"Development of a prototype for an Omni-Directional Dummy Neck"

Caroline Carlsson

Abstract

Car accidents can result in non-physiological motion in the neck and lead to injuries even at low collision speeds. These injuries are usually soft tissue injuries and are denoted whiplash injuries. Whiplash victims suffer from symptoms, which include pain in neck/head, upper thoracic spine and limited range of motion. Even if whiplash is not life threatening it can lead to long term consequences such as disability, sick leave and lost work productivity. This in turn means a great loss to the individual as well as the society.

The aim with this thesis was to develop a mechanical prototype for a dummy neck with the same 3-dimensional range of motion in each vertebra joint as the human neck has. A model of this type could be used in impacts from all directions.

In the human neck there are seven vertebrae surrounded by ligaments and muscles that give stability to the neck and ability to move. The articular processes (on the vertebra body) in the human cervical spine play an important role in the motion pattern of the neck. They guide the motion during flexion-extension. The obliquely situated processes cause a coupled motion for lateral bending and rotation.

The prototype dummy neck developed in this work was a modification of BioRID II, a dummy that is able to perform flexion-extension motion in the neck. Just like in the human, the new dummy neck has seven vertebrae. Two (one for the upper part and one for the lower part of the neck) two-pin-joint solutions gave the dummy neck the same range of motion and motion pattern as the human neck has. The upper pin-joint allows flexion-extension and pure lateral bending and is situated between the occiput and C1. The joints in the lower pin-joint system represent the articular processes and are situated in the same oblique angle. Rotation and lateral bending is always coupled (except between C0-C1 and C1-C2 where pure lateral bending and rotation respectively can occur like in the human neck). The range of motion in the prototype model is similar to that observed in humans.

The results of this work therefore represent a significant contribution towards efforts to make realistic mechanical models of human neck movements in car crash situations.

Acknowledgements

This master thesis was performed at Chalmers University of Technology, Department of Machine and Vehicle Design, Crash Safety Division.

There are many people to thank for helping me with this work. I would especially like to thank:

Dr. Mats Y Svensson, Associate Professor at Department of Machine and Vehicle Design. For supervising me during my thesis. For giving me ideas and guidance in the same time.

Dr. Magnus Karlsteen, Associate Professor at Department of microelectronics and nanoscience, Gothenburg University. My examinator, who ensured that physics was present in this thesis and for answering many practical questions around the work.

Dr. Johan Davidsson at Department of Machine and Vehicle Design who answered questions of all kind during the work. Especially for all information about BioRID II he gave me.

Anders Udén, at BoMek workshop who helped me to manufacture the prototype vertebrae. Who with patience interpreted my drawings and explained the basics about production.

To all at Crash Safety Division who were good company during the working days, for laughs and all good cakes and cookies at the coffee brakes I got to taste.

Table of Contents

1 Introduction

In car-to-car accidents the car occupants body is exposed to forces of a greater magnitude then the muscles can counteract. That can result in non-physiological motion and lead to injuries even at low speeds. One of these injuries is the whiplash injury. Whiplash Associated Disorders (WAD) is the generic term for neck injuries with symptoms like pain in neck/head and upper thoracic spine, limited range of motion and a variety of poorly defined symptoms (Eck J. C., 2001). Each year about 150 persons get severe neck injuries and a number get slight neck injuries in Sweden, most of them are from car accidents (Folksam FoU, 1985). In USA the number of whiplash injured are approximately 4 per 1.000 citizens per year. Even if whiplash injuries are not life threatening it can lead to long term consequences such as disability, sick leave and lost work productivity for the patient. Between 4% and 42% of patients with accident related neck injuries report symptoms several years later (Eck J. C., 2001). The uncertainty in the figures has to do with variation in reported cases (it can be related to admittance for compensation from insurance companies) and lack of a specific diagnosis for whiplash. The consequences following from whiplash means a great loss to the individual as well as the society (Harrison D. E., 2000)

In the process of learning more about how the human body responds during impact in car accidents, crash tests are being done with volunteers, dummies and Post Mortem Human Subjects (PMHS). Data from volunteer tests and PMHS tests are used for validation of crash test dummies. The aim is to make the dummy respond in a human like way. The validated dummy is a repeatable and reproducible instrument that can be used in the development of safer cars.

The majority of whiplash studies have been carried out as rear-end or frontal car collisions and most dummies are therefore only capable of extension-flexion motion (bending the head forward and backward). However a large proportion of whiplash injuries occurs in accidents where the vehicles strike each other in an angle. 60% to 70% of the frontal accidents are offset (Friedman D., 1993). Frontal offset accidents means that the vehicles strike each other front to front but with a displacement to the side. Knowing this, it is important to develop dummy necks that can be used in lateral and oblique testing. Existing Omni-directional dummy necks can move in three dimensions but do not have the restricted motion pattern as the human neck has.

The aim with this thesis was to develop an Omni-Directional dummy neck prototype with a mechanical solution to make the dummy neck imitate the human neck motion. The three-dimensional human-like motion of this new neck could then be used in lateral, oblique, roll-over, far side, frontal and rear-end impacts. The dummy neck developed in this work was given the name Omni Directional Dummy neck (ODD-neck).

Considering the lowering of quality of life for those affected and the large societal cost, more research is needed to find out what it is that causes WAD and how to avoid it.

1.1 Anatomy of the cervical spine

In the process of developing a dummy neck, it is necessary to identify the essential parts of the neck and therefore, knowledge about the human neck anatomy is needed. The basic mechanical elements of the neck are the vertebrae, the intervertebral discs, the muscles and the ligaments. In this chapter the fundamentals of the human cervical spine will be presented.

The human spine has 33 vertebrae and it is divided into five sections. From up to down the sections are the cervical spine (C1-C7), thoracic spine (T1-T12), lumbar spine (L1-L5), sacrum (five fused vertebrae) and coccyx (four fused vertebrae).

The seven cervical vertebrae (where C1 is the upper most) give support to the head, ability to move the head and protection of the spinal cord. The cervical vertebral column can be divided into two parts, the upper one and the lower one. The upper part of the cervical spine consists of the two upper most vertebrae, C1 and C2. These two vertebrae differ in their appearance compared to the five other vertebrae (C3-C7) in the lower cervical vertebral column. The different features of C1 and C2 allow them to have a different range of motion, compared to the rest of the vertebrae.

C1, also called “the atlas”, has two superior articular facets (Figure 1), which are cup shaped and allow the occiput to glide on them to perform extension, flexion and lateral bending. The vertebra foramen (the hole in the vertebra body) is much larger compared to those in the rest of the cervical vertebral column.

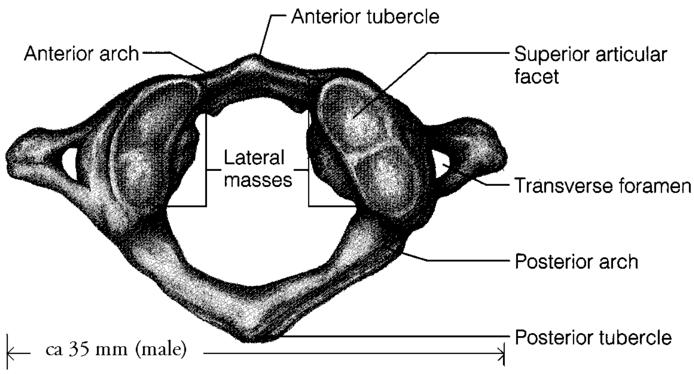


Figure 1. C1 from a superior view with the anterior side upwards. (Adapted from Marieb, 1998)

C2 (seen in Figure 2) is called “the axis” and has a knoblike dens, the odontoid process, projecting superiorly from its body. This dens fits into the vertebral foramen of the atlas. This atlanto-odontoid joint allows horizontal rotation in the upper part of the cervical spine, C1 rotates on top of C2 with the dens as the centre of rotation.

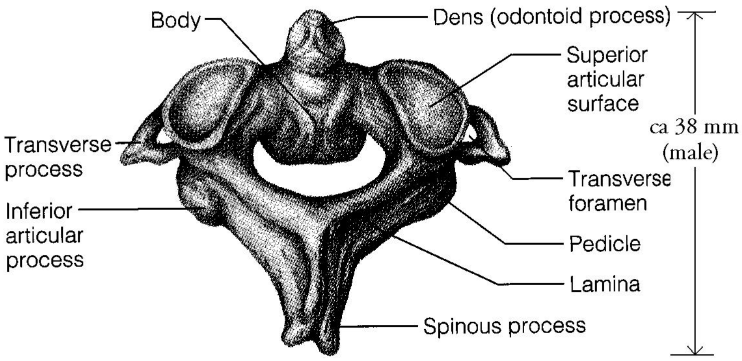


Figure 2. C2 from an oblique superior view with the anterior side upwards. (Adapted from Marieb, 1998)

The lower cervical spine consists of C3-C7 and they are all, except C7, very similarly built. They are represented by C5 in Figures 3 and 4. The vertebra body is the centre of the vertebra. The spinal cord run through the vertebra foramen. The spinous processes are located on the posterior side of the vertebra. Ligaments and muscles are attached on these places among others. The spinous processes are an outpost and function as a lever. When the neck perform hyperextension (bending the head backward to the extreme) the posterior spinous processes will come in contact with each other. The transverse process works much in the same way as the spinous process but on the lateral side.

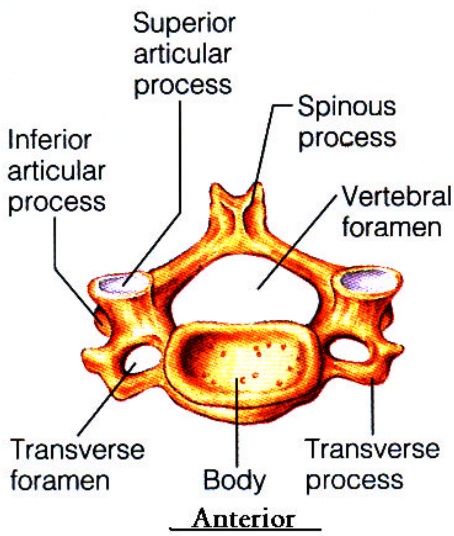


Figure 3. A typical cervical vertebra, superior view with the anterior side downward. (Adapted from Marieb, 1998)

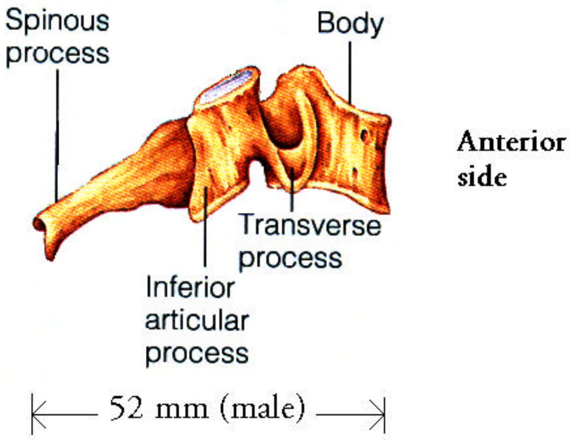


Figure 4. A typical cervical vertebra, lateral view. (Adapted from Marieb, 1998)

The articular processes (easily seen from a lateral view in Figure 4) are obliquely oriented and the flat surfaces function as facets. The rakes of these facets vary in the cervical spine but the mean value is about 42° in the sagittal plane. The facets are bearing a lot of the weight of the spine and because of their oblique position and flat surface they also influence strongly on the motion of the spine, this will be described later.

In-between all adjacent vertebrae bodies except between C1 and C2, there is an intervertebral disc that works as a damper. The intervertebral disc has a soft and elastic nucleus that compresses during pressure. Layer of collagen fibres, the annulus fibrosus, surrounds the soft nucleus. The strong fibres prevent the nucleus from too much bulging during compression and gives stability to the disc. In the same time as the discs support the spine they render bending motion possible. As the spine is bending, the discs bulge toward the curved side.

The ligaments give stability to the spine and connect the vertebrae to each other. Ligaments are not stretchable except ligamenta flava, which run between the spinous processes. These ligaments prevent an abrupt stop in motion when the head is bent forward. There are both long ligaments that run along the whole spine and shorter ones that goes between two neighbouring vertebrae. Two ligaments are distinguished, the long longitudinal anterior ligament and the long longitudinal posterior ligament. These two ligaments run along the whole spine on the anterior and posterior side. The anterior ligament is thinner and run closer to the spine while the posterior ligament is stronger and run between and outside the processes. Apart form these long ligaments; shorter ones connect two, three or four vertebrae to each other. The articular processes have ligaments that capsule the joints.

Just like the ligaments the muscles give the neck stability but also ability to move. Seen the neck in a cross-section the largest area is muscles. The muscles exist in several layers and just as with the ligaments they come in different lengths. They can be divided into three groups. One of the groups runs between close vertebrae. These short muscles (the deep muscles) control the movement of individual vertebra and attach the vertebrae to one another. The second group of muscles is longer and run from the head to the vertebrae. These muscles belong to the superficial muscle group of the neck. The last group is the intermediate muscle group; it contains of those muscles that go from the head to the clavicle or the upper part of the thoracic spine.

On the posterior and lateral side there is a larger number of muscles. The explanation for this is that the centre of gravity in the head is a bit in front of the geometrical centre. More muscles are needed on the posterior side of the neck to keep the head upright. Muscles are attached to the vertebra body and the processes of the vertebrae.

1.2 Biomechanics of the neck

Biomechanics of the neck describes the motions that the neck can perform, how they are done and the range of these motions. The motions in the human neck can be defined as four movements (see Figure 5) and the combinations of these ones.

When extension or flexion occurs, each vertebra in the cervical spine glide on the vertebra below, guided by the flat and oblique oriented surface of the articular processes (seen in Figure 6). Flexion and extension stretches the fibre if the disc in between the vertebrae as the vertebrae tilts a bit as they move. The flat surface and oblique orientation of the articular processes is a hinder for pure rotation or lateral bending in the same time as it guides the motion. When the vertebra bodies moves, the disc in between are stretched on the posterior side (flexion) or the anterior side (extension).

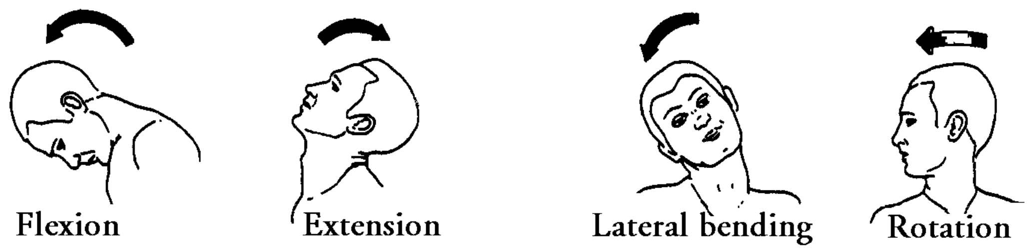


Figure 5. Terms for neck motions (Adapted from Hulkey and Nusholtz, 1986)

The neck moves with a coupled motion (both rotational and lateral bending in the same time) as two neighbouring vertebrae rotates around the axis perpenicular to the articular processes. This coupled motion is a main characteristic for the biomechanics of the neck. Finding a mechanical solution for this motion was an essential part in this work. For example, during lateral bending to the left, the left articular facet glide downward and the right one glide upward. It is still possible to turn the head to one side and hold the **head** horizontally. Pure motion of this type can be done since a compensated motion takes place in the upper cervical spine, with C1 and C2 that has a different shape as mentioned before.

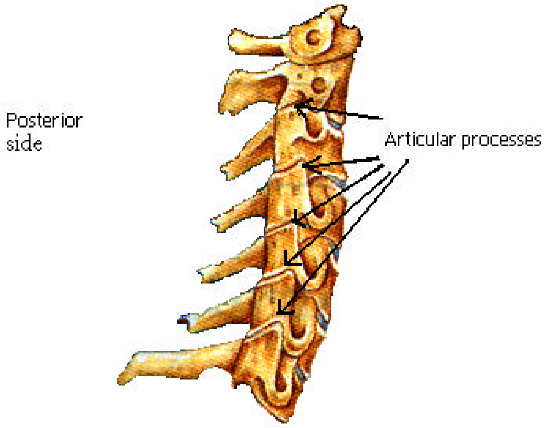


Figure 6. Lateral view of C1-C7 and T1, the oblique position of the articular processes is visible. (Adapted from Marieb, 1998)

1.3 Range of motion

The range of motion in the cervical spine is depends on several factors and differs from person to person. Age and individual elasticity influence on the flexibility in the spine and determines the maximal range of motion for the neck. In Table 1 the range of motion (according to White and Panjabi, 1978) can be seen. The values are to be considered as a representative range of motion. The objects of that study were both in vitro and in vivo and the angles were detected with radiographic technique. The values of the upper cervical spine differ from the lower cervical spine that has somewhat more similar values. The coupling occiput-C1 has no rotation while the coupling C1-C2 has a high degree of rotation (47° to each side) but no lateral flexion. The reason for these two couplings to differ has been described earlier and has to do with the individual shape of these vertebrae.

In Table 2, Kapandji´s values for the range for motion is presented. These values were found using oblique radiographs in the extreme positions (for flexion and extension). They differ from Panjabi and White's values in the range for extension-flexion between C2-C7, rotational motion between occiput-C2 and C2-C7. The differences can be due to the selected samples and measurement method.

Table 1. Range of motion for flexion-extension, lateral bending and rotation.

Coupling	Flexion-Extension (total)	Lateral bending (one side)	Rotation (one side)
Occiput.-C1	13°	8°	0°
C1-C2	10°	0°	47°
C2-C3	8°	10°	9°
C3-C4	13°	11°	11°
C4-C5	12°	11°	12°
C5-C6	17°	8°	10°
C6-C7	16°	7°	9°
C7-T1	9°	4°	8°

(White and Panjabi, 1978)

Table 2. Range of motion in the cervical spine according to Kapandji.

Coupling	Flexion-Extension (total)	Lateral bending (one side)	Rotation (one side)
Occiput-C2	20-30°	8°	24°
C2-C7	100-110°	45°	80-90°

1.4 Bio-mechanical motion during an impact

When the body is subjected to an impact, like the one in a car crash, it is exposed to forces of greater magnitude than it can obstruct. Muscles react instinctively with a counteraction but the head and neck will move in a non-physiological motion, the muscles are not strong enough to control the motion. It is not yet clear how the neck muscle reflexes influence on the cervical spine during an impact but they respond in time to affect the motion (Siegmund and Brault, 2000).

In rear-end car collisions, the car seat will start to accelerate when the vehicle is hit. When the seat is moving in the accelerated motion it forces the body to move as well. Since the head in a normally seated car passenger does not have contact with the head restraint in the initial phase of the accident the neck will be submitted to the non-physiological motion. The motion of the neck during rear-end crashes can be divided into three phases, retraction, extension and flexion (flexion is showed in Figure 5). Retraction and extension are seen in Figure 7.

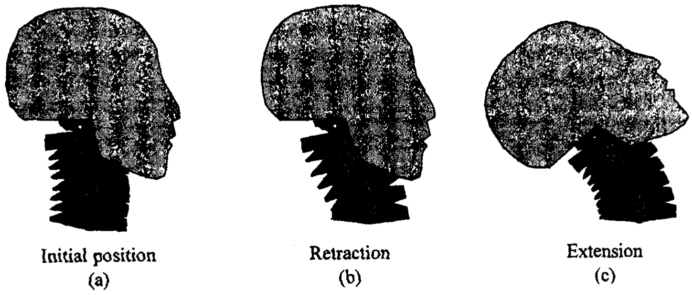


Figure 7. Motion of the spine during a rear-end collision. (Adapted from Linder, 1999)

Due to the inertia of the head and the fact that the head does not have initial contact with the head restraint, the head and neck will not move simultaneously. For a short time the lower cervical spine will move forward while the head is still in its original position. This causes the non-physiologic motion of the neck, called retraction (some times referred to as the S-shape) as seen in Figure 7 b. During retraction, the lower part of the spine will undertake extension motion while the upper part will undertake flexion motion. Some theories are based on that whiplash injuries take place during the retraction. It causes pressure changes in the spinal canal which can lead to soft tissue damages (Eck J.C., 2001 and Rosenfeld M., 2001).

After that, the head will move backward relative the back (as the body is forced to accelerate forward by the seat). The whole cervical spine will be in an extension motion as seen in Figure 7 c. At this stage the whole back, neck and head will be accelerating forward. Another theory of the cause of whiplash is failure of the facet capsules (especially if the head was rotated in the time of impact) during extreme extension in this phase of the crash (Eck J.C., 2001).

The next change in motion occurs when the acceleration of the car becomes zero. While the car is retarding, the body will continue to move until the seat belt stop the body from further forward motion. The neck and head are stopped in the forward motion by the body. This leads to the whiplash-like motion for the head that has given the injury its name.

Car occupants that are struck on the side (or in a frontal accident) experience similar motion, with the only difference that the motion is to the lateral side (forward-backward) instead of backward-forward. As in the case of a rear-end impact.

2 Existing multi-directional dummy necks

Evaluation of a crash test dummy is done by comparison between test results from the dummy and human subjects from an impact. The human subjects are either volunteers or PMHS. Tests done with volunteers are usually done with speeds around 6-9 km/h, to eliminate the risk of causing injuries to the volunteers. No speed limit has to be taken in concern while using PMHS but the effect from the neck muscles is lost. Among the more used existing dummies there are three dummies developed for lateral impacts and two others developed for frontal impacts but can be used in lateral impacts as well.

In early 1980, Some head-neck models were made in the effort to resemble the human as much as possible. Examples of such models are the Zero-Order Head–Neck Model (Kabo and Goldsmith, 1983) and the Advanced Head-Neck Model (Winters and Goldsmith, 1983). These models had a head of a cadaver (water-filled), manufactured vertebrae, muscles substitutes (all muscles of the neck, except some of the smaller hyoid muscles, were modeled) and ligament elements. The models made a comparison between head motion and muscle behaviour possible. The simplified and robust models described below replaced these very advanced models.

BIOSID, SID and EUROSID-1: Are dummies produced for lateral impacts. BIOSID has a Hybrid III neck (see below in Figure 9) and SID has a neck developed by National Highway Traffic Safety Administration (NHTSA). EUROSID-1 (seen in Figure 8) has a neck design capable of translation, rotation, extension and simple lateral flexion.

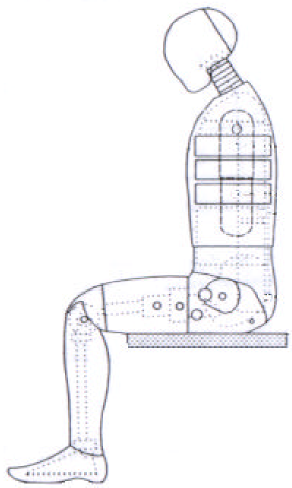


Figure 8. EUROSID-1 in a lateral view (adapted from Kanianthra J. N., 1991).

Hybrid III: This dummy neck (see Figure 9) 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. Hybrid III represents 50th percentile male (average size and weight of men). Hybrid III is mainly used in frontal and rear-end impacts. It is able to move slightly in the lateral direction but since it is not validated in this direction it is usually not used in these crash tests.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.

Figure 9. Hybrid III. The neck and the steel cable that run threw the centre of the neck (adapted from J. King Foster, 1977).

Thor: This is a dummy neck representative for 50th percentile male just as the hybrid III. Thor (Figure 10) was mainly developed for frontal impacts but has also been used in lateral and oblique tests. It has a multi-directional neck to enable accurate head motion.

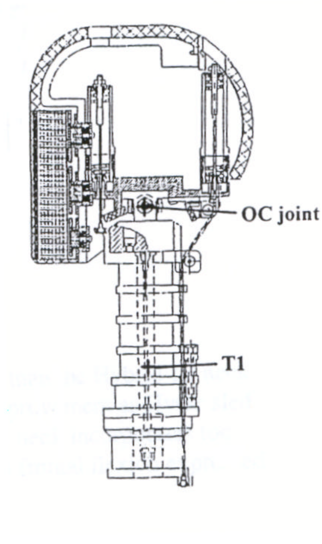


Figure 10. Thor dummy neck and head (adapted from Hoofman M., 1998).

The neck gets the S-shape in frontal impact tests. This dummy neck is an improvement compared to the Hybrid III neck.

3 The ODD neck

As mentioned earlier, the aim with this work was to develop a dummy neck with ability to move with a motion similar to the human neck. The construction is based on the BioRID II neck (Figure 11). BioRID II is able to perform flexion and extension only. The reason for choosing BioRID II as a base has to do with its design, which is similar to the human body.

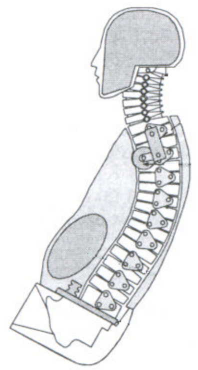


Figure 11. BioRID II in a lateral view (adapted from Davidsson J., 2000).

Like the BioRID the whole new dummy neck consists of seven vertebrae, one occiput piece (C0), which is a block to fasten the neck to the dummy head. C1 is different from the others to fit C0 and the two-pin-joint rectangular box connecting C0 to C1. The remaining six vertebrae are identical (C2-C7) and are positioned in an angle to each other that is representative for the human neck.

3.1 The whole ODD neck

When all parts of the neck are put in place, the whole neck (seen in Figure 12) is representing a dummy neck with a human range of motion. The ODD neck can be attached to a Hybrid III head and C7 could be adjusted to fit with the thoracic spine of BioRID II. C7 could also be fastened to a future thoracic spine that is developed according to the same principle as the ODD neck.

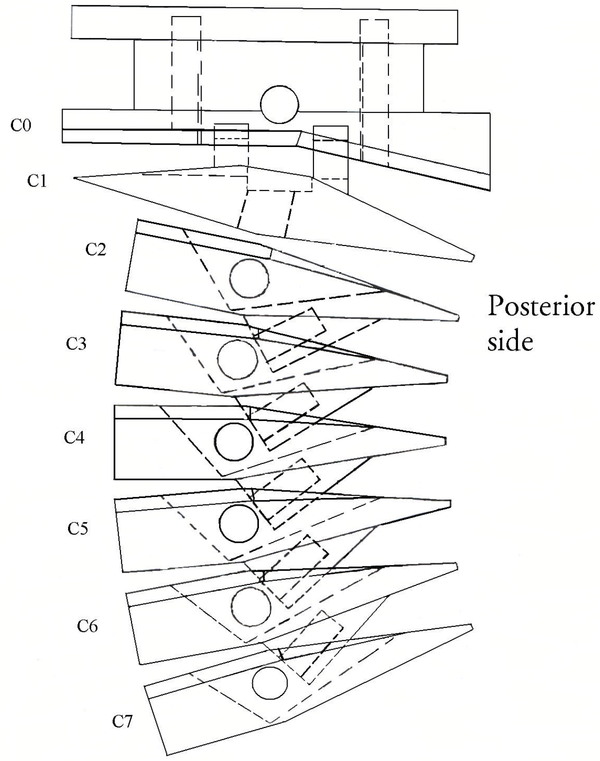


Figure 12. Lateral view of the whole dummy neck, joints are not plotted in the figure. The vertebrae are placed along the same curved line as was used in the BioRID II dummy.

3.2 The first vertebra body (C1) in the upper part of the dummy neck

C1 (Figure 13) has a sharp contour in the front to enable flexion-extension and to fit with C0. The joint between C0 and C1 is attached to C1 with a horizontal pin (Figure 13). The threaded hole underneath gives a perpendicular angle for the fastening joint to C2.

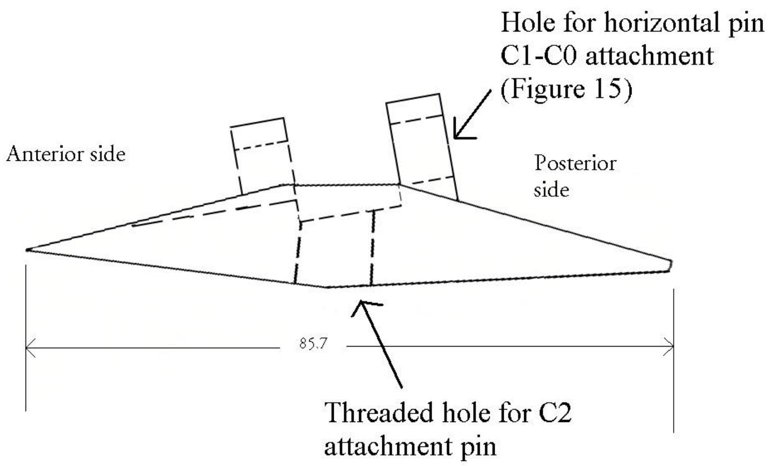


Figure 13. C1, in a lateral view. Measurement is in mm.

3.3 The vertebrae bodies in lower part of the dummy neck (C2-C7)

Figure 14 and 15 shows a vertebra representative for C2-C7 in the ODD neck. The difference to BioRID II is that the sides are sloped to enable the lateral/rotational motion and the centre of the vertebrae is also adjusted to fit with the new joint between the vertebrae.

Since the human cervical spine has a curvature of about 37° (from C0-C7), all vertebrae in the dummy neck are positioned in an angle of 5.3° to each other.

The jutting part underneath the vertebra is the attachment part for the joint. The joint is a substitute for the articular processes that has the average angle of 42° in humans. Compensation for 5.3° (between every vertebrae) leaves an angle of about 37° for the jutting part underneath the vertebra.

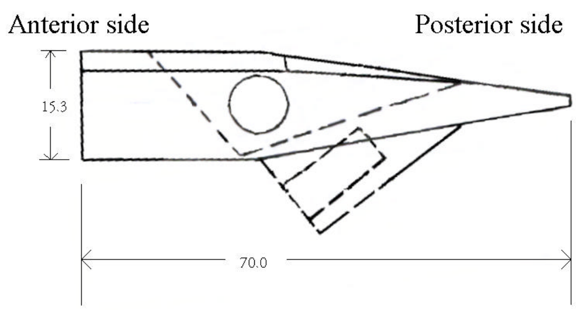


Figure 14. Vertebra C2-C7 seen from a lateral view. Measurements are in mm.

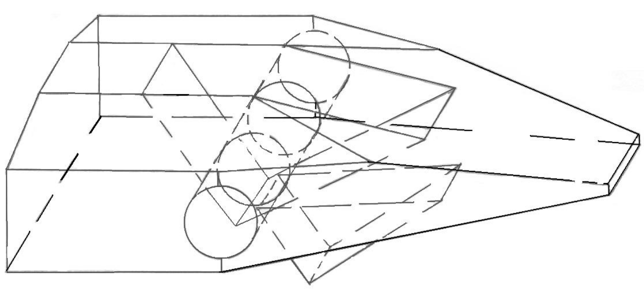


Figure 15. Vertebra C2-C7 in an oblique view 3-D view, not to scale.

3.4 Joint solution for the upper part of the dummy neck

Lateral bending can occur between C0 and C1. The mechanical joint solution is a rectangular box with two pin-joints (see Figure 16). The pin-joint box is fastened to the vertebrae by pins that runs threw the holes in the rectangular box and the vertebrae.

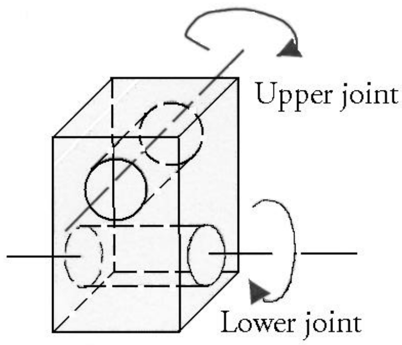


Figure 16. C0-C1 joint with the two pin joint holes.

The upper pin-joint allows flexion and extension while the lower pin joint allows lateral bending. There is no coupled motion (between rotation and lateral bending) since the box is positioned without an angle. In Figure 17 the pin joint box is placed in its position in the ODD neck.

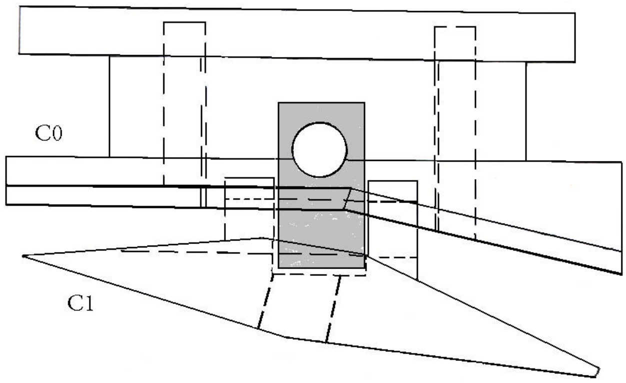


Figure 17. C0-C1 coupling in its position in the neck, lateral view.

3.5 Joint solution for the lower part of the dummy neck

C1-C2 belong to the upper part of the cervical spine but will be presented together with the lower part of the cervical spine since the joint solution is similar. The only difference to the other pairs is that lateral bending is not possible (according to White and Panjabi, 1978). This condition was accomplished in the neck model by fastening pin 2 (seen in Figure 18 below) into C1 in a vertical position –all rotation around pin 2 will be pure rotation.

Important in this work was finding a mechanical solution for the role that the articular processes have. In the lower cervical spine the vertebrae should be able to move in all directions but without pure lateral bending or rotation. This was solved with a two pin-joint system as seen in Figure 18.

The first pin joint (pin 1, in Figure 18) function as the rotational centre for the vertebra above.

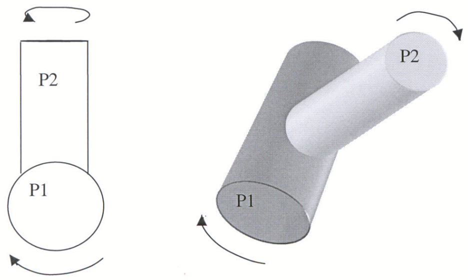


Figure 18. The pin joints pin 1 and pin 2 attached to each other. In a lateral and oblique view.

In the description of the anatomy of the cervical vertebra, the articular processes was mentioned as providing guidance for flexion and extension as well as being a hinder to lateral movement. In this neck model, the second pin joint (pin 2) can be considered as a substitute for those processes.

Pin 2 connects the upper vertebra to the lower vertebra and is fastened to pin 1 by a loop. The upper end of pin 2 is screw threaded. The connection between pin 2 and pin 1 make extension and flexion possible.

The angle of pin 2´s attachment to pin 1 is representative for the average value of the slope for the articular processes in the human cervical spine. Since pin 2 is leaning, rotation of the upper vertebra around the screw naturally creates the coupled motion of lateral bending and rotation relative the lower vertebra. In Figure 19 the pint joint is positioned between two vertebrae.

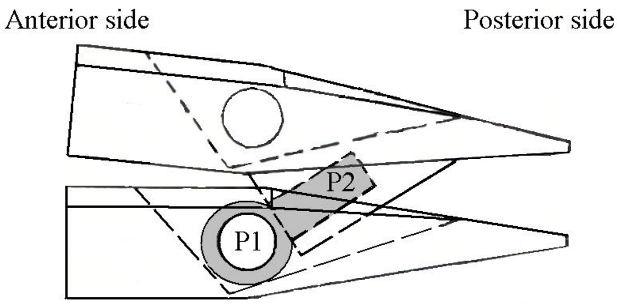


Figure 19. The pin joint positioned between two vertebrae.

3.6 Damping

An important property of a dummy neck is the stiffness properties of the various joints and of the complete neck assembly. The neck stiffness represents the influence of muscles and ligaments on the motion during an impact. The stiffness property also ensures that the neck has the correct initial position in a test. Without proper stiffness the ODD neck can not be used in dynamic tests.

Below are some of the mechanical solutions that theoretically seem to give the neck stability and damping without reducing or affecting the motion too much. These suggestions are an attempt to imitate the ligaments in the human cervical spine.

3.6.1 C0-C1

Damping in the coupling between C0 and C1 could be achieved by use of four cushions of energy absorbing rubber material. Placed in front, back and one on each side will supply stiffness, just like cushions do in existing dummies in extension-flexion motion. Figure 20 shows an example of placement of the rubber cushions.

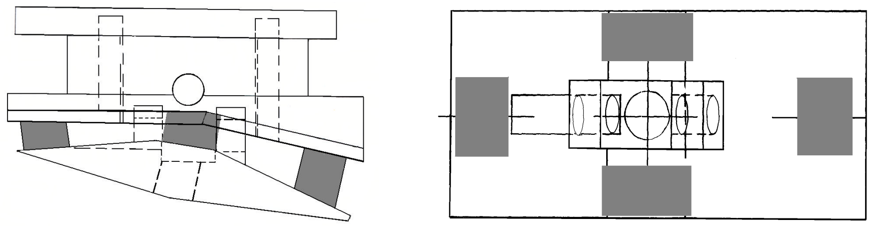


Figure 20. To the left rubber cushions marked as grey areas between C0 and C1 in a lateral view. To the right a superior view of C1 to show the position of the damping cushions.

3.6.2 C1-C7

The damping solution for the couplings between C1-C2 and down to C6-C7 is a bit more complicated. Only cushions are not a good solution, it will most likely affect the motion too much during rotation/lateral bending. Instead, the suggestion is to imitate the ligaments with cables. It should be one cable in each corner in the anterior side and one in the posterior side. The cables would then prevent too large motions and give the motion a characteristic, more similar to the human without affecting or hindering the motion too much. In order to get a more adequate characteristic, the cables could be complemented with damping cushions like the ones between C0-C1.

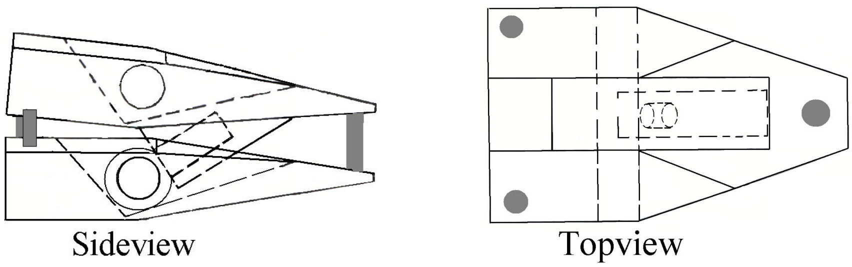


Figure 21. Wires can be identified as dark areas in the pictures. To the left the damping and vertebra is seen from a lateral view and to the right seen from a superior view.

3.7 Materials

A prototype of a vertebra was manufactured during this thesis project. It was made of acetal plastic. That is a material with low weight, it is very strong and in the same time it is easy to shape. All pins used for the joints were made of stainless steel. Damping cushions could preferably be suitable made of some kind of rubber that has a high-energy absorbing characteristic. The cables could be of steel or carbon fibre.

4 Results

For simplicity, the range of motion is the same for C3-C7 and is based on the mean value of Panjabi and White's values. C1 and C2 also have their motion range based on Panjabi and White's measured values. Those values are mean value for adults of both sexes.

As a difference to most other dummies, that have a size and weight corresponding to a specific group of men or women, this new dummy neck has not. It is only a prototype for finding a mechanical solution for the human movement in the cervical spine. The solution with a two pin joint system in the lower spine and a rectangular box with two joints in the upper cervical spine gave the ODD neck ability to move in a human like way. It has a representative range of motion and representative limitations to pure rotation and lateral bending.

Table 3. Range of motion for the ODD neck.

	Extension-Flexion (total)	**Lateral bending (one side)**	**Rotation (one side)**
C0-C1	**17°**	**8°**	**0°**
C1-C2	**18°**	**0°**	**180°**
C2-C3, C3-C4, C4-C5, C5-C6 and C6-C7	**18°**	**9° (In the front) 9° (in normal pos.) 7°(in posterior pos.)**	**7° (in the front) 8° (in normal pos.) 10° (in posterior pos.)**

The figures in Table 3 are calculated from the drawings for the prototype dummy neck and are therefor theoretical. Maximum range of motion in a direction was defined as having the two nearest sides parallel. To find out the slope of the vertebra for a desired amount of motion, equation (1) and (2) can be used.

Rotation: $q * \sin a = b_r$ (1)

Lateral bending: $q * \sin(90 - a) = b_l$ (2)

θ = Slope of the side of the vertebra

α = Angle of rotation centre (representing the articular processes)

b_r = Amount of desired rotation

b_l = Amount of desired lateral bending

5 Recommendations

Since this work was theoretical a natural first recommendation is to manufacture the neck and do dynamic tests on it. The neck can be made to represent a specific size and sex. If a ODD neck is manufactured it would be most useful make it as an 50^{th} percentile female, since women are over represented in whiplash injury statistics. In an improved ODD neck every individual vertebra could have a specific range of motion, representative for that specific coupling.

It would also be of importance to find a damping that can function in dynamic tests and gives the right characteristic for the motions.

The ODD neck could be equipped with a pressure measurement device to detect pressure changes in the spinal canal during motion in an impact. For example the system developed to measure pressure changes during impacts in BioRID II (Olofsson, L and Persson, I, 2001).

The damping effect that the intervertebral discs have in the vertical axes could be built-in in the ODD neck. A suggestion for that solution is to enlarge the hole in the vertebrae for pin 1 into an ellipsoid shape. Damping material placed in the new ellipsoid hole would serve as substitute for the intervertebral discs.

Evaluation of the neck is also possible by using a mathematical model. The multibody dynamics software MADYMO (TNO, 1998) could be used for example. A computer simulation does testing of different stiffness and damping easier.

6 Conclusions

The aim with this work was to evaluate the possibility to develop a mechanical neck with accurate motion pattern and limitations compared to the human cervical spine. ODD, the dummy neck developed in this work has a range of motion that is representative for the human cervical spine. It also has the same limitations in pure rotation and lateral bending. The solution for the coupled motion between lateral bending and rotation is two two-pin joints (one type for C0-C1 and one type for C1-C7). The construction with the two two-pin-joint connections between the vertebrae gave a motion pattern in the dummy neck, quite similar to that in the human cervical spine.

If a proper damping is added to the vertebrae and the model work in dynamic tests, ODD neck could be used in impacts from all directions. It could also be used in roll-over crash tests, tests where the vehicle is vaulting. This type of neck is also suitable in impacts on the opposite side of the dummy (far side impacts) since it has a large ability for lateral motion. The ODD neck can also be seen as a complementary to the robust and simple crash dummies mostly used.

The conclusion from this study is that a dummy neck can be given the same motion pattern and limits as the human neck has. Further work made on the dummy neck developed in this study, could result in a generation of dummy necks that have an impact behaviour closer to that found in volunteers studies, compared to the behaviour from the most commonly used dummies today.

References

Caillet Rene: Neck and arm pain. F.A Davis Company, USA, 1981

Davidsson J. (2000) Development of a mechanical model for rear impacts, *Department of Machine and Vehicle Design, Chalmers University of Technology,* S-412 96 Göteborg, Sweden.

DeSantis K. (1991) Development of an improved multi-directional neck prototype, *35th Stapp Car Crash Conference,* pp.435-446.

Eck J.C., Hodges S.D. and Humphreys S.C. (2001) Whiplash: a review of a commonly misunderstood injury, *The American journal of medicine*, *2001 Jun 1;110(8):651-6*.

Folksam FoU (1985) Nackskadesymposium, Åre sjukhus 1985

Friedman D. and Friedman K.(1993) Frontal offset and angled impact passive protection, SAE paper No. 930637.

Hoofman M., M. van Ratingen and J. Wismans (1998) Evaluation of the dynamic and kinematic performance of the Thor dummy: Neck performance, *Proc. International IRCOBI Conference on the Biomechanics of Impact*, pp. 497-512.

Harrison D. E., Harrison D. D., Cailliet R., Janik T. J. and Troyanovich S. J. (2000) Cervical coupling during lateral head translations creates an S-configuration, *Clinical biomechanics 15 (2000) 436-440.*

Hulkey, F.H and Nusholtz, S.G, (1986) Cervical spine biomechanics: A review of the literature. *Journal of orthopaedic research 4:232-243, Raven Press, New York*

Kabo J.M. and Goldsmith W.(1983) Response of a human head-neck model to transient saggital plane loading, *Journal of Biomechanics* 1983;16(5):313-25

Kanianthra J. N., Willke D. T., Gabler H. C. (1991) Comparative performance of SID, BIOSID, and EUROSID in lateral, pendulum, sled, and car impacts, *13th International Technical Conference on Experimental Safety Vehicles*, 573-587.

Kapandji, I.A.: The physiology of the joints. Churchill Livingstone, Edinburgh, 1974

King F. J., Kortge J. O. and Wolanin M. J. (1977) Hybrid III –A biomechanically Based Crash Test Dummy, *21st Stapp Car Crash Conference*, pp. 975-1014.

De Jager, M.; Sauren, A.; Thunnissen, J.; Wismans, J. (1994) A three-dimensional head-neck model: Validation for frontal and lateral impacts, *38th Stapp Car Crash Conference*, pp. 93-110.

Linder, A. (1999) Mathematical and Mechanical neck models for low-velocity rear-end impacts. Crash safety division at Chalmers University of Technology, Gothenburg

Marieb E. N.: Human anatomy and physiology, Addison Wesley Inc, California, 1998

McMinn, R.M.H. and Hutchings R.T. and Logan B.M: A colour atlas of head and neck anatomy. Netherlands, 1981

Mendis, K., Stalnaker, R. L., Pritz H. B. (1989) Multi-directional dummy neck prototype, *12th International Technical Conference on Experimental Safety Vehicles*, pp. 645-649.

Moffat E. A.(1979) The human neck-anatomy, injury mechanisms and biomechanics, Society of automotive engineers,. SP-438

Olofsson, L and Persson, I (2001) Ryggradskanal til mekanisk nacke. Master thesis report, Högskolan i Halmstad, Sweden

Rosenfeld M. (2001) Whiplash,*The American journal of medicine, Volume 110.* pp 667-668.

Siegmund G. and Brault, R, 2000. Role of cervical Muscles during whiplash. Published in *Frontiers in whiplash trauma*. Royal Smeets offset b.v., Netherlands, 2000

TNO (1998), MADYMO: Applications manual version 5.3, TNO, pp75-80

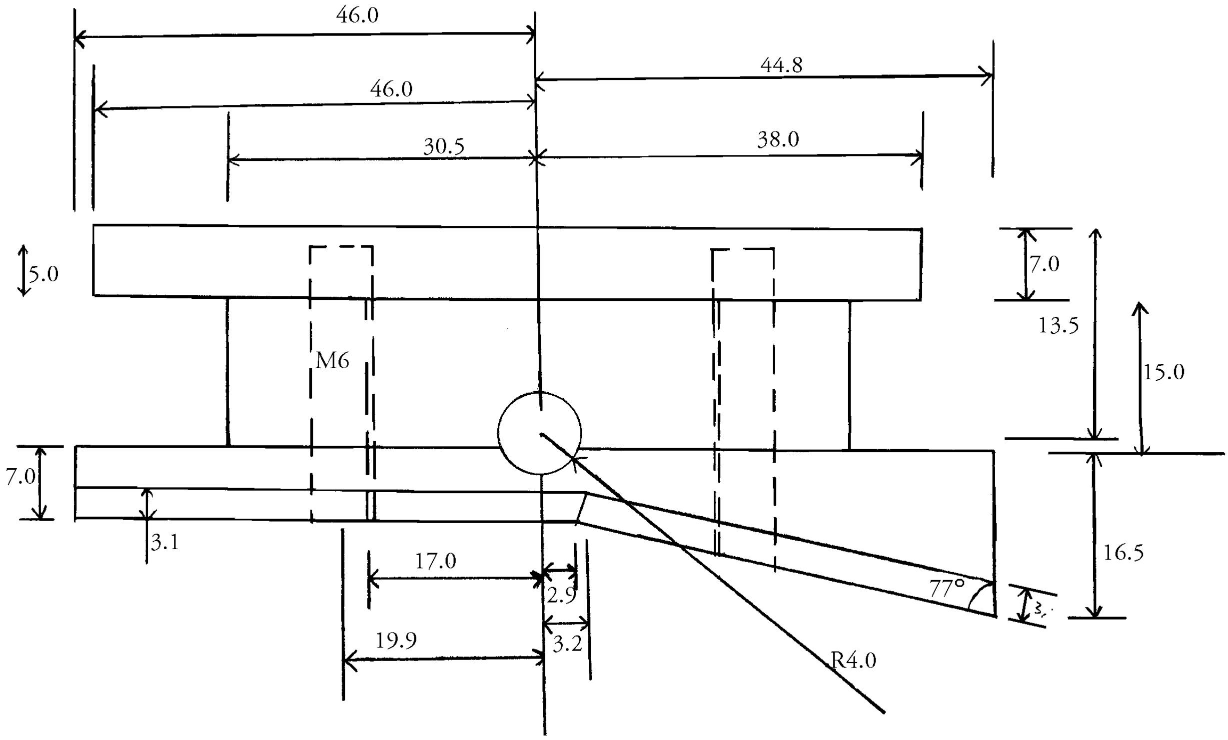
White III, A. A. and Panjabi, M., 1978. Clinical biomechanics of the spine. J.B.Lippincott, USA

Winters J.M. and Goldsmith W. (1983). Response of an advanced head-neck model to transient loading*, Journal of Biomechanical Engineering, 1983 Feb Vol. 105, 63-70*

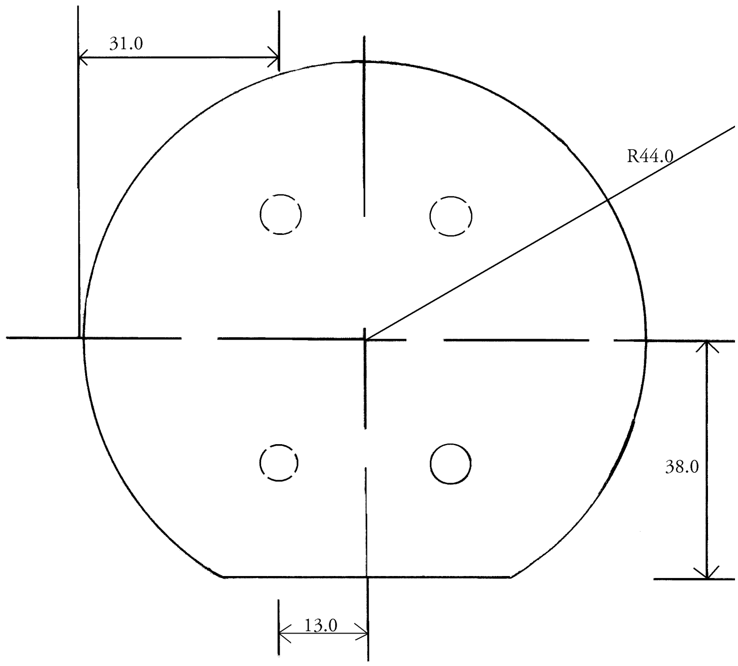
Yoganandan N. and Pintar F. A. Frontiers in a whiplash trauma. Royal Smeets offset b.v., Netherlands, 2000

Appendix

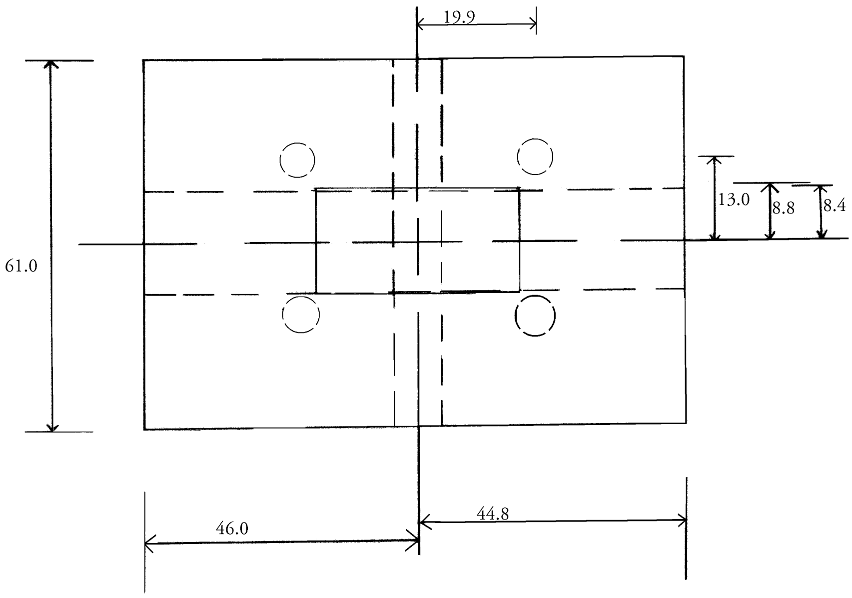
Lateral view of block to fasten the neck to the dummy head with and C0 in one figure.



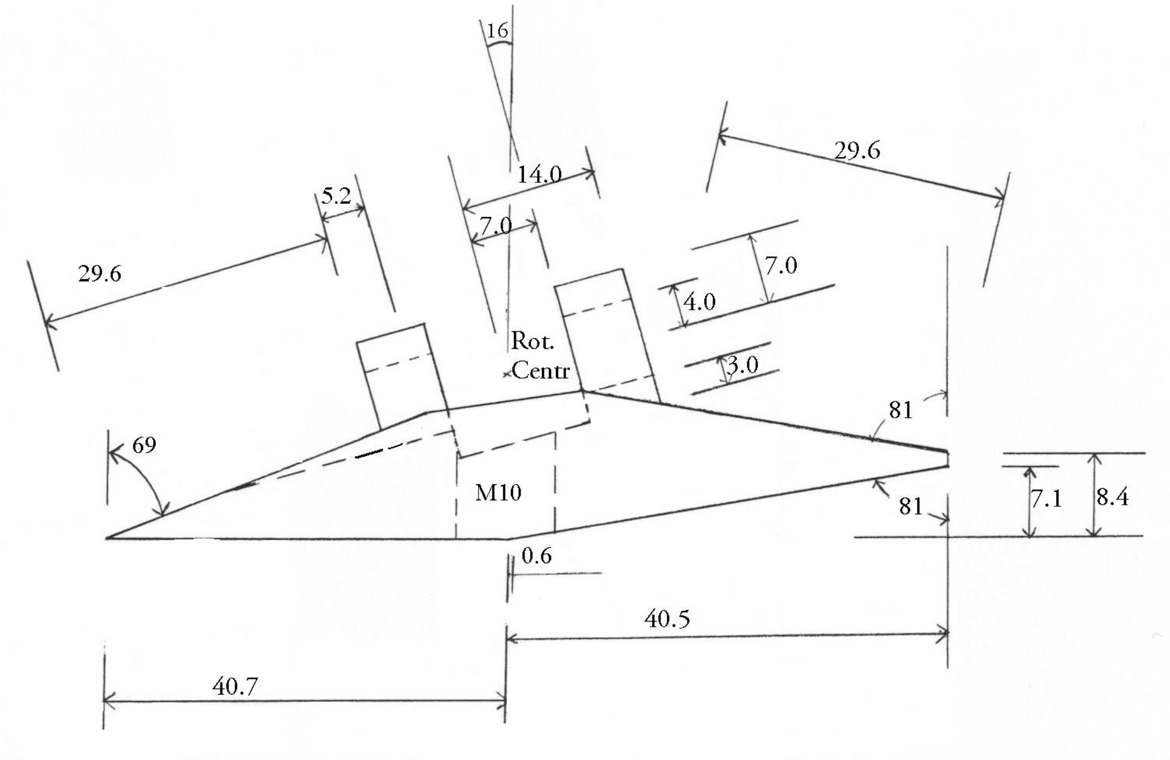
Superior view of the block to fasten the neck to the dummy head with



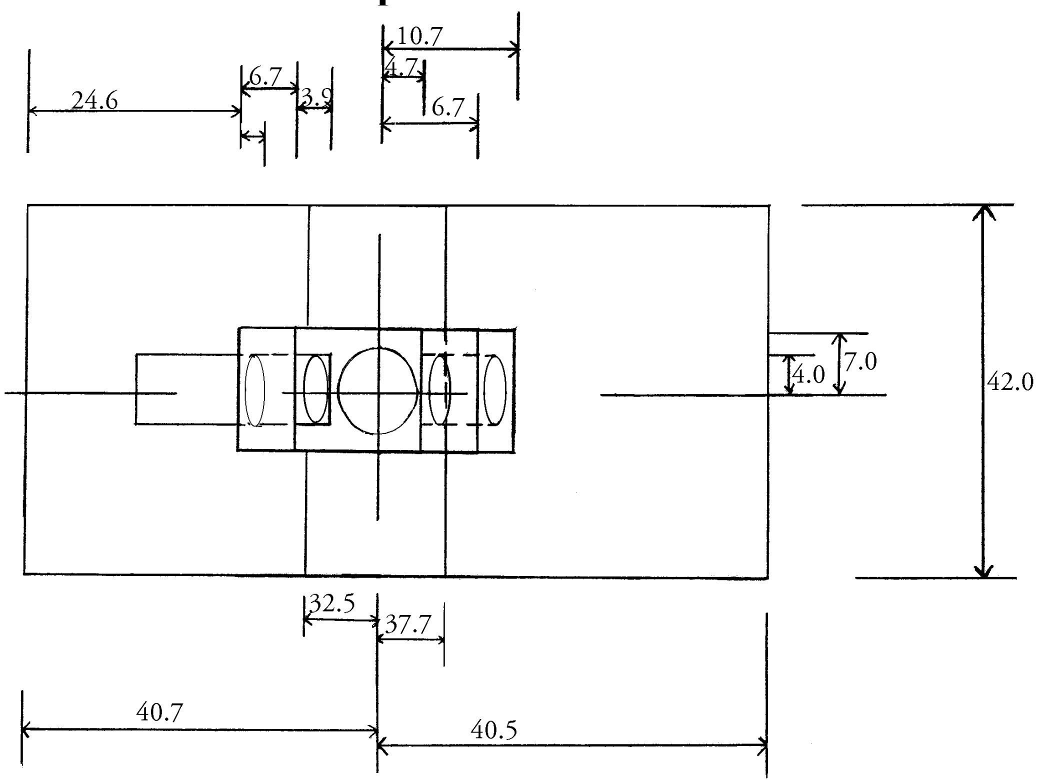
Superior view of C0



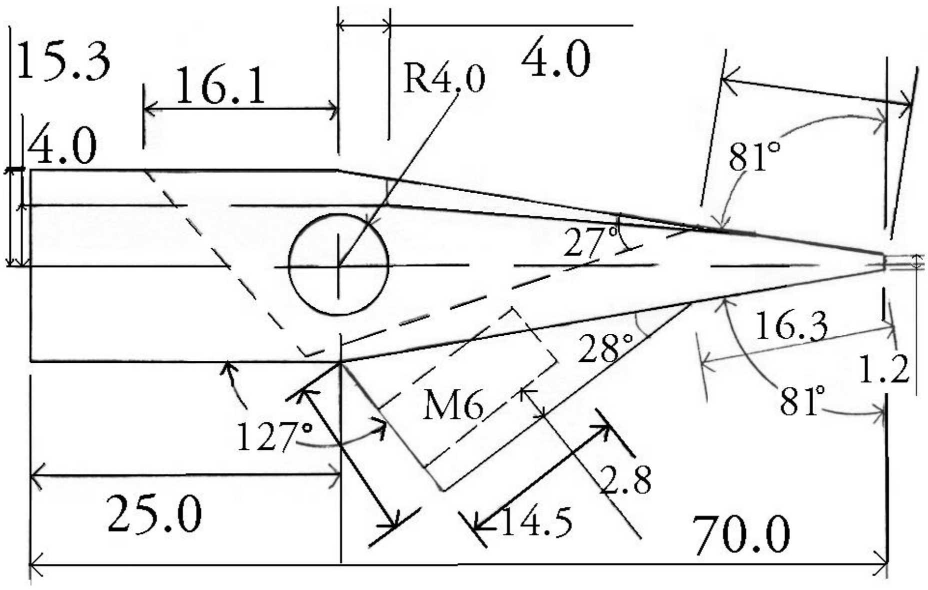
Lateral view of C1



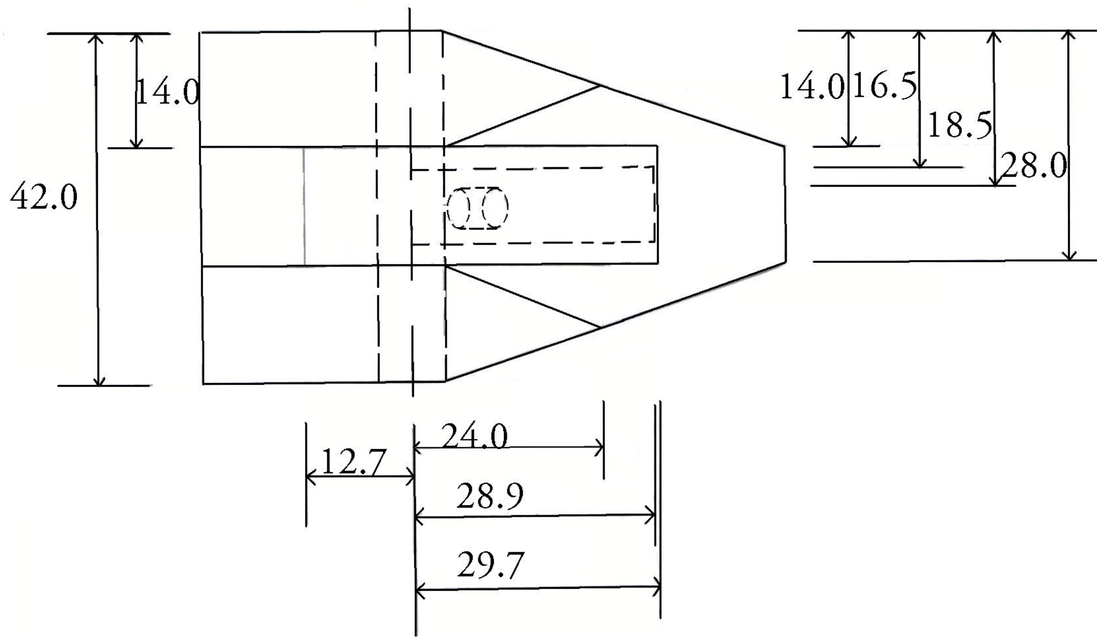
Superior view of C1



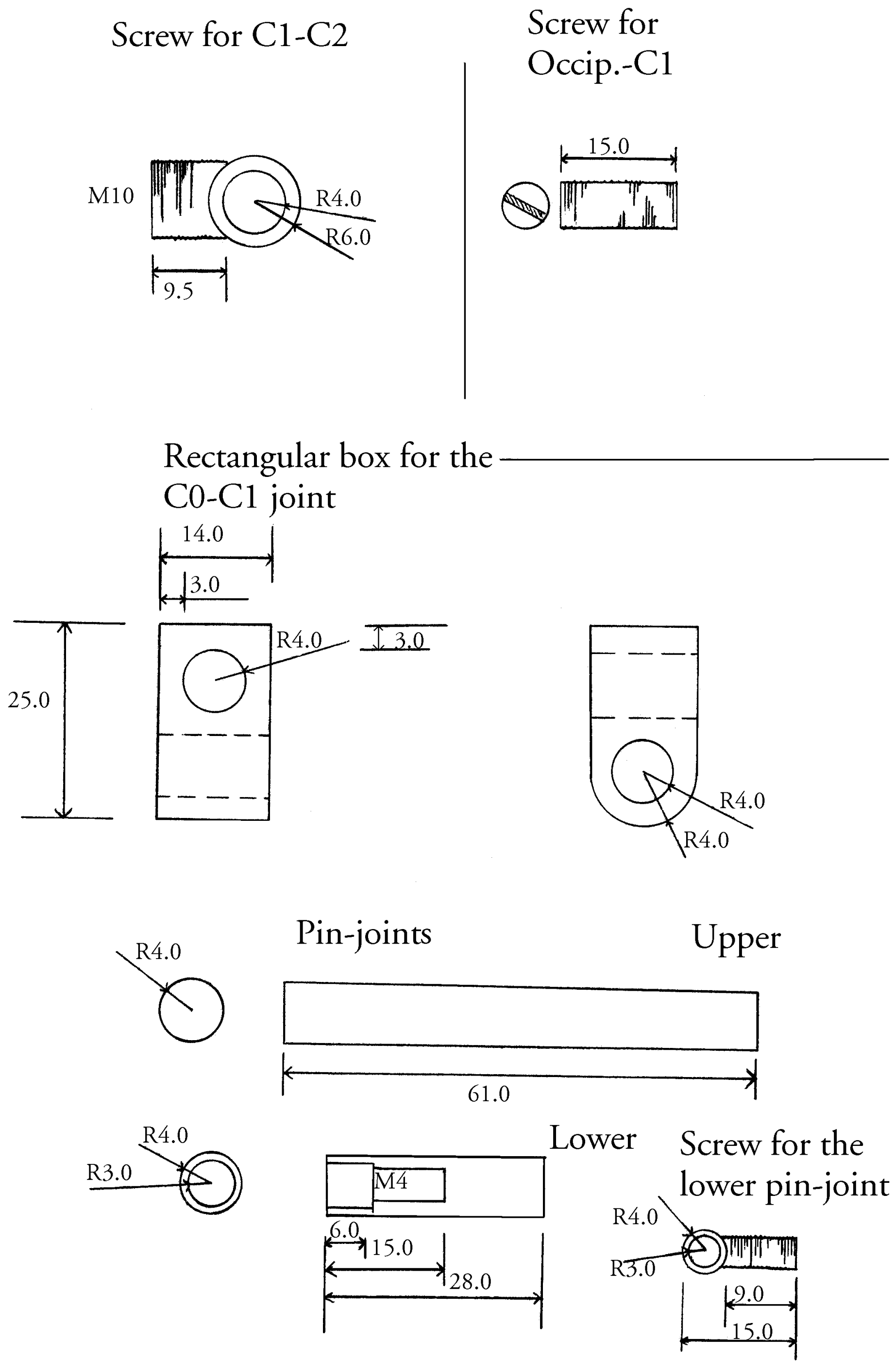
Lateral view of a C2-C7 vertebral



Superior view of a C2-C7 vertebral

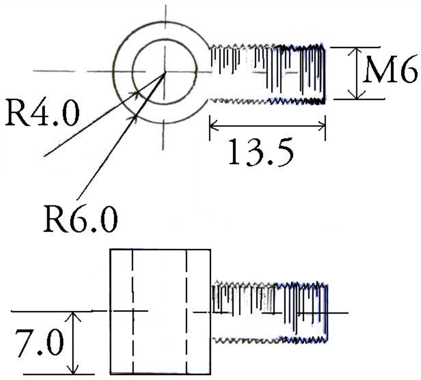


Pins and screws for the upper part of the cervical spine



Pins and screw for the lower cervical spine

Pin 2



Pin1