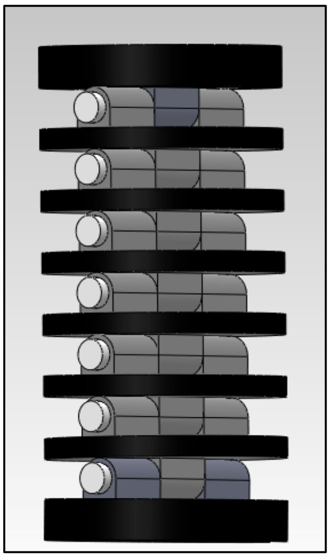

Figure 3.38: Combination of all cervical vertebrae parts

Figure above show how connector between each cervical vertebra was positioned and tightened using pin joint to each other. Connection of pin joint must not be too tight so it is not preventing each part from moving freely. If not, friction will occur and affect the bending.

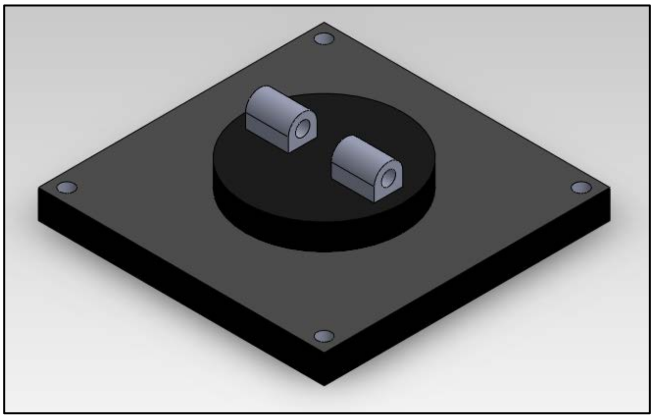

Figure 3.39: C7 and base part

Above diagram show the base part. It will be made from steel. No specified calculation was made to make sure it strong enough to hold neck during test impact. Actual base is much bigger than in the drawing and supposed to be much stable.

3.4 FINITE ELEMENT ANALYSIS

After solidwork modelling has been done, finite element analysis must be conducted so mathematical solution can prove the design will work properly. In this study, finite element analysis is a simulation of model to get angle of deformation. So mathematical calculations will estimate deformation will occur with given force and selecting material.

In this simulation, 5 different value of forces was given onto top of neck model which is 900 N, 1000 N, 1100 N, 1200 N and 1300 N. this value of forces was chose according to range of force obtained from calculation during heading experiment with Majlis Sukan Negeri Terengganu athletes.

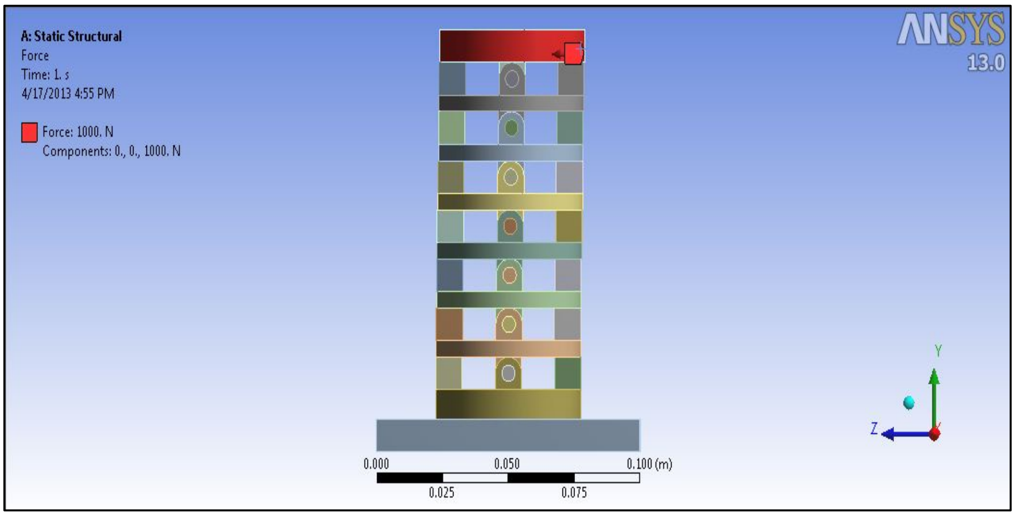

Figure 3.40: Simulation setup

Simulation was done using ANSYS 13.0 software. Method use is by importing IGES file of solidworks model into this software. Some setting needed to be done such as model, geometry, engineering data and force setting.

Table 3.1: Material properties

	Rubber	Steel	ABS
Poison ratio	0.49	0.29	0.35
Young Modulus (Gpa)	0.1	210	2.2
Density (kg/m³)	945	7800	1050

Source: Eurapipe Duraflo datasheet (2010)

In this simulation, force was applied at the top side surface of model. Fixed support was decided to be at the bottom of the base which mean bottom base surface. Force was applied straight on z axis.

The data that was key in is 3 important properties of material which is poison ratio, young modulus and density. Other property such as tensile strength, bulk modulus and others is out of consideration.

This simulation was done due to earlier material selection to fabricate the product. In this simulation also does not include mass of head which is insignificant contribution to the bending due to smaller force if compared to the applied force.

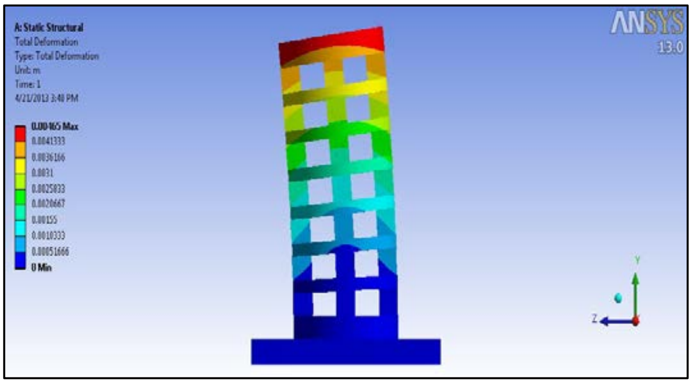

Figure 3.41: Simulation bending

Figure above show how deformation of model was displayed on the screen and value of deformation was given. The colour indicates how much stress absorbed by the material due to force applied.

3.5 FABRICATION OF NECK MODEL

During fabrication process, changing of idea was occurred. Instead of using wood as main material, ABS (Acrylonitrile / butadiene / styrene) material was chose due to material availability and method of fabrication. To fabricate model using ABS, rapid prototyping machine was used. By only key in STL file of the 3D model, rapid prototyping will produce it accurately similar with the drawing given. Even everything was automatic but cost to produced using ABS material is high.

That is not only idea that has been changed, but also part of model was modified a bit so material cost can be reduced.

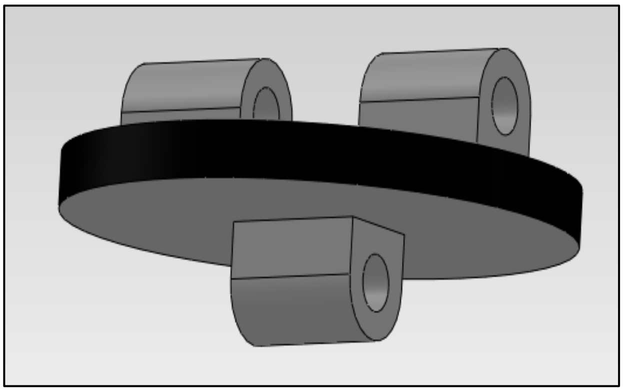

Figure 3.42: Original part of C1 - C6

Instead of using this drawing, connector part was eliminated from main part and fabricated separately.

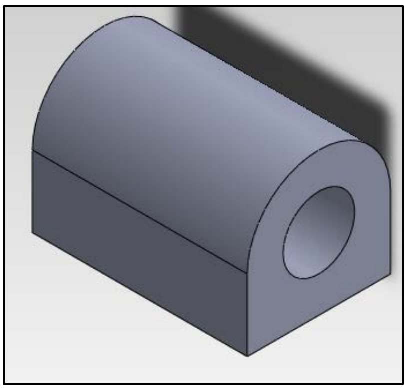

Figure 3.43: Separated connector part

This is because if bottom surface is flat, it will reduce using of supporting material (PLA) and also will reduce a cost. So new drawing has been made so it will have flat surface at the bottom.

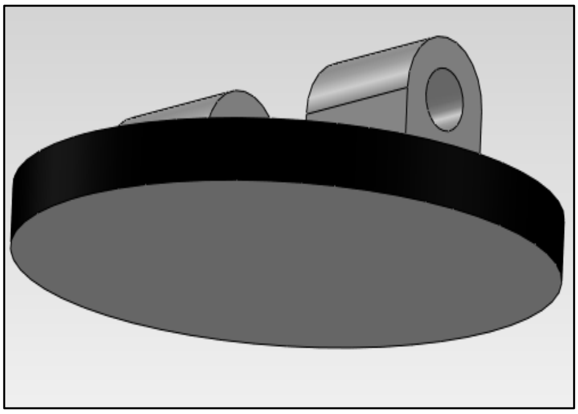

Figure 3.44: Separated cervical vertebrae part

Diagram above show the final drawing of the modified part. The part that affected by this modification is c1, c2, c3, c4, c5, and c6 parts. Meanwhile c0 and c7 drawing was stick to original plan.

Advantage of using rapid prototyping fabrication process is it will reduce production time, final product will be exactly like in the drawing. Besides, the method is easier than produce manually.

Disadvantages of using rapid prototyping method is the cost is high even for a small parts, material properties is not same with material in the simulation and limitation of material strength. All parts were fabricated simultaneously and take about less than 24 hours to finish it. All parts were arranged side by side in the machine trail and supporting material was reduced in a large of amount.

But noted that even material was changed to ABS, it does not affect the movement limit of model. The only part that will affect model deformation is only the rubber part.

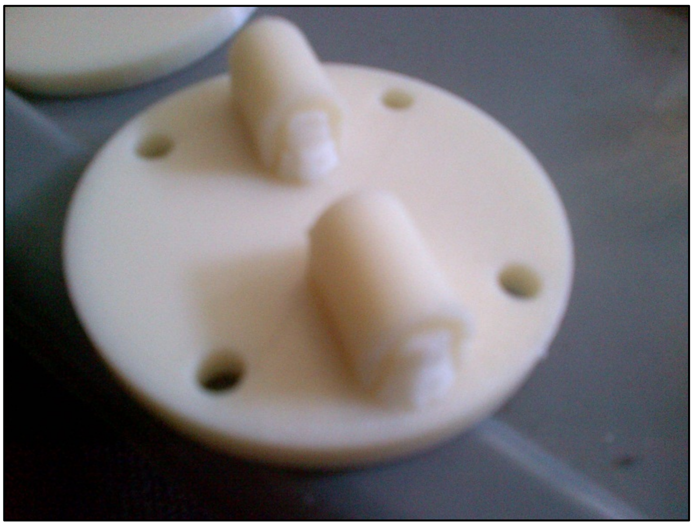

Figure 3.45: Supporting material

After product produced using RP machine, there are supporting material (PLA) that stuck in a narrow part such as in connection hole and need to be removed manually. This is due to fabrication of structure that needed to be support from below due to gravity force and if not support, ABS material cannot stand alone for early stage of production.

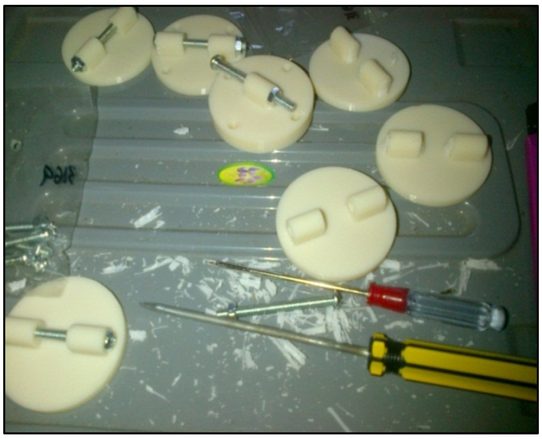

Figure 3.46: Removing supporting material

Supporting material was removed manually using simple tools such as screwdriver and knife. This process need to be done carefully so it not removed any other parts. To make sure supporting material was fully removed, screw (pin joint) was used to determine whether the contact of screw and connector is smooth or vice versa. Process was repeated until the contact is fully smooth.

Figure 3.47: Reducing connector surface

Because of no tolerance was considered in 3D drawing model as much as 0.03 mm, another process is to reduce surface of connector so it can be fit in between other connector and to make sure surface contact is as smooth as possible. Surface reducing process was done using sand paper.

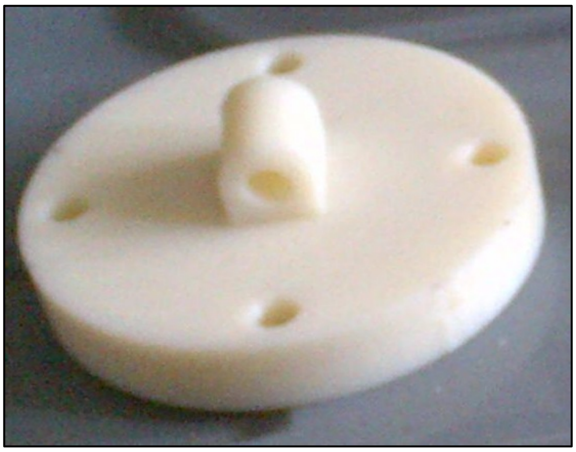

Figure 3.48: After supporting material removed

Previous picture finished part of supporting material removing process. After surface reducing and supporting material process, screw and connector were assembled together to make sure the movement is really smooth.

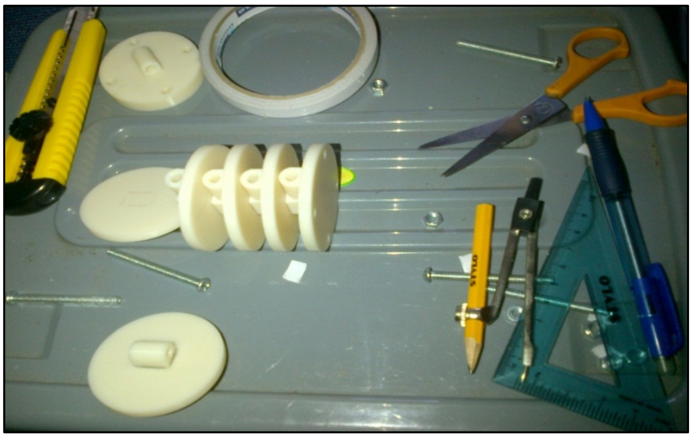

Figure 3.49: Attaching connector part

Due to separate part of cervical vertebrae part with connector, next process is to glue them together so all parts can be connected from c0 until c7. The challenge is to make sure connection was made at the centre of cervical vertebrae part. Indicator used to make sure parts is centre is by looking at their edge when they are bending. If both sides produce same contact (edge to edge) so automatically connector was assembled at the centre of cervical vertebrae parts.

Figure 3.50: Epoxy

Initially connection was made using DEVCON epoxy glue and let it dry for 3 hours and along that duration, parts cannot be touched because beware of centre mark of connector will moving. If parts is not centred, movement of neck will not as same as in simulation. Before the glue is dry, there are probabilities the connector part will moving itself due to weak connection at the beginning of time. So it is needed to be observed from time to time so it will keep constant at centre.

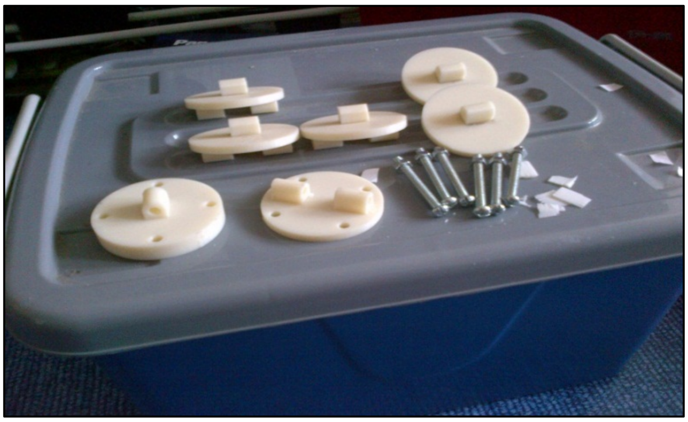

Figure 3.51: Drying glue

Picture above show how drying process take place.in beginning of process, parts cannot be let in not inclined surface such as in picture due to its weak connection. This picture was taken long after glue starting to dry.

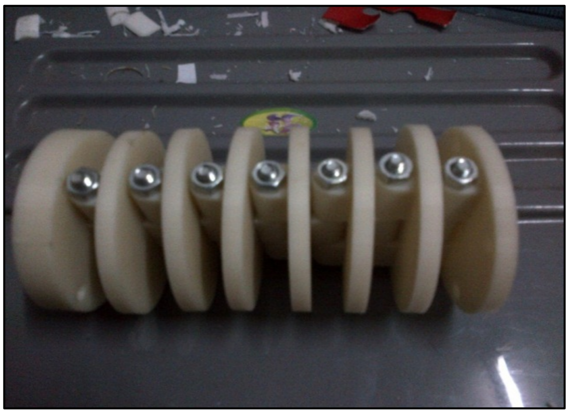

Figure 3.52: Fully assembled

This picture was taken long after glue starting to dry. After 3 hours, product was ready to be assembled. Model was rechecked so it have perfect curve edge to edge and luckily it have. So far, c0 until c7 was succeeded built and ready for assemble with rubber part.

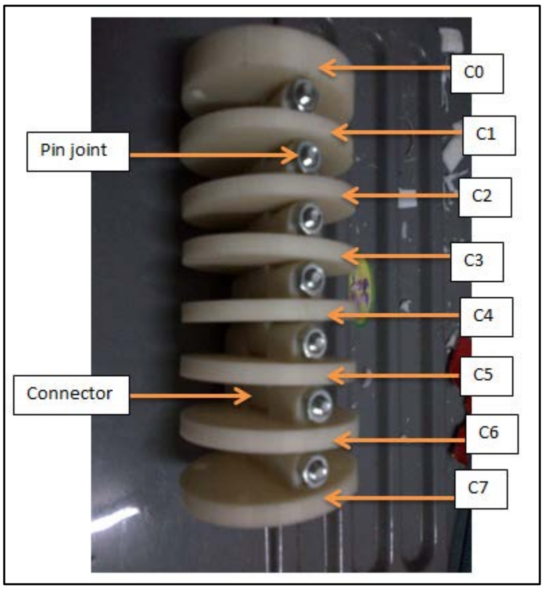

Figure 3.53: Each cervical vertebrae part

Screw that used to fitted in the connector can smoothly moving and can be considered as a frictionless. While nut at other end is not tightened with full concentration so it will not disturb surface of touching connector.

For every connection made, only co and c7 has a fixed connector to their surface. So connection between c0 and c1 and c6 with c7 is not affected by use of glue as a connection method. Actually if c1 until c6 has changed its position, there is nothing affected because of the uniform shape that they have. C0 was a thickest one so it is the most critical part that will absorb force during impact according to the simulation result.

3.5.1 Preparation of Rubber

As rubber is the important part of this study and treated as a manipulated variable, it is a concern to prepare it for more than 1 sample. So few rubbers type was selected and being tested its properties for simulation data purposed. Two types of rubbers was chose that is natural rubber, and 2 types of eraser with different hardness. Hardness of the rubber has shown obviously on tested by hand but need to run experiment to get exact properties.

Rubber need to be prepared with same dimension as in 3D drawing. Whatever shape of rubber from the store was reduced until it met mutual dimension as in 3D drawing.

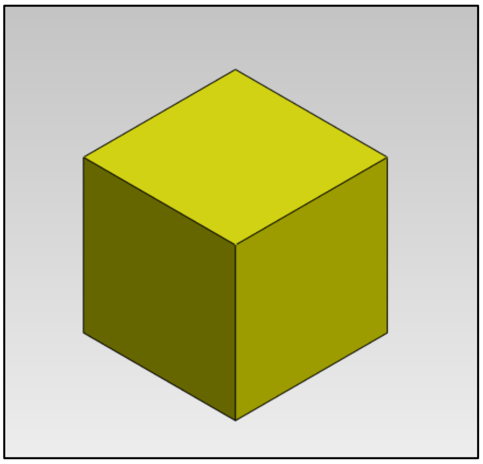

Figure 3.54: Benchmark of rubber shape

Figure show cube shape of rubber drawing. The design was chose so it can fit properly with other parts.

After rubber was selected to become part of the study, first thing to do is test its properties. The most important value that needed to know is its Young Modulus. The elasticity properties will determine the bending and support other parts during impact test and also when dummy stand alone. So rubber actually one of the supporting part of neck dummy.

Figure 3.55: Synthetic Eraser

Figure show an example of standard eraser that selected. Synthetic erasers are made from soft vinyl materials which contain minimum of the abrasive substances (erasersworld.com). Using manual method it will be reduce the dimension not to use in the dummy, but to run compression test. This compression test need the sample to be cut off as small as possible because the compression force at the machine is only limited until 30 KN. But even different dimension of same material were tested, it still will display same result because of the evaluation considering surface, height of sample and its elongation percentage. So the different dimension of samples will not affect the result accuracy.

Figure 3.56: Rubber preparation

Figure 3.56 show how each material selected was reduced its dimension. This process was done manually using ordinary knife. Cutting skill need to be as straight as possible so an accurate dimension of sample can be measured. If surface is no straight enough, reading during compression test will be affected.

Figure 3.57: Rubber before compression test

Figure show selected material before tested using compression test. It is so hard to cut natural rubber in exact dimension and edge due to its elasticity and the smell is so strong. Compression test was conducted using INSTRON universal machine. This machine are capable to do both test, tensile and compression. But according to rubber application in this study will be compressed during impact (refer design), so compression test was conducted.

Figure 3.58: Compression test

Figure 3.58 show how specimen was put at the centre of the compressor. There is some precautions that need to be followed during this test such as surface of compressor not touch specimen surface before test and it will test until rubber crack and achieved its yield strength point.

Figure 3.59: Rubber after compression test

Figure 3.59 show a cracked sample after done compression test. If it cracks, means no more elongation reading will produced and this is the end of the elastic deformation. This state is called plastic deformation.

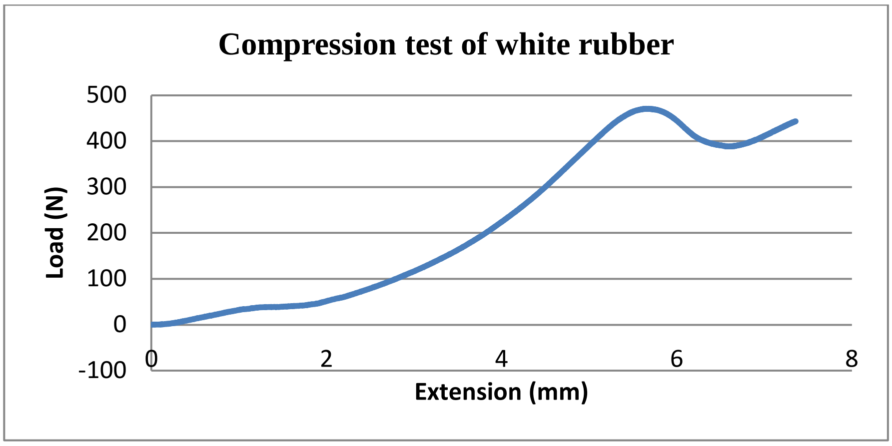

Figure 3.60: White rubber compression test

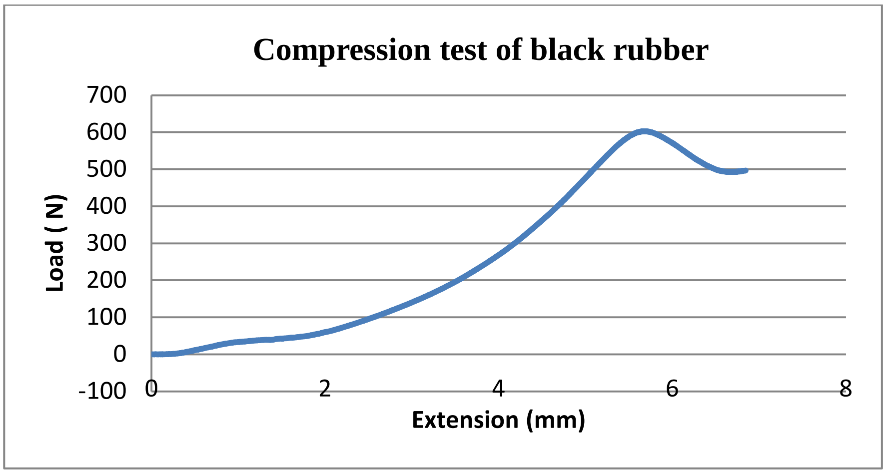

Figure 3.61: Black rubber compression test

That is the resulting curve from the experiment. So the value of young modulus achieved is 0.01 Gpa for white rubber and 0.002 Gpa for black rubber, the softer one. So it is proved by engineering method.

This Young's modulus was defined by the gradient of any straight line on the curve before force was applied and until its ultimate tensile strength point (at the top of the curve). But not the same thing happened to natural rubber. Even the structure is pure rubber and not mixed yet with any compound, but it still not being fully compressed at its manufacturing factory. Which mean it have a porous structure and got many air trapped in it. So somehow the curve obtained is illogically accepted and the structure is easily met plastic deformation.

Figure 3.62: Natural rubber

Figure 3.62 show original shape of natural rubber before being cut. Surface of rubber obviously show how porous it is. To reduce the error, need to test certain part so average can be recorded. But due to graph obtained, nothing can be done. To make it useful, the block of this natural rubber need to be compressed with high force and turn into a very strong rubber and not easily compressed and also eliminate porosity in the structure.

Finally white rubber was selected to be a part of the study according to the properties and the material availability. One more advantages of using this eraser is it can be shaped easily.

3.5.2 Assembly

Until this, finished part is cervical vertebrae part, rubber part, pin joint and also base part. So, next task is to assemble all of the part to become one. First part was assembled into main part, cervical vertebrae is rubber part. To make sure rubber will maintain its position, it needed to be attached to the main part. But in the same time the attachment method need to be not too strong so the model can change its manipulate variable when needed (rubber). The most suitable material can be used is double sided tape. If strong glue was used, it will affect the structure of the rubber and properties of rubber is not valid anymore because it will become harder. Double sided tape can be used only once after rubber was detached from ABS part. But it can be replace with a new one and easily can function as a previous one.

Figure 3.63: Double sided tape

Any brand of double sided tape can be use and it is none of the concern as long selected tape is thin enough and not affecting so much the gap between cervical vertebrae part. Double sided tape used is very thin.

Rubber was arranged at the edge of the each cervical vertebrae part and it is arranged as uniform place as possible so it will be same just like in the simulation. Mission to attach rubber is accomplished.

Figure 3.64: Rubber attached

Figure show the completed assemble of rubber with ABS part. Rubber also functioned as a supporting material.

After rubber, next structure that needed to be assembled is c0 with neck dummy. To do this, same dimension of connecting hole required. Method to connect these 2 parts is by using suitable size of screw (5 mm).

Figure 3.65: Attached C0 with skull dummy

Figure show how c0 part was connected to skull dummy. The connection is strong and stable. In the skull contain silicone gel. It was prevent from leak by using silicone seal. The silicone seal is not permanent. After c0, next part need to be assembled is c7 with base. As c0 with skull dummy, c7 with base also need exact dimension and position of connecting hole. This is already settled in the drawing.

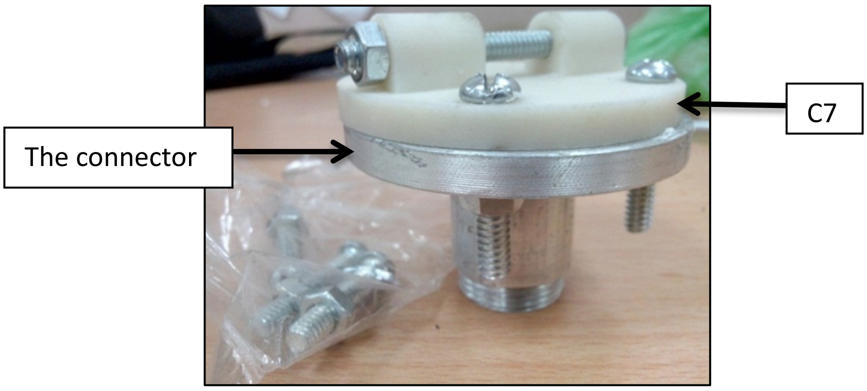

Figure 3.66: C7 attached to base connector

But c07 is not directly connected to the base. It first connected to the base connector that used a thread to be fitted in the base part. Base connector is made up from aluminium. While the connector is connected to another aluminium part that being tightened to the steel base. So actually connector has 2 parts, one stick with neck model and one is stick to the base.

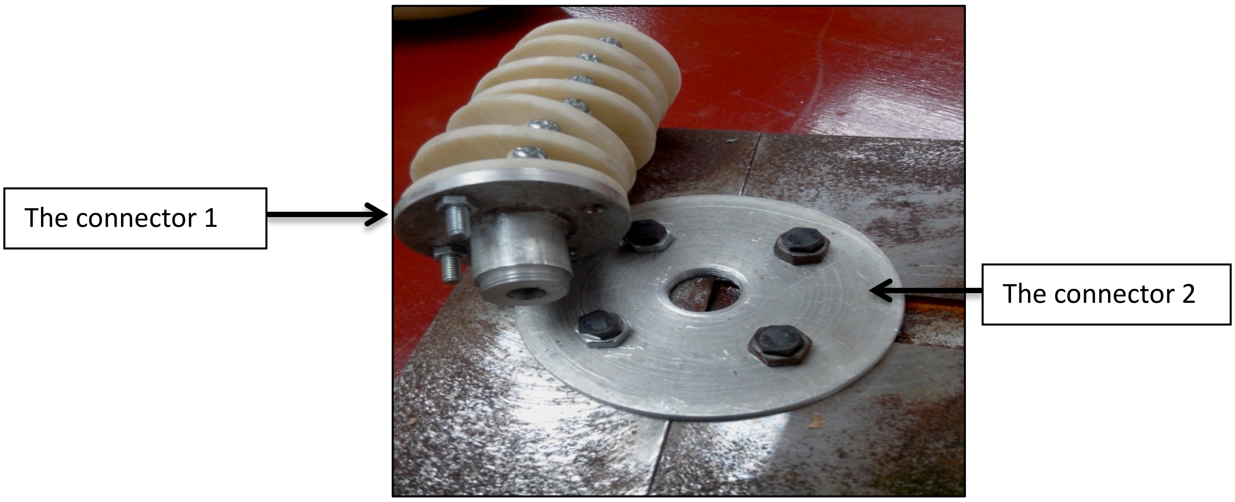

Figure 3.67: Connection of base connectors

Base is made up from steel that its weight is more than enough to support neck model from collapse during impact test. So it can be treated as a fixed support of the structure.

But there is one problem when those parts were assembled. The weight distribution of the skull dummy is not equal to both back and front side. It is more to front part due to real human head structure. While neck was connected not exactly under head's centre of gravity but a little bit behind.

So the problem is soft rubber will not stand this kind of load and frontal rubber need to be replaced with something harder. Due to material availability, wood was selected to be frontal supporting material.

Figure 3.68: Wood preparation

Figure 3.69: Wood assembled

Wood first was shaped into 30mm x 13mm x 10mm dimension. The height of wood need to be same with rubber and its length is out of consideration as long it can support weight of skull dummy. Method of arrangement of wood is exactly same with arrangement of earlier rubber.

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 RELAXED MUSCLE REACTION

In heading skill, there are many kind of way to heading the ball. One of them is by not resist the ball and just allowing the ball freely impacted to the head. The bending angle will affected by the velocity of ball and neck muscle activity. To develop of neck dummy, experimental setup is very important to collect the data from real human neck response. Without this data, there will be no source to make a comparison for angle obtained from neck dummy with actual head response.

That is why obtained result from experiment (relaxed) is included as a result to assist human neck dummy development process. Even this data is not helping in the fabrication process, but it will help so much in the validation process. Experiment was held onto non – athlete subject by using 7 subjects and with condition that stated in the methodology section.

Result obtained by averaging the ball speed and the neck bending angle and the result is for every 2.5 m/s of the ball velocity will result 6.28 degree of neck bending. This result was compared with simulation from previous study that obtained 11.6 degree of neck bending from 4 m/s of ball velocity (Stefan Lehner, 2010). So the experiment result was validated.

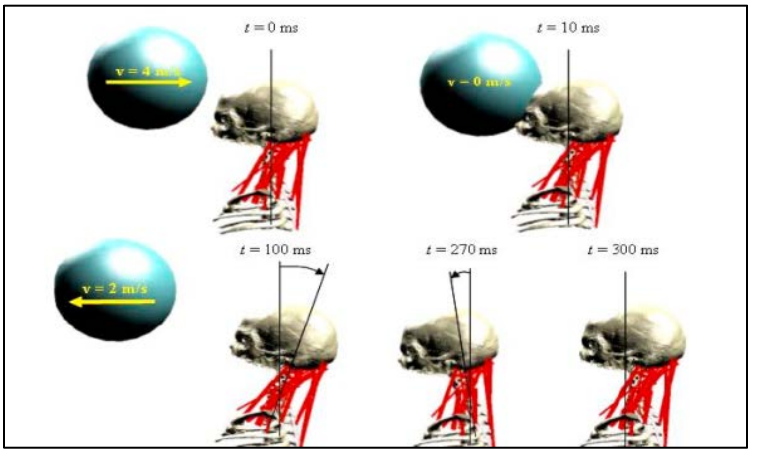

Figure 4.1: Neck simulations from previous study

Source: Veit Senner (*2010)*

Above diagram is a setup of simulation by using relaxed muscle and in the simulation, head model does not moving. Same like the way experiment was conducted. So this data is very useful to choose suitable rubber to use at the neck model that can give same bending angle.

vball (m/s)	angle (degree)
2.5062	7.57
2.3178	7.07
2.4474	7.27
vball (m/s)	angle (degree)
2.496495413	6.71
2.4864	6.87
2.2296	7.75
vball (m/s)	angle (degree)
2.449117647	5.78
vball (m/s)	angle (degree)
2.699714286	3.16
2.902114286	4.35
average (m/s)	average (degree)
2.503871292	6.281111111

Figure 4.2: Averaging the result

Table 3. Calculated contact duration, peak contact force, and maximum extension of the head for different ball velocities

ball velocity v_{Ball} [m/s]	contact duration t_K [ms]		peak contact force F_{K_max} [N]		maximum head extension γ [°]	
	without	with	without	with	without	with
4	12,2	12,5	347,1	319,2	11,6	11,4
10	12,2	12,3	844,9	826,2	31,8	30,7
20	12,2	12,2	1683,1	1648,8	62,8	62,6
30	12,2	12,2	2534,4	2470,2	91,4	89,2

Figure 4.3: Simulation result from previous study

Source: Veit Senner *(2010)*

4.2 ACTIVE MUSCLE ACTIVITY REACTION

For active muscle activity, it means the muscle is strength up during heading the ball. Human neck has very strong muscle but it is depend on frequent of one person practice heading the ball and his muscle strength. No muscle strength was recorded in this study.

So for best result of high activity muscle response, athletes were used to perform this action. Using 10 subjects from MSNT athlete, they are allowed to perform real – like heading skill just like they playing on the field.

Obviously, even velocity of ball is twice, but the bending angle recorded was smaller. This can be conclude as muscle activity won’t allow neck to bend so much and real athlete neck muscle is much stronger than ordinary person who rarely playing soccer every day.

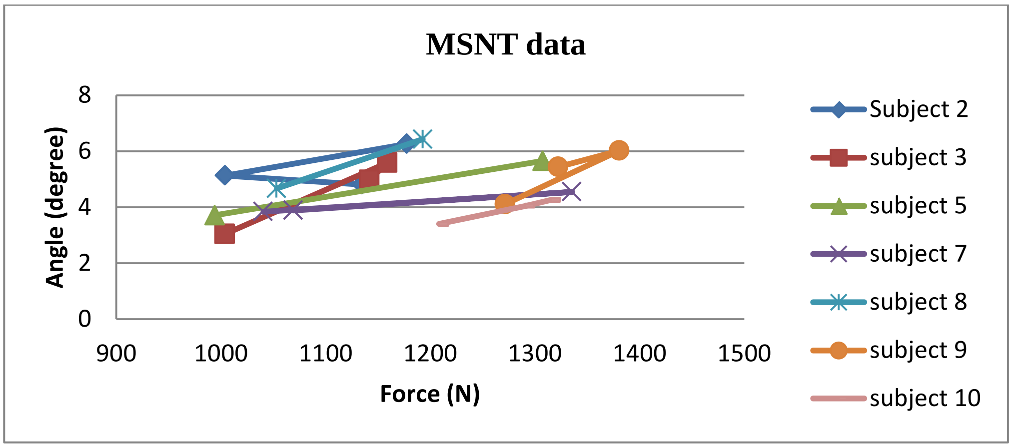

Figure 4.4: MSNT data

Figure 4.4 show maximum bending angle not even exceed 7 degree with applied force up to 1300 N. this means when the neck muscle is activated, it is much stronger than relaxed muscle. This data is helping to choose suitable rubber properties to imitate same reaction for active muscle condition.

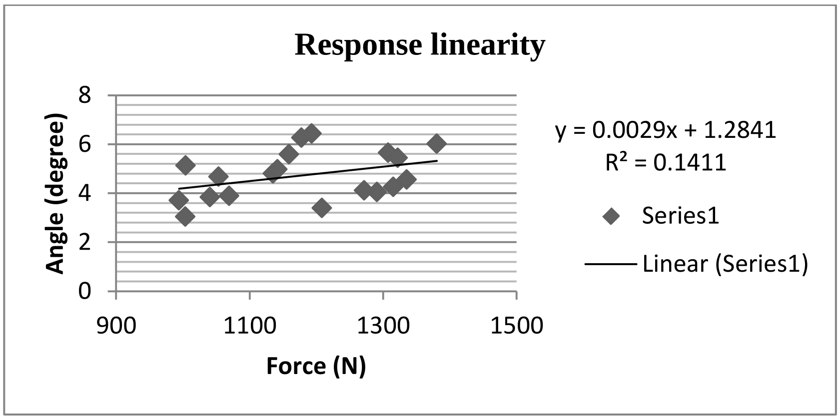

Figure 4.5: Linearity of neck response

Tabulated data above show the linearity of neck reaction with force. Gradient and correlation obtained y = 0.0029x + 1.2841, $R^2 = 0.1411$. Higher resulting velocity of ball will lead to larger value of neck based on data recorded in the experiment. No opposite result was recorded. As a conclusion, higher amount of force or higher velocity of ball, neck bending angel will be larger and vice versa.

Figure 4.6: Different of heading style

Figure 4.6 show the difference position of relaxed muscle and active muscle with assist of body posture during heading. Both methods of heading will result different velocity and direction of ball after impact.

4.3 FABRICATION OF NECK DUMMY

First failure to build real dummy is coming from weak connection method of connector part with cervical vertebrae parts. Those parts were detached for many times and no impact force can be applied onto head dummy. But it still can stand with loading the weight of skull on it. But if small force applied onto it, failure will occur. It is not because of material selected (ABS) but the connection method.

Figure 4.7: Views of attached neck dummy with skull dummy and base

Figure show side view, frontal view and rear view of the model. This is complete assemble of model with skull dummy and base. Even it cannot be used to collect data of impact testing but it can replicate every detail of the parts at the real dummy that can be used in real testing.

4.4 SIMULATION OF DUMMY

Rubber used is 10 times harder than used in prototype (0.1 Gpa compare to 0.001 Gpa). Simulation proved that model analysis can imitate real neck response. Simulation was done by using ANYSYS 13.0 software. Analysis setting is by using data as shown in methodology.

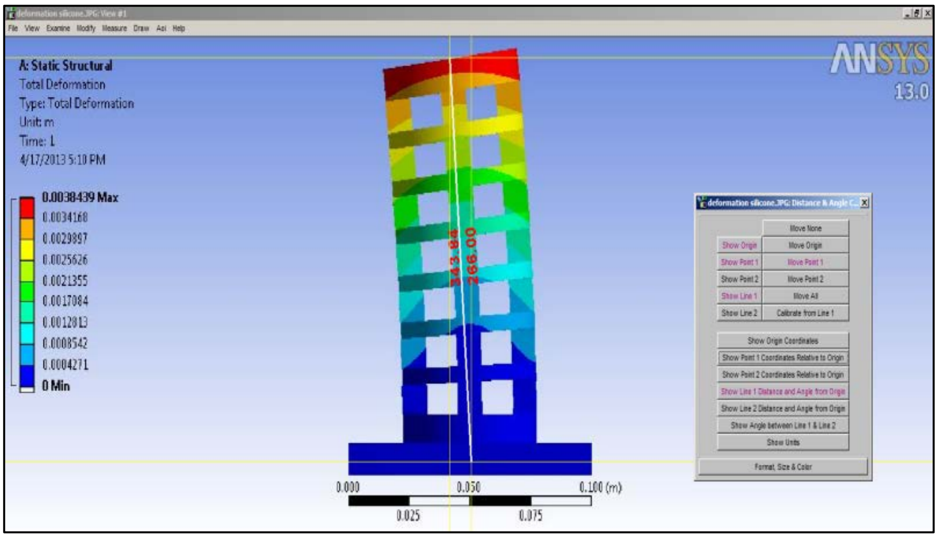

Figure 4.8: Angle analysis from simulation

Figure above show method of angle calculation by using XICAP software. It is calculated from straight line of original position of neck until to the centre of top part at maximum deformation.

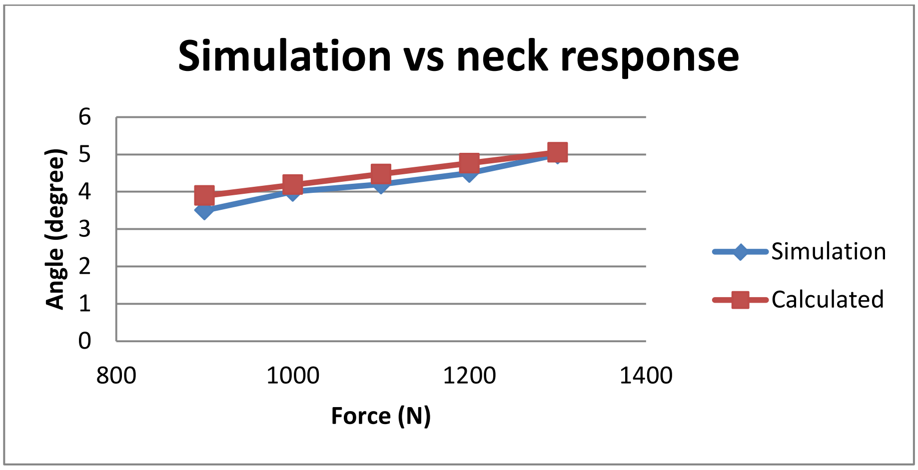

Figure 4.9: Simulation and calculated neck response

The line defined as 'calculated' is meant the reaction of real neck if given same force as simulation. This method was used to compare reaction of real neck and simulation of neck dummy at given same amount of force that is 900N, 1000N, 1100N, 1200N, and 1300N.

This kind of comparison is needed due to none of forces applied to real neck during experiment was as exact as in simulation. Besides, even velocity of ball in same range but it is not in constant velocity due to type of launcher was used during experiment. For example, if ball launched in position that supposed to give 9m/s of velocity, but real velocity obtained will be less than that value and it is varies for every trial conducted. That is what called no constant velocity of ball was recorded.

Line of 'calculated' was obtained by using gradient of neck response during MSNT experiment. By substituting every value of forces used in simulation into 'x' value in formula of

$$y = 0.0029x + 1.2841$$

New value of 'y' was obtained and that indicate how much real neck will bending if given same amount of force in simulation.

Graph show how close model can follow real neck reaction with no large value on angles differences. This model can be define as a successful design and can be produce with exact material and method of connection.

4.5 DUMMY TESTING RESULT

After few modifications was made onto dummy due to failure of dummy to withstand impact force applied, finally dummy was be able to be used for data recording. Noted that rubber used in this experiment is 10 times softer than rubber used in simulation (0.01 Gpa compared to 0.1 Gpa). But result was compared with previous study, not with MSNT data due to properties of rubber used during experiment. This time each part of cervical vertebrae was connected using cable tie after screw have made small part of connector cracked. Cable tie was proved to withstand small velocity of ball (below 4m/s).

Figure 4.10: Cable tie replaced pin joint

Figure below show how dummy was set up and same movement limitation of neck still can be performed by this dummy. Cable tie was in fix position so each vertebra not move exceeded the centre of each part or otherwise result will be not valid. Using same methodology to find real neck response (relaxed muscle), neck dummy was tested. Angle of bending was captured using high speed camera and analysed using XCAP software. Two different size of 0.01 Gpa young's modulus rubber were used in this experiment.

20mm (W) x 19mm (L) x 11mm (H)……(A)

35mm (W) x 19mm (L) x 11mm (H)……(B)

For each specimen, three trials were conducted and bending angle was averaged, same method was used in simulation of real neck response from previous study. As stated, no constant velocity was recorded due to lack of equipment such as launcher.

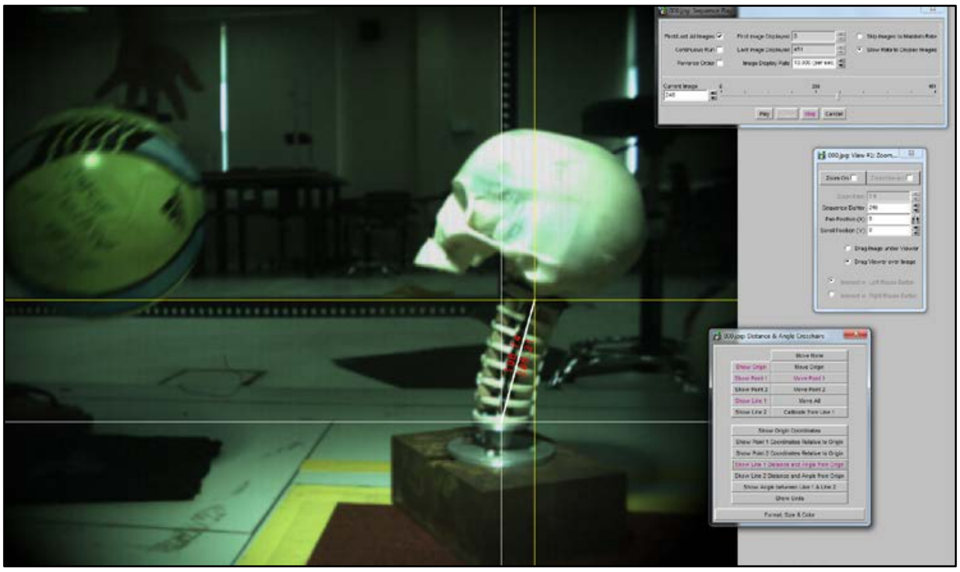

Figure 4.11: Angle analysis of neck dummy

Table 4.1: Experiment result

Specimen	Ball velocity (m/s)	Force calculated (N)	Bending angle (°)
A	3.32118	331.1897	22.62
B	3.434682	348.7842	18.26

4.6 DISCUSSIONS

Analysis of real neck response during both different condition, static heading where subject do not resist the ball and also when subject resist the ball was analysed. Response of resisting the ball using neck muscle strength lead to much more smaller of bending even with given higher speed of ball compared to subject who does not allowed to resist the ball. Neck muscle activity played a big role in contributing to head responses such as acceleration, velocity after impact and also amount of force absorbed during heading.

Values of bending angles from neck model is varies depending on dimension of rubber used. From same properties of rubber (elasticity), dimension take place as a manipulated variable that can be adjusted so resulting bending will varies. According to experiment conducted, 0.01 Gpa Young's Modulus of rubber capable to mimic neck response from relaxing muscle. For smaller dimension rubber lead to 22° of bending and when using larger dimension it was contributed to only 18° with higher speed of ball. To obtained value as same as in simulation from previous study, adjusting to larger dimension of rubber will lead to same neck response (11° by 4m/s of ball speed).

Rubber dimension have a limited space allowance due to space available at the neck model. So if the model does not reach any desired range, type of rubber need to be changed to higher elasticity that will give smaller elongation with same value of force applied.

Smaller bending obtained from simulation of neck model is assisted by a larger value Young's Modulus of rubber (0.1Gpa) and it is 10 times harder than rubber that was used in the current study.

Besides simulation, trial and error method can be used to obtain desired neck response. More samples of rubbers need to be prepared from different material properties. Trial and error will help in conducting experiment to find suitable type of rubber that can be used.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Main conclusion for this study is method to develop dummy for head impact testing was successful developed. This dummy will be able to perform almost similar reactions to real human neck responses during ball heading. Bending angle is a parameter that indicates whether dummy have perform right action or not.

Second conclusion is data from real human neck response in both active and inactive muscle was successfully recorded and analysed. Without this data we will never know how neck will response to certain amount of force impacted at the head in a certain condition. Next conclusion is even product has not been developed yet but replica has already fabricated. This replica having similar dimension to the real dummy and share mutual movements range that is flexion and extension. Early planning is to treat replica as a dummy but according to weak joining method (epoxy) so it cannot be done. But with simulation prove, with correct set up it will work properly.

The most important is this study can be used for further studies to develop neck dummy that less sophisticated and only can perform extension and flexion. This study has already collected data from real human neck response and prepared a drawing for model design. Model design was proved using simulation that it will work properly as planned. So only fabrication needed for further studies and can validate the dummy using collected data.

5.2 RECOMMENDATIONS

There were some recommendations for further studies in building neck dummy for head impact experimental setup. First of all is material selection. This dummy is simulated by using ABS as a part of cervical vertebrae. Heading speed in real game can be up to 24 m/s. So with this high speed, new material will be needed to replace wood. Aluminium is the best material due to its properties is so hard and can bear a bunch of load.

Samples of rubber need to be prepared from various kind of its type. This is for selection to be used as a muscle represent. Harder the rubber, smaller the bending. But for relaxed muscle dummy, softer rubber will be needed due to its larger bending with small amount of force applied.

Simulations result not always similar with real experiment. But by adjusting the manipulated variable that is rubber type, right amount of bending can be obtained. If simulation is not helping so trial and error method can be used.

If the hardest rubber was used to get bending but resulting larger angle than needed, model design allow us to modified the size up to 20 mm x 30 mm x 10 mm of rubber. The dimension of rubber can be modified until desired angle was achieved.

About the replica, if it not detached due to epoxy connection, it will be able to stand the force applied and can be used to record data of dummy bending. But when it have detached even for a small force applied, no impact test can be conducted.

Mass of head is insignificant to the neck model because it act on vertical axis, exactly on the head and the value of force from skull weight is too small compared to amount of force applied during impact.

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