Finite Element Modelling of Chiasmal Compression

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There are a number of theories for the way chiasmal compression, from the growth of an abnormality such as a pituitary tumour, causes bitemporal hemianopia. In order to determine which theory is the most accurate, a greater understanding of the mechanism by which compression causes the loss of vision is needed. It has been proposed that the selective partial blindness, referred to in bitemoral hemianopia, is caused by a combination of the location of the optic nerves within the chiasm and the nature of crossing nerve geometry. The use of finite element modelling techniques to model the pressure present at various locations within the optic chiasm, and the pressure differential experienced by a crossing nerve as opposed to a non-crossing nerve has produced results supporting this theory. This thesis work will extend research previously conducted in an attempt to produce more accurate results through improving the geometry and accuracy of the material properties used in the modelling.

I. Introduction

BITEMORPORAL Hemianopia is the loss of peripheral vision, and it is agreed that it is most often it is caused by the compression of the optic chiasm by an abnormality such as a pituitary tumour. However the mechanism by which this compression of the chiasm only affects the peripheral visual fields is the subject of much debate. McIlwaine et al. (2005) proposed that the selective loss of peripheral vision is due to the crossing nature of nasal nerve fibres, which carry peripheral visual information, as opposed to non-crossing temporal nerve fibres.

This thesis will extend the work done by Howard (2008), by refining the accuracy of the Finite Element Modelling (FEM) conducted, to investigate the theory proposed in an attempt to provide medical experts with a greater understanding of the cause of bitemporal hemianopia.

II. Background

A. Bitemporal Hemianopia

Bitemporal Hemianopia is a partial blindness in both eyes. A hemianopia is a defect in the visual field of half of one eye; the bitemporal term refers to the fact the blindness is equally present in the temporal vision fields of both eyes (O’Connell, 1973), i.e. patients with this vision defect lose their peripheral vision. Bitemporal hemianopia is caused by extrinsic compression of the optic chiasm, most commonly from the presence of a pituitary tumour (Kosmorsky et al., 2008), but also by abnormalities such as a suprasellar meningioma, craniopharyngioma, or aneurysm (McIlwaine et al., 2005). The growth of an abnormality impinges on the optic chiasm causing it to be displaced and causing pressure to be experienced by the optic nerves within. Greater effect is felt by the crossing nerves in the centre of the chiasm (known as the nasal nerves). These are the nerves which carry the information for peripheral vision and it is the reason why, in the early stages of bitemporal hemianopia, the extrinsic compression only affects the temporal vision fields. The mechanism by which this compression has greater effect on the nasal nerves is what is not agreed upon and the various theories will be explained later. Figure 1 shows how, initially, the loss of vision strongly respects the midline of the visual fields; this indicates the very selective “targeting” of the nasal nerves within the chiasm. Nasal visual field loss does occur in more advanced cases of bitemporal hemianopia. To better explain the symptoms experienced in bitemporal hemianopia, and their causes, understanding of the geometry and operation of the eye and its associated visual systems is required.

Figure 1. Visual Field Loss. The figure shows the visual loss in advanced onset bitemporal hemianopia (Howard, 2008)

1 Aeronautical Engineering: Project, Thesis and Work Experience, ZACM4050
B. Geometry and Operation of the Human Eye and Brain

The eyeball is made up of two spheres, the anterior sphere is smaller and contributes approximately one sixth of the size of the eyeball. The posterior sphere is larger and contributes the other five sixths of the eyeball’s volume (Gray et al., 1977). Approximately 1.2 million optic nerve fibres (or axons) are connected to the rear of the eyeball and group together into approximately 1000 bundles to form the optic nerve (Snell et al., 1998). The spherical shape of the eyeball means that light incident on its front transitions through the eyeball and falls upon nerve fibres on the opposite side and at the rear of the eyeball. The result of this is that light from the peripheral visual fields falls upon the nasal nerve fibres and light from the nasal visual fields falls upon the temporal (outer) nerve fibres. In this way light from the right side of the head falls upon nasal nerve fibres of the right eye, and vice versa for the left eye. This combined with the nature of the left side of the brain controlling the right side of the body and vice versa, means that the nasal nerves from both eyes must cross to reach the opposite side of the brain. The above explanation is best shown in Figure 2.

The point at which the nasal nerves cross is known as the optic chiasm. It is approximately 13 mm wide, 8 mm long front to back, 3-5 mm thick (O’Connell, 1973) and roughly X-shaped. The nasal nerves cross over here, whilst the temporal nerves transition directly to the rear. Behind the chiasm, the new nerve fibre groupings transition rearward and upward to the brain and are now known as the optic tracts. Figure 3 shows the location and shape of the optic chiasm.

The optic nerves emerge from the skull through the optic foramen (Gray et al., 1977) and cross over at the chiasm, above the pituitary gland. The length of the nerve from where it emerges from the skull to where it meets the chiasm (intracranial portion) varies from 6 mm to 21 mm (O’Connell, 1973). This means that the position of optic chiasm with respect to the pituitary gland can change significantly. The two situations where the chiasm does not sit directly above the pituitary gland are known as pre- and post-fixed, where chiasm is in front of and behind the pituitary gland, respectively. According to O’Connell (1973) the majority of subjects (91%) have a chiasm fixed predominantly over the diaphragma sellae, with 5% and 4% having pre- and post- fixed chiasms respectively. Figure 4 shows the location of the chiasm with respect to other structures near the base of the brain.

The optic nerve is made of, as previously mentioned, 1.2 million nerve fibres gathered into around 1000 bundles. These are then surrounded by three layers, an inner vascular sheath of pia mater, a middle delicate sheath of arachnoid, and a thick outer sheath of dura mater which peels away from the nerve and attaches to the dura mater lining the skull once the nerve leaves the optic foramen (Snell at al, 1998). Figure 5 shows the cross section of the optic nerve. It is important to note for this thesis that O’Connell (1973) mentions that temporal and nasal nerve fibres differ not only in the position at which they exist in the chiasm but also in their physical make up.

C. Theories for the Cause of Bitemporal Hemianopia

Hedges (1969) proposed his theory that the reason for the visual field loss experienced in bitemporal hemianopia was due to the differing tensile stress experienced by the various regions of the chiasm. Hedges’ (1969) experiment involved the use of fresh, normal, adult necropsy material, where the skull cap and brain of the subject were removed in such a way as to cause minimal disruption to the optic chiasm. The optic chiasm was then folded forward to allow the

Figure 2. Visual Pathway. The figure shows how light incident on the eye is transmitted to the brain, note the necessity of crossing at the Optic Chiasm (Snell et al., 1998)

Figure 3. Structures at the Base of the Brain. Figure shows the longitudinally asymmetric shape of the optic chiasm (Gray et al., 1977)

Figure 4. Structures surrounding, and position of the Optic Chiasm. (Snell et al., 1998)

Figure 5. Cross section of the Optic Nerve (Snell et al., 1998)
pituitary gland to be removed and a Foley catheter (effectively a small balloon) inserted in its place. The optic tracts were then pinned back to simulate their being fixed to the brain and the Foley catheter was inflated, simulating the growth of a tumour. Figure 6 shows the optic tracts re-pinned in place with a Foley catheter inserted centrally under the chiasm. Hedges’ (1969) theory extends from his observation of the order in which the structures in the chiasm were subjected to tensile stresses; firstly the upper crossing (nasal) nerve fibres in the centre of the chiasm, followed by the lower crossing fibres, the upper non-crossing (temporal) fibres, and finally his observation that the lower temporal nerve fibres were ‘spared’ from stress. This led Hedges (1969) to propose that it was the direct tensile stress experienced by the nerve fibres, due to their location in the chiasm, which created the loss of the temporal visual fields.

This theory has been supported by Kosmorsky et al. (2008) in which the optic chiasm of a number of subjects was tested, in vivo, without the cutting of the optic tracts. In this experiment the right temporal lobe was removed to expose the chiasm, and the brain placed back on styrofoam blocks to simulate its natural position. The pituitary gland was not removed and a smaller paediatric gauge Foley catheter inserted on top of the pituitary fossa and inflated to create the same type of deformation created in Hedges’ (1969) experiment. Kosmorsky et al. (2008) then quantified the results by measuring the pressure present in central and temporal regions of the chiasm through the use of needles connected to pressure transducers, this is shown in fig 7. Two of the subjects in Kosmorsky et al.’s (2008) experiment repeatedly showed a higher pressure in the central chiasm than the temporal region. No measureable pressure changes were recorded in the other three subjects; this was considered likely due to decomposition before testing.

In testing this theory, the experiments used assume that the chiasm is centrally located above the growing tumour and that the tumour grows in a rounded balloon type shape. The assumption that the chiasm is centrally located above the tumour causes the deforming body to load the chiasm in such a way that the maximum deformation occurs in the centre of the chiasm, this is explained as a bulging effect (Kosmorsky et al., 2008). Loading in this way obviously creates a much greater stress in the nerve fibres located centrally in the chiasm, supporting Kosmorsky et al.’s (2008) theory that the selective damage to nasal fibres is due to their position in the chiasm. However this assumption fails to address the situation of pre- and post-fixed chiasms, where the central point of loading occurs forward or rearward of the chiasm centre. In these cases it is likely that the pressure experienced by the nasal nerves will decrease and become more similar to that experienced by the temporal nerves, yet the visual loss is still restricted to the temporal fields. The use of the Foley catheter to apply a deforming force to the chiasm also enhances the bulging effect seen by Kosmorsky et al. (2008), yet this assumes that the impinging tumour would experience minimal deformation relative to the chiasm. The tumour may in fact be much less rigid and deform around the chiasm, reducing the bulging effect and creating a much more even distribution of stress.

The second theory for the mechanism by which only crossing nerve fibres are affected by chiasmal compression is that of vascular insufficiency, proposed by Bergland et al. (1969). Bergland studied the vascular supply of 480 human optic chiasms. He hypothesised that the temporal nerve fibres are supplied by a superior and inferior group of blood vessels, whereas the nasal nerve fibres are supplied only by the inferior group.
(Kosmorsky et al., 2008). His theory is that compression of the optic chiasm from below causes a restriction of the flow in the inferior group of vessels, resulting in insufficient blood supply to the nasal nerves and a bitemporal hemianopia. This theory fails to address the fact that if the supply from the inferior group of blood vessels is restricted there may also be an effect on the nasal visual fields due to lessened blood supply to the temporal nerve fibres. It also fails to address the fact that abnormal growths which compress the chiasm from above can sometimes still result in a bitemporal hemianopia, yet the inferior blood supply to the central chiasm remains unaffected. Figure 8 shows the theory proposed by Bergland (1969) that the visual field loss is due to restricted blood flow in the centre of the chiasm.

The most recent theory, and the one this thesis aims to investigate, is that proposed by McIlwaine et al. (2005). This theory proposes that the selective targeting of the nasal nerve fibres is due to their crossing nature. The theory is based on the differential surface area in contact between fibres in the central chiasm to that of the temporal fibres. When subjected to an external compressive force the pressure experienced by a nerve fibre is inversely proportional to the area which that fibre is in contact with a neighbouring fibre. This is explained by the definition of pressure, \( P = F/A \), where \( P \) is the pressure experienced by a body, \( F \) is the force on the body, and \( A \) is the area of the body over which that force is spread. Figure 9 shows the difference in surface area in contact between a parallel temporal fibre and a crossing nasal fibre. Using simplified geometries and assuming that the crossing fibres cross over perpendicularly; McIlwaine et al. (2005) provided preliminary results indicating a much higher pressure experienced by crossing nerve fibres. As can be seen in Figure 9, assuming that a nerve fibre in contact deforms slightly to provide a flat surface area over which contact is spread, then a parallel nerve fibre spreads a load over an area of \( p_d \) whereas a perpendicular nerve fibre spreads the load over an area of \( r^2 \pi d^2 \) therefore giving a ratio of pressure, of \( 1/p_\pi \), as shown by equation 1.

\[
\frac{P_{\text{nasal}}}{P_{\text{temporal}}} = \frac{A_{\text{temporal}}}{A_{\text{nasal}}} = \frac{p_d d^2}{r^2 \pi d^2} = \frac{1}{p_\pi}
\]

In this case, assuming \( p \) is much less than 1, then the pressure in the nasal nerve fibres can be seen as being much more than that in the temporal fibres. It is theorised that the increased pressure in the nasal nerves causes deformation, resulting in interruption of the nerve fibres conduction due to distortion of its architecture (McIlwaine et al., 2005).

This hypothesis does make a number of assumptions, and as McIlwaine et al. (2005) admit, it is not easily tested or verified in laboratory conditions. Assuming that fibres cross perpendicularly, and that equal ratios of circumference would flatten under loading in both temporal and nasal nerves, will increase the ratio of pressure experienced in nasal to temporal fibres. However it could safely be assumed that the length of fibre in contact between two temporal fibres is much greater than the diameter of that fibre, thereby significantly increasing the ratio of pressure in nasal to temporal fibres. The use of Finite Element Modelling, suggested by McIlwaine et al. (2005), has shown that pressure increases of around 25% are experienced through crossing geometry alone (Howard, 2008).

The theory proposed by McIlwaine et al. (2005) provides a reason for the selective damage to nasal nerve fibres, and is the theory this thesis aims to test. However, it is important to note that the previous work conducted by Hedges (1969), Kosmorsky et al. (2008), and Bergland et al. (1969) provide irrefutable evidence of other ways, based on certain conditions, that damage could occur in the nasal nerve fibres, and that these various theories are not mutually exclusive. The cause of bitemporal hemianopia is likely a combination more than one theory.

### D. Biomechanical Finite Element Models

McIlwaine et al. (2005) suggested the use of Finite Element Modelling (FEM) to model the effect of a tumour impinging on the optic chiasm. FEM works through the use of computers to obtain an approximate solution to a boundary value problem. The solution of a boundary value problem is where one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain (Hutton, 2004). It is used in the case where the geometry of an object means calculating an exact solution to a problem is impractical. The object being analysed (such as an optic chiasm) is divided into small elements for which it is possible to calculate the deflections present. Each element is then calculated, leading to a final solution for the entire geometry. In this way accurate solutions can be obtained for complex geometry problems.
The use of FEM in biomechanical analysis applications is not a new concept. FEM has been used to model the impact of a blunt object on the eye and surrounding structures by Cirovic et al. (2006). In this study a model was created based on data from a Magnetic Resonance Image (MRI). The geometries in the scan were simplified to shapes more easily recreated on a computer. Once the model is analysed the predicted magnitude of the stress in each element is known, as is the deflection of each element. Figure 10 shows the model used in the analysis in its normal and deflected states. The mesh overlaid on the surface shows how the model is broken up into smaller elements that allow the complex geometry to be analysed piece by piece, and how each individual element is deformed by the model of the finger. In FEM the properties of the various materials in the geometry are input to the program along with the initial positions, velocities and the position and movement constraints.

This thesis work is based around increasing the accuracy of previously built FEM models of the human optic chiasm, in an attempt to gain more accurate information on the stress condition in the optic chiasm due to chiasmal compression.

### III. Previous Research

In addition to the research by Hedges (1969), Kosmorsky et al. (2008), Bergland et al. (1969), and McIlwaine et al. (2005) research has been conducted by Howard (2008). As with this thesis, the work done by Howard (2008) was conducted as a final year undergraduate thesis at the Australian Defence Force Academy. This thesis work aims to extend the work done by Howard (2008) in an attempt to produce more accurate results of the stress produced in a deformed optic chiasm. A summary of the work done by Howard (2008) follows.

Initially the work performed consisted of a study of the relevant literature, in order to understand the nature of the problem and also to find the relevant material data necessary to construct accurate FEM models. This required the density, Young’s modulus, and Poisson’s ratio for the various tissues used in the model, namely: sclera, neural tissue, and bone. Howard (2008) then made a number of models using both CATIA (a CAD program with some FEM capability) and ANSYS (a FEM program with some CAD capability). The models contained simplified geometrical representations of the chiasm and nerves within. Initially Howard constructed a model with a single pair of crossing and non-crossing nerve fibres running through the centre of the chiasm. Unfortunately problems with the definition of the contact regions between various surfaces led to a further simplification of the model and the removal of specific fibres. Unfortunately the more accurate models developed in CATIA would not easily transition across to ANSYS, and as the purpose of the project was FEM the decision was made to use the more limited CAD tools in ANSYS. The final working model is shown in Figure . As can be seen symmetry in two planes was assumed, individual nerve fibres were replaced with a single homogenous block of nerve tissue surrounded by a sheath, and the tumour modelled by a balloon made of sclera material. In this way the model was testing the theory proposed by Hedges (1969) of higher stress being present in the centre of the chiasm due to its geometry. This model showed good similarity to the pressures found in Kosmorsky et al.’s (2008) experiment.

Secondly Howard (2008) created a model of two simple crossing nerve fibre bundles and two parallel nerve fibre bundles. This was to model the pressure differential between temporal and nasal nerves. The model used for this is shown below in Figure . The maximum pressure present in the crossing nerve fibres was found to be 25% higher than in the parallel nerve fibres.

Howard (2008) also conducted a number of parametric studies to determine the effect of varying the properties of the neural tissue, the mesh density, and the sheath thickness.

The simplifications and assumptions made in Howard’s (2008) research provide a number of areas for further investigation and increasing the accuracy of the model; these are listed and explained as below along with a number of recommendations for future investigation proposed by Howard (2008).
The geometry of the chiasm has been modelled as symmetric in two planes, that is, assuming that the chiasm is a regular X shape and is symmetric left to right as well as front to back. This assumption allowed reasonable preliminary results, yet as can be seen in Figure 3 the chiasm is clearly not symmetric front to back, so the stress distribution will not be regular. The geometry is also simplified as straight cylinders with chamfered edges at the join; however the chiasm can be seen to be much rounder in its centre than the diameter of the nerves and tracts.

The model of the tumour was that of a balloon with properties of sclera, and a relatively thick wall. It can be seen in Figure that the balloon modelling the tumour stays relatively undeformed, yet the properties of a tumour may be somewhat less rigid than previously assumed (Lueck, 2009) meaning a much greater deformation of its shape and therefore a much more even distribution of stress.

As with Kosmorsky et al. (2008) and Hedges (1969) experiments the loading was applied centrally under the chiasm and the chiasm and tumour were perpendicular in their axes. In reality, however, there is a significant angle between the tumour and chiasm as the optic tracts are secured much higher than the optic nerves. Also as mentioned earlier the central loading point can vary significantly with a pre- or post-fixed chiasm.

The models used for material properties by Howard (2008) assume linear-elastic stress-strain behaviour. The research of Miller et al. (1997) and Miller et al. (2000) show that adult swine brain matter (that used in by Howard (2008) for its similarity to human neural tissue) has a non-linear stress-strain relationship and exhibits visco-elastic behaviour (stress-strain rate dependence).

Finally the analysis of only a single nerve fibre in crossing may not necessarily model the stress difference accurately as stress created by adjacent crossing locations may combine to create a higher stress state. This is important to examine as nerve fibre bundles cross roughly 100 times within the chiasm (Howard, 2008).

IV. Project Aims

The aim of this project is to investigate the material properties and models of human neural tissue, the methods of converting MRI data to CAD usable format, and to modify existing FEM models in order to more accurately model the stresses present in the optic chiasm due to the growth of a tumour; to determine the cause by which chiasmal compression selectively targets crossing nerve fibres.

The purpose of this project is to extend the work done by Howard (2008) in testing the theory proposed by McIlwaine et al. (2005) that the primary reason for the selective damage in nasal nerve fibres, in a range of loading situations, is the crossing nature of the nasal nerve fibres. Analysis of the stress caused in the optic chiasm is intended to create a greater understanding of the factors causing bitemporal hemianopia, allowing medical experts to use this information to further analyse the situation in the hope of formulating a treatment for the condition.

V. Project Scope

This project is grouped roughly into three areas of further investigation and research. Each area is explained below along with the intended deliverables and what has already been done. The areas are: continued investigation into the material properties used, particularly the accuracy of linear elastic models, and the relevance of possibly using a visco-elastic model, investigation into the use of MRI data and how that may be converted to for use in ANSYS or CATIA, and finally the modification of existing and new FEM models to simulate more varied conditions.

E. Material Properties

As previously mentioned, the models created by Howard (2008) used linear elastic data for the material properties of all tissues used in the experiment. Howard (2008) also mentions the lack of data available on material properties of human neural tissue. In assuming a linear elastic model the material response is simplified and the accuracy of the results may be compromised. The properties of human neural tissue and/or human optical tissue have not been measured experimentally, so data is not available. It is generally considered that adult swine (pig) neural tissue is the most similar to that of human neural tissue, and experiments have been performed to measure the properties of swine neural tissue. Miller et al. (1997) performed uni-axial, unconfined compression tests, in vitro, in an attempt to determine a mathematical model for the properties of neural tissue by
fitting a linear visco-elastic model. Miller et al. (2000) performed further experiments to attempt to fit a hyper-visco-elastic model to adult swine brain matter by performing an in-vivo experiment. To better understand the relevance of these models and their data explanation of the terms visco-elastic and hyper-elasticity must be given.

Visco-elasticity is the dependence of mechanical properties of a material on the strain-rate at which it is loaded. The behaviour seen in human tissues is that they are stiffer when loaded rapidly than when they are loaded slowly (Hukins, 1990). Hyper-elasticity is a non-linear stress response to deformation.

Through their research Miller et al. (1997) found that attempting to fit a linear visco-elastic model to their experimental results could not be done, as the experimental curves were all concave upward with no linear portion from which a meaningful elastic (Young’s) modulus could be obtained. This led Miller et al. (2000) to attempt to fit a hyper-visco-elastic model to experiment results obtained from their in-vivo test of swine brain matter. This was done by creating a FEM of the swine brain they were testing and plotting the calculated results. The results of their research are shown in Figure where it can be seen that the hyper-visco-elastic model built in FEM behaves in remarkably similar fashion to the experimental results, though on average gave a result 30% lower. Similarly work done by Galle et al. (2007) aimed to investigate the method of axon injury in the spinal cord. In this experiment, testing of the stress response to deformation of guinea pig spinal matter showed a very non-linear relationship between stress and strain. The graph of results from Galle et al. (2007) is shown in Figure 14.

The relevance of the above research to this project is that in bitemporal hemianopia the strain-rate is very low, ie even a fast growing tumour will only deform the chiasm at strain rates much lower than that used by Miller et al. (2000) and linear stress-strain responses are not seen. It is very difficult to obtain exact data on the speed at which a tumour grows meaning exact strain rates are unavailable. However, based on an illustrative case report from Wilson (1968), in which a tumour appeared to have grown over a period of 9 months, in conjunction with very simplified geometries used to estimate strain, a strain rate of approximately $4\times10^{-8}\text{ s}^{-1}$ was calculated. This is far lower than the lowest strain rate of $0.64\times10^{-5}\text{ s}^{-1}$ used by Miller et al. (1997).

In selecting an appropriate material model for this project it must be ensured that the data selected comes from an experimental result obtained at the lowest possible strain rate, to ensure that strain-rate dependence does not affect the stress response.

The aim of this portion of the project is to further research the work done by Miller et al. (1997, 2000), Galle et al. (2007) and others to produce numerical results that can be used to create a more accurate model of neural tissue properties that can be used in the FEM work in this thesis.

Additionally, Galle et al. (2007) gives percentage deformation of the spinal cord at which neurological deficit occurs and then becomes irreversible. A secondary aim of this portion of the project will involve investigation into the relevance of this for optic nerve damage, and whether this numerical information can be applied to the optic nerve or if not, whether information of this nature exists for neural or optic nerve tissue.

F. Conversion of MRI data

The simplifications made by Howard (2008) in the building of his FEM models allow for reasonable initial results to be obtained. However in order to increase the accuracy of these results more accurate geometries must be used in the building of new models. The best way to obtain more accurate geometries is to use real measured data. MRI uses high powered magnets to align the nuclear magnetisation of atoms within the body, and when radio frequencies are also passed through the object, magnetic fields are produced which can be measured and recorded. Different tissues in body have different nuclear magnetic properties, and so produce varying magnetic fields for the scanner to register and record. In this way MRI is used to build up a picture of the internal structure of the body, allowing accurate 3D and 2D visualisations to be built without invasive surgery.

MRI produces digital data and is therefore already processed by computers, so optimally direct file format conversion would allow MRI to be read by a CAD package such as CATIA. Unfortunately the file formats are not yet compatible so pre-processing must occur to allow the MRI data to be used in CAD software. Three steps to create a 3D model from MRI data are listed as data acquisition, image segmentation, and construction of the 3D model from 2D curves (Kaazempur-Mofrad et al., 2004).
The format which MRI data is provided in is the DICOM format. DICOM is a medical imaging standard format which contains more than just the image data. Information on the referring doctor, type of scanner, settings used, patient information, date etc. is provided in the beginning of the file in a header. The actual image data is in 2D picture format that can be converted through easily accessible DICOM readers to JPEG or BITMAP formats, as shown by Figure 15, which is a 2D image of a horizontal ‘slice’ through the brain that displays the optic chiasm in the centre. A series of 2D images or ‘slices’ are taken at regular intervals through the object being imaged, from this a 3D representation can be built. The data obtained by MRI is saved such that each pixel in the image has an intensity value, ie how bright it appears on the image, which is dependent on the tissue at the location being imaged. The hardest part of converting MRI data to a format compatible with CAD software is selecting which portions of the image are required, for example, in this project the required portion of the image is that containing the optic chiasm, but to use the optic chiasm in the CAD software it must be distinguished from the rest of material in the image. To do this computer algorithms must be written to analyse the image and detect similar intensity values in adjacent locations both on a single image and on adjacent images. This can be used to then build a 3D solid by following the paths and contours of similar intensity values. This could also be done manually, but would be very time consuming and possibly not as accurate.

Liu et al. (2005) used a software package called Brain Extraction Tool (BET) to pre-segment MRI data, in their building of a FEM model of the human head. Todd et al. (1996) created a computer program to pre-process MRI data stored in a BITMAP format and create a NASTRAN input file which can be converted into other FEM solvers. In addition to this there are a number of programs available online which also claim to convert MRI data to a format usable in FEM or CAD programs. For example Simpleware available from www.simpleware.com offers “fast and easy conversion of 3D images… into high quality meshes which can be used for Finite Element Analysis (FEA)…”

This portion of the thesis will investigate the methods by which these programs process the MRI data, with the aim of either using an existing program or writing a new program to process MRI data of the optic chiasm for use in FEM models. A program to automatically process the MRI data and avoid laborious manual reconstruction of 3D solids is the desired outcome. However, given the relatively short timeframe for the project it may not be possible, depending on the availability of existing software, or the difficulty in writing new software. If it is not possible achieve this within the timeframe of the thesis, the aim is to manually convert MRI data so that a geometrically accurate model can be used for FEM.

G. Finite Element Modelling of Chiasmal Compression

This section is where the research and investigation described earlier will be input into ANSYS to obtain more accurate results of the stresses present in chiasmal compression. The two major tasks in this section will be to modify the existing models created by Howard (2008) and to create new models with more accurate geometries. In order to use the FEM programs adequate understanding of their operation is needed. This has required attendance at weekend courses and hours spent working through tutorial books to ensure that the programs can be operated to a level sufficient for the requirements of this thesis.

The modification of existing models is closely related to the areas of further research identified in analysis of the work done by Howard (2008). The first modification to be made will be to investigate the effect of moving the location of the tumour relative to the chiasm. This will simulate the difference in loading experienced by a pre- or post-fixed chiasm. As can be seen...
in Figure 16 there can be significant variability in the relative locations of the tumour and chiasm, which could lead to a significant difference in the pressure distribution. When moving the relative positions of the tumour and chiasm attention must be paid to the relative lengthening and shortening of the optic nerves and tracts. As mentioned by O’Connell (1973) the length of the intracranial portion of the optic nerve can vary from 6 mm to 21 mm, with a pre- and post-fixed chiasm respectively. This is particularly important for the optic nerve as it emerges from the optic foramen, part of the skull, which will act as solid, non-deforming attachment point that could induce stress when the distance to the chiasm is short.

The second modification to be made to existing models will be to alter the angle at which the chiasm and tumour meet to be more realistic. Figure 16 shows that the chiasm is at an angle to the horizontal. The point at which the optic tracts are secured into the brain is much higher than the point where the optic nerves leave the optic foramen, creating an upward angle from front to back in the chiasm. This may affect the stress distribution in the chiasm and the bulging effect observed by Kosmorsky et al. (2008).

The model of a tumour used by Howard (2008) was a thick-walled balloon shaped object with the same material properties of sclera. It can be seen in Figure 17 that the tumour model has experienced minimal deformation, so it still applies a very central force to the chiasm. The properties of the tumour may be much less rigid than originally thought (Lueck, 2009), so it will deform to the shape of the chiasm. The third modification to the existing FEM models will be to alter the tumour to create a tumour that experiences greater deformation and applies a less central load. This can be done by either altering the material properties of the tumour or reducing the thickness of the surface of the ‘balloon’ used. Figure 17, although a drawing, shows that the size of the tumour is much larger than the chiasm, so the physical size of the tumour will also be altered to see what effect this has on the stress distribution.

To model the effect of crossing nerve fibres in an accurate geometry, an attempt will be made to include crossing and non-crossing nerve fibre bundles within the model of the chiasm. This is important to the thesis work to view the overall effect of the geometry and crossing nature of nerve fibre bundles. However, it is also important that the chiasm geometries and crossing nature of nerve fibres are modelled separately; as this will allow insight to be gained into which theory for the selective damage of crossing nerve fibres is the more relevant.

The final modification will be to add additional crossing nerve fibre bundles to the model of a crossing nerve to see the effect of multiple adjacent crossing points.

VI. Project Management

Project planning documents have been created to describe the project and detail how and when tasks will be carried out, these can be found in annex A. As can be seen the task list divides the thesis into achievable portions which can be achieved. It includes the essential as well as desirable objectives of the thesis. Descriptions for each task are contained in Project Scope, as well as the task list included in annex A. The Gantt chart shows that the thesis has been planned to be completed by 06 October 2009, allowing the thesis supervisor, Dr Andrew Neely, two weeks to assess the final draft before the submission date. The Gantt chart includes planned completion dates and space for the thesis supervisor to sign that a task is completed; this will allow the progress of the thesis to be monitored, much like a milestone chart. A client brief listing the deliverables and objectives can be found in annex B.

No proposed expenditure has been planned for this thesis as no materials or technical support is required. The only area of this thesis which may require funding is the conversion of MRI data to a CAD usable format. Commercially available programs claim to provide the capability required, however prices for these programs are not readily available and, more importantly, investigation of their suitability needs to be conducted before expenditure is proposed. If, as a result of investigation, it becomes clear that purchase of a program is the most viable option to complete the thesis, expenditure evaluation and justification will then be done. A risk assessment has not be conducted for this thesis as no physical experiments will be carried out, so there is no chance of injury or death relating to the work done during this thesis.

The final tool used to help manage the project is the mind map, which can be found in annex C. The mind map is a large document best viewed in the program in which it was created. It allows thoughts and research to be organised into logical groups, which assist with writing reports, directing further study etc.
VII. Summary

This report has explained the condition known as bitemporal hemianopia, including the background of how extrinsic compression of the optic chiasm by an abnormal growth causes the loss of the temporal visual fields. The condition has been researched and explained to a level that will allow further research to be conducted through the use of FEM. Modifications will be made to existing FEM models that will improve the accuracy of the results obtained and provide a clearer picture of why nasal nerve fibres are selectively targeted.

The geometry, properties, locations, and orientations of the structures used in the FEM models will be modified to more realistically model those present in the optic chiasm and its surrounding structures. This requires that research be conducted into the material properties of the structures involved and into the conversion of MRI data into a CAD usable format.

This thesis will extend and attempt to improve the accuracy of the work done by Howard (2008) in an attempt to provide medical specialists with a greater understanding of the cause of bitemporal hemianopia.

Reference List


Appendices

A. Project Management Documents
B. Client Brief
C. Thesis Mind Map