THE DAVINCI GROUP: A SECOND MODERN OPTHALMOTROPE

William R. Pruehsner, John D. Enderle
University of Connecticut Biomedical Engineering
260 Glenbrook Road, Unit 2247 Storrs, CT 06269-2247

ABSTRACT

A group of undergraduate students at the University of Connecticut Biomedical Engineering Program has formed a “club” in order to more fully understand and educate themselves in modeling anatomical processes. This group is called the DaVinci Robot or DaVinci Group. Experiments to mechanically model the six extraocular muscles of the eye have been performed, each meeting little success. While researching methods that would lead to better success, the concept of the Ophthalmotrope was discovered. The Ophthalmotrope is a mechanical visual aide used in teaching the function of the extraocular muscles, prevalent in the mid 1800’s. The Group decided to study this device and ultimately decided to build one.

The paper presented here discusses our third experiment, currently under investigation, that is, to build an Ophthalmotrope. Difficulties with this task are lack of any information with regard to how to construct this device. Presented are descriptions of the Group’s initial experiments and research conducted into the construction of the Ophthalmotrope. In the main body of the presented paper is a description of how the DaVinci Group Ophthalmotrope is constructed. Concluding is a discussion of the progress of the construction of the Ophthalmotrope along with a brief listing of research conducted in order to build the device.

Keywords: Ophthalmotrope, Biomedical Education, DaVinci Group, mechanical modeling, extraocular muscles

INTRODUCTION

A number of semesters ago, a group was formed at the University of Connecticut in the Biomedical Engineering Program that was to ultimately devise a robot inspired by Leonardo DaVinci’s drawings. This ongoing, semester to semester group consists of undergraduate students who are not seniors and is all voluntary in nature to join and participate. This group named their “club” The DaVinci Robot or The DaVinci Group. The main intention of this group is to educate themselves in the anatomical and physiological operation of the body in part or whole by building models of it that reflect anatomical reality.

The concept of building a full robot (although not completely rejected) is now narrowed to building a robot head. However, it is one of the main intentions of this group to build a robot head that mimics the human as anatomically close as possible. It is also the intention of this group to model the movements of the eyes, either mechanically, electrically, or a combination of the both, using the six major muscles, these being the Superior, Inferior, Lateral, and Medial Rectus muscles and the Superior and Inferior Obliques.

The group determined that they would begin experimenting with learning how to build such a device by starting to mechanically model the eye. The first experiment consisted of attaching four strings mimicking the rectus muscles to a three inch diameter plush ball, placing this ball in a plastic cup (acting as the orbit of the eye), cutting holes through this cup so that the “muscles” could pass through and then attaching the strings to a pulley system fashioned from a set of children’s play toys. The successful result of this experiment is to observe vertical or horizontal eye movement. The actual result of this experiment is that the strings pulled in such a manner that the ball simply turned around in the cup. The
fact that the ball is plush and thereby could not slide easily in the orbit and that the orbit is a flat bottomed cup is determined to be the causing factors of the failure of this experiment.

A second experiment using the same general setup as the first experiment utilized a different orbit, in this case a plastic rounded bottomed champagne glass and a three inch diameter styrofoam ball. Again the successful result is to observe either vertical or horizontal eye movements with the actual result being the same as that of the first experiment.

Recalled from a particular classroom text [1] is the concept of the Ophthalmotrope. The group determined that by studying this device, and although it is not a new idea, perhaps it would be able to more effectively model the eye and its six muscles for our educational group. It can be briefly said that an ophthalmotrope is a mechanical visual aide that models the extraocular muscles. Nearly all ophthalmotropes consist of a freely suspended ball and equipped with cords in such manner as to represent and mimic the extraocular muscles.

Our review of the Ophthalmotrope led to a third experiment, currently under investigation, that is, to build one. However, research into the device itself proved difficult and not at all revealing to the nature of how one might be constructed. Group members on a visit to the Psychology Department at the University of Connecticut found an instructor with a colleague in Eastern Europe that collected Ophthalmotropes, but nothing returned from this lead. Searching the database of the Rare Book Library at Yale University found nothing. Some web based literature [2] [3] exists on these devices but they usually show just a frontal view of the device along with a brief description. In time an article published in 1951 (cited below) proved useful in its description of how they had built an ophthalmotrope. Once receiving this description, the group undertook construction and study of the extraocular muscles.

**METHODS**

The Ophthalmotrope built is a copy of one reported in an article published in the American Journal of Ophthalmology in 1951 [4]. The design of the DaVinci group Ophthalmotrope is derived entirely from a four column worded description. The left eye is modeled so all references to lateral or medial directions should be taken in that context. The Ophthalmotrope consists of a number of parts. They are the base, a solid wooden ball, the inferior, medial and posterior supports, also known as the thrust plate, an indicator board, cords, pulleys and weights, and pointers. They are in that order described below. Please refer to Figures 1 and 2.

The base of the Ophthalmotrope is a twenty-one inch long by eleven inch wide board, this board cut from a piece of shelving to ensure that it would be flat. Four rubber feet, one at each corner is under the board to support the device. The lengthwise center axis of the base is also considered the center axis of the eye when it is in primary position. Central to the Ophthalmotrope is a six inch diameter wood ball this ball acting as the eye. Protruding from the ball at the pupillary center is a three-quarter inch diameter wood dowel which acts as the handle to manipulate the Ophthalmotrope. When this handle is aligned to the center axis of the base with no upward or downward angle, the eye is considered to be in primary position.

The eye is supported inferiorly by a yoke manufactured from a one inch square dowel forming a T shape. Attached to the top of this T are two thruster bearings. The eye rests on the thruster bearings of this yoke slightly in front of the equator of the eye. (The equator as referred to can be illustrated best if one assumes the pupillary center is the North Pole.) This yoke is the anatomical representation of the Ligament of Lockwood. The eye rests medially on another support. This support is devised of a standing one inch square dowel with two thruster bearings placed at such point that the globe will turn
on them. There is a pulley mounted at the top of this support by means of a bracket and standoff. This medial support is anatomically represented by the medial wall of the orbit. It is noted that the thruster bearings on the yoke and medial support are placed so as not to interfere with the Inferior or Medial Rectus muscles. The posterior support consists of a five and a half inch wide by nine and a half inch tall wooden board (one quarter inch thick) supported by two one inch square dowel pieces and a bracket. This construction is set at an angle of sixty five degrees from the central axis of the base. Protruding from the posterior support is a dowel with a plate at the end, this plate containing four thruster bearings. The resulting orientation of this, the thruster plate, is such that it expresses its force upon the globe at an angle twenty five degrees from the centerline of the base. These twenty five degrees represents the central axis of the rectus muscle cone in relation to anterior-posterior axis of the head. The thruster bearings also act anatomically as the support of the eye from the rear of the orbit. When the three supporting mechanisms are attached to the base in proper manner, the six inch wooden ball freely turns upon all eight thrust bearings without touching any part of the support apparatus. The center of the ball is also seven and one half inches from the base.

Mounted on the rear of the base is an indicator panel. The indicator panel is a box which is as wide as the base and two feet tall. Seven and one half inches from the bottom of the base is a cross board. This particular board is called the pulley board for reasons described below. Two inches above this is a
small square dowel upon which are attached seven one and a half inch wide slats whose tops are attached to the top of the box. Resultant are six slots approximately a quarter inch wide and approximately fourteen inches long.

The muscles themselves are modeled with cords that are inserted on the globe, follow back through the posterior support passing through a pulley mounted on the back of the support, then through a second pulley on the pulley board of the indicator panel and then around a second set of pulleys at the top of the indicator panel wherein at the end of the cord a weight is attached.

The insertion of the muscles upon the globe of the eye and the routes that they take (especially the obliques) follows anatomical fact. It is found that the four main muscles, the Superior, Inferior, Medial and Lateral Rectus muscles attach to the globe of the eye by a tendinous expansion into the sclera about six millimeters from the margin of the cornea. Determination of where the location of this point on our globe was done graphically using a picture from the web-based version of Gray’s Anatomy [5], on the described device this attachment is twenty-three degrees in front of the equator at ninety degree spacing.

The route of the Superior Oblique (without describing its tendinous construction, etc.) is that it arises near the optic nerve and passes through a pulley (the Trochlea) from whence it reflects downward, backward, and lateralward beneath the Superior Rectus and inserts into the sclera behind the equator of the eyeball between the Lateral and Rectus Superior. The pulley on the top of the Medial Support aforementioned acts as the Trochlea. The Inferior Oblique arises from the orbital surface of the maxilla, passes lateralward, backward, and upward passing between the Inferior Rectus and the floor of the orbit and then between the globe of the eye and the Lateral Rectus inserting into the globe of the eye between the Lateral and Rectus Superior near to and somewhat behind the Superior Oblique. A small post, also with a pulley matching the one on the Medial Support is attached to the base near the aforementioned inferior support yoke and acts as the location whereupon the Inferior Oblique arises. [6] Although a good description of how to route the Oblique Muscles, the location of their inserts and attachments plus the location of the Trochlea were also confirmed using an anatomical plastic model of the eye and its orbit.

Figure 3 (left): The Superior Rectus (labeled “SR”) is tied to the globe via a three inch strap. Note then how the “muscle” runs through a hole in the support plate and over a pulley mounted to the support plate and back towards the indicator board.

Figure 4 (right): The Superior Rectus passes through a pulley located on the “pulley board” of the indicator panel, then rides up and over two shafts at the top of the indicator board with its corresponding weight suspended at the end.
We shall concentrate on the Superior Rectus Muscle to describe the general construction and attachment of the typical muscle to the Ophthalmotrope. (Labeled “SR” in Fig. 3 and 4 (prev. page). Attached to the globe is a strap that is three inches long and one half inch wide. This strap is cut from aluminum flashing. At the end opposite to the attachment is a small key-chain ring. Tied to this ring is the cord. The cord used is known as Masons String. Masons String is polypropylene and does not stretch. (These straps and cords are also used on the other five muscles.) The cord follows back and passes through a hole drilled in the posterior support next to the dowel that supports the thruster plate, thus mimicking as close as possible the location where the Superior Rectus arises next to the Optic Nerve. Behind this hole on the posterior support is a pulley mounted on a bracket. The cord then continues back to a pulley on the pulley board. These two aforementioned pulleys are set at angles that prevent the cord from scraping against any structure of the support apparatus and to also align the particular cord with one of the slots in the Indicator Panel. This is accomplished graphically and is repeated for all six major muscles of the eye. The cord then follows up the center of its particular slot (and about one inch behind it) and turns over a pulley at the top of the Indicator Board (also aligned with the same slot), then runs back to a second pulley wherein the cord drops down whereupon a weight is attached to it. It is noted that in the entire system, there are twenty six pulleys. The weights are fashioned from one and a half inch diameter Cold Rolled Steel Bar. Attached to each cord is a pointer. The pointer is cut from the same aluminum flashing. The pointer protrudes through the slot of the indicator board for that particular muscle and is then bent at ninety degrees. A point is formed by cutting the flashing in an appropriate manner. (These pointers are not yet installed at the time of this writing.

RESULTS AND OPERATION

Operation of the Ophthalmotrope is easy. One grasps the dowel protruding from the globe, this dowel essentially being the direction of the eye gaze. As the person moves the eye gaze, the pointers on the indicator board move up and down in accordance with their degree of contraction or relaxation. As a cord shortens (or contracts), its corresponding pointer will go up the indicator board. As a cord lengthens (relaxes), its corresponding pointer will go down. The weights in the rear react oppositely to that of the pointers. When the positions of the pointers on the indicator panel of the Ophthalmotrope are compared during (or before and after) any given direction of gaze of the globe, the observer can see: 1) which muscles contract; 2) which muscles relax; and 3) how much the muscles contract and relax in relation to each other. Please see figures 4 and 5 below.

Figure 5 (left): The gaze angle on the globe has been displaced upward. Note that the Inferior and Superior Rectus muscles (IR and SR) have reacted as would be expected for a vertical eye movement. The other two rectus muscles have remained generally at their primary position.

Figure 6 (right): The gaze has now been turned to the right. The SR and IR remain generally in primary position, but the Lateral and Medial Rectus (LR and MR) muscles have reacted accordingly as would be expected for a horizontal eye movement. During any eye movement all muscles will relax or contract somewhat. The obliques are not shown for this demonstration.
CONCLUSIONS

The DaVinci Group, as well as the construction of the Ophthalmotrope and future improvements upon it is an ongoing semester to semester project. This past semester, student members of the group researched many aspects of the eye muscles and attempted many constructions as noted. Researching the building of the ophthalmotrope was pursued with much vigor and curiosity. Researching the Ophthalmotrope and its construction provided the student members of the DaVinci Group many new experiences. They interfaced with members of the faculty outside of the Biomedical Program. They learned new anatomical facts such as the routing of the six extraocular muscles including the location of their inserts and attachments – even what the Ligament of Lockwood is and its purpose. Determining exactly how to build an Ophthalmotrope, translating parts described in a paper published in the early fifties to modern day parts, and then taking all of the anatomical knowledge learned and applying it to a mechanical device provided a great challenge. The Ophthalmotrope served its purpose in providing an eye anatomy education to the participating students. Future implementations of this project may be to motorize, use spring scales instead of weights and the indicator board or perhaps miniaturize the device.

ACKNOWLEDGMENTS

Acknowledgements for aiding in the research of how to construct and assistance in building the Ophthalmotrope go to the members of the DaVinci group. The DaVinci group, who call themselves “Team Leo” are: Kimberly A. Carr, Alaena DeStefano, Kristen Gingras, Sadia Jabbar, Becky Lussier, Danielle McGeary, Scott Micholski, Raj Shah, Nolan Skop, and Sajal Swarop. They maintain a webpage at http://www.bme.uconn.edu/bme/davinci/. Thanks also to Dave Kaputa and Heather Grady, both students at UCONN, for also assisting in the construction of the device.

REFERENCES


[6] Ibid.