Occipito-Cervical Fusion

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Student Number: BCKSIM004

Submitted to the University of Cape Town

In fulfilment of the requirements for the degree

Master of Medicine (MMed)

Orthopaedic Surgery

Faculty of Health Sciences

University of Cape Town

Date of submission: 15 August 2011

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DECLARATION

I **Simon Millard Bick** hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other University.

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Part A – Protocol

Study Proposal

Title

Occipito-Cervical Fusion: Retrospective review of surgical indications, techniques and clinical outcomes.

Principal Investigator: Dr SM Bick

Co-investigator: Prof R Dunn

Introduction

Occipito-cervical fusion (OCF) is undertaken to offer stability to the region rendered unstable due to inflammatory diseases, trauma, tumours, infections and congenital abnormalities. Various surgical techniques exist, ranging from uninstrumented autologous bone grafting, to fixation with wiring, rods and screws, and plates.

Studies have shown OCF with rod/plate systems to be superior to wire-based systems (Hurlbert *et al* 1999)

Separate surgical techniques exist to decompress the upper cervical spinal cord affected in this instability, with resultant adjustments of cervical fixation methods occurring. Specifically, pedicle screws have been shown to be the most rigid form of cervical fixation (Oda *et al* 1999), although other options are often employed according to surgeon preference, anatomy and pathological distortion.

Several studies have shown rigid posterior internal fixation to be safe, effective and although technically difficult, the current accepted treatment (Abumi *et al* 1999, Grob *et al* 1991, Jeanneret *et al* 1996, Lieberman *et al* 1998, Nockels *et al* 2007, Paquis *et al* 1999, Sasso *et al* 1994, Smith *et al* 1993, Vale *et al* 1999).

OCF has not been reviewed at our institute yet, and although Prof A. Heywood has published on this topic (Heywood *et al* 1988), the techniques used in his study are no longer in practise at our institute.

Study Design

A 6-year review of patients undergoing single-surgeon OCF at Groote Schuur Hospital, Red Cross Children's Hospital, and Constantiaberg Medi-Clinic.

Objective

The aim of this study is to review the different surgical indications, techniques and outcomes of occipito-cervical fusion, including C2 fixation methods, the influence on clinical outcome, patient scoring systems and complications.

Material and Methods

This study is a retrospective outcome-based study. Patients who have undergone OCF at the three hospitals above will have their records, images and data reviewed. All patients have had their surgery performed by a single surgeon (Prof Dunn), and all operative notes will be reviewed.

All information, images and folders will be requested and accessed through Groote Schuur and Red Cross medical records units. Constantiaberg Hospital data will be accessed through the surgeon's private records.

There will be approximately 30-35 patients reviewed.

Patient data will be reviewed for:

Age, sex, reason for presentation, surgical indication for OCF, patient scores pre- and post-op, influence on pain and neurology, complications.

Patient images (radiographs, CT scans, MR films) will be examined for:

Surgical technique (including C2 fixation techniques, fusion levels, decompression performed), fusion (rate and time), stability, complications, outcome of spinal cord decompression where appropriate.

As this is a retrospective review, no patients need to be contacted, examined or admitted.

Report of Findings

This study will be submitted for publication in peer-review journals (for example, South African Orthopaedic Journal), and will be submitted for discussion at the annual South African Orthopaedic Association Congress. Results will also be presented and discussed at faculty and departmental research meetings.

Budget and Funding

No funding is required, and no remuneration is necessary.

This study will form part of the investigators required academic responsibilities.

Ethics

Patient consent is not required, as this study is a retrospective review.

Patient confidentiality and anonymity will be maintained at all times.

The Declaration of Helsinki (2008) will be maintained at all times.

Conflict of Interest

None

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Part B – Literature Review

Literature Review

Introduction

Occipito-cervical fusion (OCF) refers to the surgical stabilisation of the region rendered unstable due to a variety of acute and chronic conditions. The most common conditions include: congenital abnormalities, inflammatory diseases (rheumatoid arthritis in particular), trauma, tumours and infections.

A clear evolution of surgical technique and implants has occurred, from simple onlay bone graft techniques and Halo brace immobilisation, to wire fixation methods, to internal fixation with plates and screws, finally to internal fixation with modular rod/plate systems with multiple screw fixation methods. Each step in the evolutionary process has resulted in improvements in fusion rates, implant rigidity and longevity, and associated immobilisation techniques. The aim of this procedure evolution is thus to provide immediate rigid fixation, followed by reliable fusion, and to obviate the need for lengthy external immobilisation allowing for the patient's early return to function.

The unique anatomy and function of the region, the high risks involved in surgery in the region, and the flexibility required by the surgeon to adapt to anatomical variants and multiple fixation systems, make OCF a challenging procedure.

The aim of this literature review is to document the evolutionary steps in OCF, discussing relevant anatomy, fixation points and techniques, fusion adjuvants and study outcomes.

Beginnings

In 1927, Foerster first described OCF for a patient who had sustained a dens fracture, using fibular graft augmentation.[1] Prior to this, upper cervical and occipito-cervical lesions and instability were largely viewed as inoperable and a terminal event. In 1928, Juvara and Dimitriu used tibial grafts for the same procedure, and in 1935, Khan and Yglesias reported the first case using iliac crest grafting to stabilise an atlanto-axial dislocation.[2,3] Rand confirmed this procedure for use in spontaneous atlanto-axial subluxations as well.[4]

Traditional methods used to fuse atlanto-axial instability include Gallie fusion and Brooks fusion, a central notched- and two lateral- bone graft blocks respectively, stabilised posteriorly with wire.[5,6] Unfortunately, the Gallie method of fusion has low rotational stability and requires external post-operative immobilisation, and there is the risk in both methods of acute and chronic neural encroachment by the wires. Braided cables have decreased this risk.[7,8]

Approaches

Given the complex anatomical relationships between the anterior neck structures, midline posterior approaches to surgery and fusion of the occipito-cervical region are traditionally used. An early anterior approach by Henry, further modified by Whitesides and Kelly, has allowed access to the vertebral artery and atlanto-axial fusion, although access to the basiocciput is denied.[9,10] Other anterior approaches including the Smith and Robinson, Bailey and Badgley approaches are currently used in several operations on the cervical spine, but very rarely for OCF.[11,12] In 1969, de Andrade and Macnab described a proximal extension of the Smith and Robinson approach which allowed access to the basiocciput for OCF.[13] By their own admission though, their approach is not the operation of choice for OCF, reserved however for patients with instability requiring fusion, who have previously had an extensive posterior laminectomy precluding posterior surgery. High post-operative morbidity, namely laryngeal nerve injury and tracheostomy insertions, was present in their paper.

Transoral approaches, described by Southwick and Robinson, and Fang and Ong, expose the atlantoaxial region though the mouth and pharynx, and are used for dens decompressions and extradural lesions.[14-17]

Methods

Onlay bone grafts

Onlay bone grafting of autologous cancellous bone, with post-operative immobilisation in either a Halo immobiliser or SOMI brace was described by Perry and Nickel in 1959.[18] The term "Halo" jacket immobiliser ("Halo" being the shape of the ring used for pin fixation around the skull, connected to a brace extending below the shoulders), first introduced by Perry and Nickel for stabilising an unstable paralysed neck following poliomyelitis, was popularised by Thompson for the use in trauma and post-operative immobilisation.[19] Newman and Sweetnam published good results with this method in 8 of 9 patients with atlanto-axial instability.[20] A more recent study by Elia reports a fusion rate of 89% at an average of 12.8 months with this method, highlighting its safety and simplicity.[21] The disadvantage with this simple form of OCF, however, is that prolonged external immobilisation with skeletal traction, Minerva jacket, Halo immobiliser or SOMI brace is required.

Onlay bone grafts with wiring

Wire fixation was subsequently added to OCF to secure the bone graft and assist in stability whilst awaiting bony fusion.[22,23] Hamblen published on a single- or 2-stage decompression and fusion procedure with wire fixation of autograft bone plates, in 1967. This he credits to Cone and Turner, subsequently modified by Robinson and Southwick, and his fusion rate was 100%.[24,25] Wertheim and Bohlman published on a series of patients undergoing OCF, with satisfactory results in 10 of 13 patients (of note, all patients had radiological fusion) with a "triple wire" technique, lashing iliac bone graft blocks between the external occipital protuberance and the cervical spinous processes.[26] Hamblen used iliac crest grafting in all but 2 cases, where he used tibial bone graft. Both studies highlight the extended period of external immobilisation required post-operatively - Hamblen's patients required 3 months in a plaster bed followed by 4-6 weeks in a Minerva jacket, Wertheim and Bohlman's patients required 6-16 weeks in a rigid orthosis or Halo cast. McAfee showed a fusion rate of 85% in 37 patients treated with the triple-wire technique.[27] Again, 3 months of post-operative Halo immobilisation were required. Zygmunt, and more recently Jain, have also shown success with posterior wiring techniques.[28-30] Specifically, Jain obtained an 88% fusion rate in his series using posterior occipito-cervical wiring through a built-up artificial atlas arch of bone graft, in patients with congenital atlanto-axial dislocation. Of note, 3 months of hard collar use was Jain's post-operative instruction.

Another wiring technique, the Locksley tie-bar technique of securing rib bone graft postero-laterally with wires, and a posterior T-plate, has been used but not widely adopted. The technique offers better immediate rigidity than other bone graft-wire techniques, and the advantages of rib over iliac crest bone graft usage.[31]

Bone graft

Bone grafting remains one of the key factors in successful OCF. Autograft, harvested from rib, iliac crest or occiput is commonly used, although allograft sources are available. Fusion rates remain comparable between the two main methods (iliac crest and rib), but donor site morbidity taints the success of the more common iliac crest use. Sawin published a comparison of over 600 patients undergoing bone graft harvesting from the two main sites for various spinal fusions, with an overall fusion rate of 98.8% in the rib group, and 94.2% in the iliac crest group.[32] Significantly, donor site morbidity rate was 25.3% in the iliac crest group (pain, haematoma, fracture) compared with the rib group 3.7% (pneumonia, atelectasis). Overall, both sites were deemed safe for graft harvest.

Dormans reported on successful OCF in paediatric patients using sculptured autogenous iliac crest bone graft, and more recently Cohen has used autologous rib bone graft.[33,34] These graft types were secured with occipital wires and either sublaminar or spinous process wires caudally, depending on whether or not concomitant laminar decompressions were needed. Although both techniques gave good results with regard to fusion rates, the authors believe that rib graft harvesting in paediatric patients is surgically easier due to the small crest size, fits the anatomy better, offers more multiplanar load resistance, and gives no donor site complications.

Other wire techniques

Brattstrom and Granholm developed a technique related to bone grafting and posterior wiring, by adding methylmethacrylate bone cement to the fusion mass to increase stability, thereby not using Halo immobilisation methods post-operatively.[35] This technique was adopted by several surgeons, but has largely been abandoned due to high complication rates.[28,36-39] Zygmunt published a long-term result on 163 patients with rheumatoid arthritis and OCF with this technique, 24 requiring reoperation, and 16 suffering from wound infection.[40] A study by Grob showed a 27% non-union rate, unacceptably high.[38]

Alterations and improvements in wire-based systems continued, with the Hartshill-Ransford loop being employed on a series of 43 patients with no hardware failures or external bracing required.[41,42] Custom-made Luque rods or preformed rectangular Luque-Hartshill systems have also been used with wire fixation with good results.[43-49] Fehlings used a malleable 5mm rod (an upside-down "U"-shape) secured to the occiput with wire loops, and wired to the cervical spinous processes or laminae.[50] All but one surviving patients in Fehlings' study went on to union with no external bracing required. In 1993, Sonntag and Dickman continued the expansion of wiring techniques by developing a rod-and-wire technique with a contoured, threaded Steinman pin looped through two suboccipital craniectomies (with an obvious risk of dural tears).[51] This in turn is fastened with conventional wiring techniques to the cervical laminae, and an overall fusion rate of 89% was reported. Apostolides obtained a 90% fusion rate with this method.[52] These newer methods highlighted the development of "patient-unique" techniques allowing greater surgical freedom and flexibility.

More recently, Jackson has used Fehling's techniques of OCF on 12 patients with cervical tumours, with success in pain relief and neurological preservation or improvement in all patients.[53] Zimmerman showed good results in 20 patients with primary or metastatic cervical bone tumours, using the Ransford loop technique, allowing an improvement in pain and quality of life.[54] Singh obtained fusion in 29 of 30 patients using a contoured "horseshoe"-shaped, occipital, titanium OMI (Ohio Medical Instruments) loop and cervical transarticular screws, however the pre-operative neurological status of 28% of patients did not improve.[55]

Problems with wire systems

Although the wire-based OCF procedures are relatively easy to perform, several disadvantages have been reported on. C2 sublaminar wiring or spine-graft block wiring has been associated with several complications, including cervical redislocation and neurological deterioration after tightening.[29,39,51] Naderi showed clear mechanical flaws with Brooks and Gallie –type fusions used for atlanto-axial instability, namely bone graft loosening due to cyclical loading allowing unwanted rotational and translational movements.[56] Wire and cable systems also have the tendency to abrade through bone, affecting stability.[57] Future methods were aimed at reducing the high complication rates associated with wire-based systems.

The South African connection

Heywood and colleagues have largely been overlooked in their presentation of a technique for OCF by internal fixation with a small T-shaped plate (originally used for plating distal radius fractures) and standard "small fragment set" screws used through the plate.[58] Although they credit Cregan with the first use of plate fixation, concerns over fusion rates and complications with earlier techniques (particularly wire-based systems), led Heywood to simplify the OCF procedure to plate and screw fixation, with additional wire fixation reserved for long segment fusions only. Twelve out of 14 patients went on to satisfactory fusion, with 1 failure in a rheumatoid arthritis patient.[59] All patients were immobilised post-operatively in a Halo immobiliser for 12 weeks, and routine bone grafting was performed.

Plates and screws

After the study published by Heywood, several other studies on plate fixation followed. Roy-Camille, Smith (using reconstruction plates), Grob (using inverted Y-shaped plates), Sasso (using lateral reconstruction plates), and Lieberman (using notched titanium plates) all showed good results with posterior rigid internal fixation using plates and screws.[38,60-66] The main successes with this procedure were excellent fusion rates and the end of the absolute need for prolonged external or Halo immobilisation. Combinations of pedicle and transarticular cervical screws were used through the plates, creating technical difficulties in safe screw placement and surgical confidence.

In a study by Grob *et al*, the authors showed a better outcome with their plating subgroup, over their wire fixation subgroup, including a 27% incidence of pseudoarthrosis in the wiring group.[38] This confirmed the sentiments of the time - that wire fixation was losing favour due to the high rate of reoperation and complications.

C1-2 transarticular screws

Part of Grob's success with OCF, including fusion rates of 99% and 94%, can be attributed to his use of the C1-2 transarticular screw, developed by Magerl.[38,64,67,68] Repeatedly shown to be superior to wire-based atlanto-axial fixation systems, the transarticular screw offers rotational and translational movement blockage, and hence a more stable internal fixation.[65,69,70] The risks however, are screw malposition and vertebral artery injury, the latter risk leading to the recommendation of pre-operative computed tomography scanning to visualise any vertebral artery anomalies in patients where this screw use is planned.[38,65] The risk of vertebral artery injury, however, is ultimately small, namely 2.2% per screw, with low risk of subsequent neurological fallout, despite a 20% artery anomaly incidence in normal subjects.[71] Gluf, in a review of 353 C1-2 transarticular screw insertions for atlanto-axial instability, noted vertebral artery injury in 6 screws (1.7%), 5 malpositioned screws, yet an overall fusion rate of 98%.[72] It is important to note that if a vertebral artery is violated on inserting the first transarticular screw, a similar screw on the contralateral side should not be attempted, to avoid the rare but disastrous complication of bilateral artery injuries and subsequent ischaemic brain injury. An alternative fixation method should rather be employed.

Hooks

Faure developed a new technique for OCF using a hook-claw system, effectively aiding posterior graft fusion by creating a lamina-occiput claw clamp.[73] Paquis has used this method with successful alleviation of pain in all patients with non-traumatic upper cervical instabilities.[74] Paquis recommends occipital hook usage in osteoporotic bone, where the occipital thickness is <7mm and screw pullout risk is greater. Hooks/claws are joined with malleable titanium or stainless steel rods, bent to the desired amounts.

Combinations and improvements

In order to improve on the technically challenging (although successful) posterior plating systems, as well as to allow for individual adjustments in fixation according to patient anatomy and pathology, screw-and-rod techniques were developed. Jeanneret developed essentially the precursor to modern modular OCF systems, using 3.5mm titanium rods connected to an occipital AO-reconstruction plate and cervical screw clamps.[75] Five types of cervical clamps with variable screw-hole angles allowed for optimal screw placement and rod fixation. Cotrel-Debousset rods were used by Heideke and Korovessis for OCF with fusion rates of 100% and 97% respectively, using occipital screws and cervical sublaminar hooks as fixation points.[76,77] Abumi published, based on the biomechanical work by Jones who had shown the superior pull-out strength of cervical pedicle screws over lateral mass screws, on a series using cervical pedicle screws in a screw-rod construct. Abumi's results - fusion in 24 of 26 patients, significant malalignment correction, and no screw insertion complications.[78,79] Vale also described a rigid posterior OCF system using biomechanical data from the time, improving the occipital fixation points towards the thicker skull midline under the external occipital protuberance.[58,80,81] This fixation was combined with lateral plates and transarticular screws to gain a fusion rate of 100%, with the singular complication of an acute subdural haematoma in one patient due to the inadvertent drilling of an occipital vein.

Subgroups

Paediatric Population

Paediatric patients requiring OCF lie in three main groups. Firstly, patients that have congenital vertebral anomalies alone, secondly those with cervical anomalies with a systemic disorder, and thirdly those suffering from regional trauma. Congenital vertebral anomalies include os odontium, basilar invagination, absent posterior elements, and Chiari and other malformations.[82] Systemic disorders with cervical anomalies include Down, Klippel-Feil, Morquio and other mucopolysaccharidoses, Jeune, Kniest, DiGeorge syndromes, skeletal dysplasias, inflammatory disorders and infections.[83] Traumatic causes most commonly include atlanto-occipital dislocation, dens and Jefferson fractures, and other ligamentous instabilities.

Onlay posterior bone grafting and Halo immobilisation has been shown to be an effective procedure used for OCF in children and adolescents with upper cervical instability.[84-86] However, Halo immobilisation is still relied upon to provide post-operative stability using these methods, and hence newer studies explored wiring techniques and internal rigid fixation methods.[33,82,83,87-91] The rigid internal fixation methods used contoured craniocervical loops, with cervical wiring and transarticular screw fixation, and obtained fusion rates ranging from 89-100%. The main advantage of these internal fixation methods is the reduction and/or obviation of Halo immobiliser use post-operatively, particularly in patients too small for the Halo constructs to be applied. Plating options can also be used for stabilisation after procedures requiring direct posterior structure decompression (eg. myelopathic patients) with little further dissection required. Instrumentation in paediatric patients however, is technically extremely difficult, with challenging screw/wire placement, and seldom replaces Halo or plaster cast (eg Minerva jacket) immobilisation techniques.

Trauma

Upper cervical and occipito-cervical traumatic events often result in instability of the region, and, in the case of atlanto-occipital dissociation/dislocation

(AOD), fatality. AOD is usually a high-energy injury with fatality occurring due to ponto-medullary or spino-medullary junction disruptions. AOD has been classified by Traynelis according to the direction of occipital displacement with reference to the atlas, and after immediate reduction and immobilisation (traction is avoided), fixation is required.[92] Occipital condyle fractures, particularly the unstable Anderson and Montesano type III, also require OCF, as do certain odontoid process (dens) fractures which have resulted in atlanto-axial instability.[93-95]

Rheumatoid Arthritis

Rheumatoid arthritis is a chronic, progressive inflammatory disease causing multiple systemic and regional disorders. In the cervical spine, this is notably atlanto-axial instability, which may be complicated by upward migration of the odontoid (basilar invagination or impression) leading to severe neurological symptoms, myelopathy, and even sudden death.[49] Surgery is often required, as the 7-year survival rate of patients with rheumatoid arthritis and myelopathy without surgery has been reported as zero.[96] Methods to stabilise the atlanto-axial region include traditional wire fusion procedures of Gallie, Brooks and McGraw, as well as newer wire-loop methods, Y-plates, rectangular rods, but these methods have largely been superseded by newer modular rod-screw methods.[5,6,42,44,97-101] Long term improvements with respect to survival, pain, and myelopathy are gained with surgical stabilisation.[99]

Fixation

Fifty percent of the total range of motion of the neck occurs through the occiput-C2 level.[102,103] Stable fixation remains the key to successful fusion in OCF procedures.

Occiput

The method of occipital fixation has evolved from traditional wire fixation to screw fixation.[38,104] In order to determine the best position for occipital internal fixation, Heywood continued on the cadaveric studies of Ebraheim and Zipnick.[58,105,106] The thickest part of the occipital skull was consistently found to be the central external occipital protuberance, on the superior nuchal line, and that bone thickness decreased radially from this point. Fears of damaging the intracranial venous sinuses located directly beneath this thickest occipital region, have prompted recommendations for fixation to be below the superior nuchal line, pre-operative determination of skull thickness and the use of unicortical screws.[58,64,100,105]

The biomechanics of occipital screw fixation have been studied by Haher.[81] Bicortical screws were found to have 50% greater pullout strength than unicortical screws or occipital wires. Unicortical screws, however, placed at the external occipital protuberance, had the same pullout strength as bicortical screws placed elsewhere. Roberts also showed that the bicortical screw pullout strength was directly related to the skull bone thickness, with no significant difference between cortical and cancellous screw types.[107]

A recent biomechanical study by Anderson showed that the only significant difference between lateral and midline occipital bicortical screw fixation, using modern rod-screw systems, was a slight decrease in stiffness during lateral flexion forces with the midline-placed screws.[108]

Pait developed a novel “inside-out” technique for occipital screw fixation, in order to decrease the risk of dural penetration, using a key-hole shaped occipital burrhole slotting a flat-headed screw from inside-out which is then bolted onto a standard reconstruction plate fixed to the cervical spine with traditional methods.[109] This allows the surgeon to obtain optimal occipital screw purchase (even laterally where the occiput is not as thick as the midline), and visualise the entire screw. Sandhu used this technique successfully in 20 of 21 patients with rheumatoid arthritis, emphasising a strong lateral occipital hold and an increase in torsional force resistance, although not biomechanically proven.[110] Caglar confirmed with a mechanical study in sawbone models, the superiority of inside-out screws over outside-in screw or occipital wiring methods.[111] Lee however, states that the inside-out technique is technically demanding, weakens the area of screw insertion, requires extensive and risky dissection of the dura off the inner skull table, and that traditional outside-in methods have a complication rate of less than 1%.[100] Newer techniques have also suggested occipital condyle screw fixation as an alternative method, proposed for patients who have previously undergone a posterior fossa craniectomy.[112]

Newer C1-2 fixation methods

As previously mentioned, cervical fixation methods in OCF initially used sublaminar or spinous process wires. This has been adapted to newer screw-based methods, namely transarticular, lateral mass and pedicle screws, initially through fusion plates, to modern linking with longitudinal contoured rods. Harms devised a novel technique for C1-C2 fixation for patients with atlanto-axial instability, where transarticular screw placement is to be avoided (aberrant vertebral artery location or fixed atlanto-axial subluxation), using polyaxial C1 lateral mass and C2 pedicle screws connected to contoured posterior rods.[113] Thirty-seven patients underwent this procedure without neural or vascular injury, all resulting in fusion. This allows for a two-point fixation system to be converted into a more stable three-point system.

Recent biomechanical studies have compared the different types of cervical fixation in OCF methods. Hott showed that C1 lateral mass screws and C2 pedicle screws are equivalent to C1-2 transarticular screws in *in vitro* experiments, noting that the pullout strength difference between the lateral mass and pedicle screws was insignificant.[114] Finn however, showed the C1 lateral mass – C2 pedicle screw combination to be superior to the C1-2 transarticular method.[115]

Bambakidis proved biomechanically, that occiput-C1 transarticular screws are essentially equivalent to occipital keel screws linked to C1 lateral mass screws with contoured rods, both with graft, in providing atlanto-occipital stability.[116] This has an application in adult atlanto-occipital dislocations, although has not been widely adopted.

An alternate cervical fixation method, in the form of translaminar screws, has been shown to be a safe and appropriate option by Reddy.[117] This allows for less risk to the vertebral arteries than that when using pedicle screws, and is recommended for patients with anatomical variants or small pedicles.

Biomechanics

In 1999, two significant biomechanical studies were published.[104,118] Hurlbert performed a cadaveric study proving screw fixation superior to wire fixation in OCF using four methods – a contoured Steinman pin with all-wire fixation, a Cotrel-Debousset horseshoe-rod with occipital screws and sublaminar wires, a Mayfield (similar to the Cotrel-Debousset rod) contoured loop and a custom-made OCF plate, both with occipital screws and transarticular cervical screws. The two complete screw systems provided the highest degree of immobilisation. Of note, the addition of C1 wire fixation to the construct significantly increased the construct's stability. Oda compared five types of OCF fixation methods, showing significant advantage of C2 pedicle screws and C1-2 transarticular screws over wire and hook methods. Pedicle screws have the added advantage over transarticular screws in that the laminae are not required for fixation, hence can be used after prior posterior decompression. Pedicle screws also allow easier reduction of atlanto-axial subluxation and occipito-cervical distraction than C1-2 transarticular screws.[78]

Puttlitz performed a cadaveric biomechanical study matching bilateral C1 (lateral mass) and C2 (pedicle) polyaxial screws, occipital screws, and longitudinal rods against a C1-2 transarticular screw-plate construct.[119] Both methods performed equally well, and the authors conclude that the "decision to use either construct should be made on the basis of surgical technique and not the acute biomechanical stability".

The Present

Modern techniques for OCF have thus evolved to gain advantage from biomechanical and safety improvements, and currently use modular rod-screw systems with occipital plate/screw attachments. This allows a rigid, safe, adaptable, simple-to-use system, with a high success rate with regard to patient outcome and fusion rate. The current accepted technique, the present product of the OCF evolution - posterior OCF with bicortical occipital screws placed near the midline just below the superior nuchal line, followed by C1/2 transarticular screws (or C2 pedicle screws if transarticular screws are impossible due to pathology or anatomy, with sublaminar C1 wires or C1 lateral mass screws attached to the construct according to surgeon preference), connected by contoured, patient-specific rods, adjuvant autogenous bone graft, without compulsory post-operative brace immobilisation.[100,120] Paediatric patients tolerate Halo immobilisation with posterior on lay fusion, with instrumented fusion reserved as an option for patients too small for Halo constructs, or those who require direct cord decompression (eg. myelopathic patients).

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Part C – Manuscript

This manuscript was published in the South African Orthopaedic Journal, Summer 2010. The format and referencing style is that which is required by the journal.

Occipito-Cervical Fusion: review of surgical indications, techniques and clinical outcomes.

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Study Design: A retrospective review of patients undergoing single-surgeon occipito-cervical fusion.
Objective: The aim of this study is to evaluate the surgical indications, techniques and clinical outcomes of occipito-cervical fusion, including C2 fixation methods and complications.
Materials and Method: Thirty-four consecutive patients (16 males, 18 females) who underwent occipito-cervical fusion were reviewed. The indications for fusion were instability due to inflammatory diseases (13), trauma (9), congenital abnormalities (9), infections (2) and tumours (1). Nine patients (all but 1 paediatric) underwent fusion with bone grafting and Halo immobilisation. Twenty-five patients underwent posterior instrumented fusion. Halo removal was performed after 6 weeks and soft collars were worn for 6 weeks in the instrumented group. Surgical techniques and clinical outcomes (stability, fusion, complications) were reviewed.
Results: Clinical and radiological fusion was attained in all patients available for follow-up, with an average of 2.7 months in the uninstrumented group and 5.2 months in the instrumented group. All fusions resulted in resolution of pre-operative pain and an improvement in pre-operative neurology. Two patients demised in the acute post-operative period as a result of the underlying pathology. Eighteen patients required simultaneous decompressions. No instrumentation failures occurred. Superficial wound sepsis occurred in 4 patients, one subsequently requiring instrumentation removal.

Conclusion: Occipito-cervical fusion is safe and reliable procedure, predictably providing stability and improvement in pre-operative pain and neurology. Multiple cervical fixation options are available according to surgeon preference and anatomical variants.

Occipito-Cervical Fusion: review of surgical indications, techniques and clinical outcomes.

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Introduction:

Occipito-cervical fusion (OCF) is required when the junction is rendered unstable by a variety of pathological conditions including congenital abnormalities, inflammatory diseases, trauma, tumours and infections.

Over the years there has been an evolution of surgical technique as implants have developed to accommodate the challenges of the occipito-cervical junction. These range from onlay bone graft techniques with halo jacket immobilisation to sophisticated instrumentation techniques. Early on, tenuous wire fixation methods were utilised. Prof Brookes Heywood of the Princess Alice Orthopaedic Hospital was ahead of his time, publishing on the use of the T-plate (usually used in distal radius fractures) as a fixation option.[1] His concept was not dissimilar to the modular occipital plates used today.

The unique anatomy and function of the region, the perceived high risk of vascular and neurological complications, and the anatomical variations make OCF a challenging procedure. Currently, the accepted method for OCF is rigid posterior internal fixation utilising segmental modular instrumentation .[2-9]

We undertook a retrospective review of our patients undergoing OCF assessing surgical indications, technique, clinical outcomes, and complications.

Methods and Materials:

Thirty-four consecutive patients with occipito-cervical disorders undergoing OCF between December 2002 and February 2010 were identified. All procedures were performed by the senior author at Red Cross Children's Hospital, Groote Schuur Hospital and Constantiaberg Mediclinic.

The study was approved by the Research Ethics Committee of the Health Sciences Faculty, University of Cape Town, reference 188/2010.

There were two groups in this cohort, viz. a paediatric (< 16 years) and adult group. There were 12 patients in the paediatric group included, 5 females and 7 males. The average age was 8.6 years (1-16 ± 5.0 years). The adult group included 22 patients, 15 females and 7 males, with an average age of 52.9 years (25-79 ± 15.4).

The presenting complaints at the time of surgery included non-traumatic pain or instability, myelopathy and traumatic instability as in table 1. The paediatric myelopathy was due to Down's syndrome, Morquio's syndrome, congenital kyphosis and Conradi-Hunerman syndrome. In the adult group, the myelopathy was largely due to rheumatoid arthritis (5) and one tuberculosis. The myelopathies were generally mild and the patients were ambulant pre-operatively. Other paediatric indications included traumatic atlanto-occipital dissociation and chronic granulomatous osteitis.

Rheumatoid arthritis (13) predominated as a cause in the adult group, followed by trauma (7), tumour (1) and tuberculosis (1).

Nine patients (8 paediatric, 1 adult) underwent uninstrumented fusions with Halo immobilisation (figure 1). Twenty-five patients (21 adult, 4 paediatric) underwent instrumented fusions. The PCR / Summit system (DePuy®) was used in 11 patients the Axon (Synthes®) in 14 patients.

Eighteen patients required simultaneous spine decompression due to myelopathy or stenosis. The majority were a posterior C1 arch resection (14), sub-axial laminectomy (3) and one necessitating a trans-oral odontiodectomy.

Preoperative x-rays including dynamic views, CT and MRI's were reviewed to determine stability, the extent of soft-tissue abnormalities (tumour and pannus), bony pathology and their influence on planned fixation types and level.

Patients underwent general anaesthetic induction whilst supine. The halo group then had the halo applied and halo-vest assembled. Any misalignment was reduced if possible and confirmed on lateral image. The patients were re-positioned prone on the anterior halo struts and ring. The surgical procedure was performed through the posterior halo- struts and bone graft harvested from the posterior iliac crest after ensuring the vest allowed adequate access.

In the instrumented group, a Mayfield clamp was applied before re-postitioning on a Relton-Hall frame. Fluoroscopy was used to confirm the desired neutral cervical position, the reduction of anatomical malalignment, and the placement of instrumentation. Posterior iliac crest bone graft was utilised in 27 patients. Allograft was used in 7 paediatric and trauma patients.

The occipito-cervical area was exposed via a posterior midine approach with sub-periosteal exposure of the skull from the external occipital protruberance (EOP) to the required cervical level.

Occipital fixation was achieved with a T-plate fixed in the midline with 4.5mm bicortical screws (figure 2). The EOP was burred on the caudal side to facilitate plate placement, both flat against the skull and as cephalad as possible to allow fixation in the thickest bone. Careful drilling and tapping with the use of depth restriction guides was done. After an initial observation of subcutaneous plate –rod articulation prominence, subsequent plates were inverted. Skull plates were used in all patients except in a 1 year old patient where two paramedian plate/rods were applied due to anatomical constraints. Bicortical fixation was used.

Different cervical fixation methods were employed as determined by the indication for fixation and anatomical variants (figure 3-5). There included C1/2 transarticular (3), C2 pedicle (14) or translaminar screws (7) and sub-axial lateral mass screws. The default C2 screw was the pedicle screw with the translaminar screw as a bail-out if the pedicle was not possible due to anatomical or technical limitations. All but one construct bypassed C1. In this patient C1 lateral mass screws were utilised. Seven patients were fixed to below C2 level. The fixation option was decided upon intra-operatively according to screw hold and surgeon satisfaction.

The average surgical time in the uninstrumented group was 83 minutes (40-195) and 137 minutes (85-275) in the instrumented group was. The average blood loss was 142 ml (50-300) in the uninstrumented group and 513 ml (100-3300). The 3300 blood loss was due to the vertebral artery injury.

Halo jackets were worn for a minimum of 6 weeks, and removed as soon as possible thereafter under general anaesthetic. In the instrumented group, a soft cervical collar was worn for 6 weeks post-operatively. Follow-up visits were arranged for 6 weeks, 3 months, 6 months, 1 year and annually thereafter, with radiographic follow-up at each visit.

Fusion was assessed on lateral radiographs as cross-trabeculation of bone mass, absence of peri-screw lucency and absence of instrumentation failure.

Results:

Twenty-eight patients were available to follow-up with an average follow-up of 9.9 months (6 - 48). Four patients failed to return and two demised peri-operatively.

Successful clinical and radiological fusion was obtained in all 28 patients available for follow-up. In the uninstrumented group, all 8 patients fused at an average time of 2.7 months (1.5 – 4 months). In the instrumented group, 20 patients fused at an average time of 5.2 months (3 – 12 months).

All patients with preoperative radicular pain had resolution of their symptoms. Those with myelopathy, had improvement to normal or near normal except two infants (Morquio, congenital kyphosis).

The two patients that demised in the acute period post-operatively included an adult who had suffered traumatic atlanto-occipital dissociation and quadraparesis. She succumbed to respiratory complications in ICU. The second patient was a child with Trisomy 21. She required the trans-oral decompression and suffered a gastric stress ulcer with perforation in ICU post-surgery.

There were no instrumentation failures or revisions required. Two patients had minimal occipital plate lift-off (1-2mm) on the post-operative films. This did not progress and both went on to successful fusion. One patient had an intra-operative cerebrospinal fluid leak from the occipital drill which stopped on screw insertion. There were no subsequent problems.

Four patients suffered from superficial post-operative wound infections. Two required oral antibiotics and dressings. The other two required washouts in the early post-operative period and settled on oral antibiotics. One subsequently required instrumentation removal at 2 years post-op due to recurrence of infection. Once removed, the infection settled and she continued to have pre-operative symptom resolution. Of these 2 patients requiring wound washouts, 1 was a rheumatoid arthritis patient using Methotrexate at the time of surgery and the other the Down's child. One patient, with the Atlanto-occipital dissociation had an intra-operative unilateral vertebral artery violation during C1 screw placement. This settled with local measures. One patient suffered from a post-operative deep vein thrombosis.

Discussion:

OCF has progressed a long way since 1927 when Foerster first described the technique using a fibular graft in a patient who had sustained a dens fracture.[10] Prior to this, such pathology was viewed as inoperable and a terminal event. In 1928, Juvara and Dimitriu used tibial grafts, and in 1935, Khan and Yglesias reported the first case using iliac crest grafting to stabilise an atlanto-axial dislocation.[11-12]

For years onlay bone grafting was used with post-operative immobilisation in either a Halo immobiliser or SOMI brace. Good results and fusion rates (up to 89%) have been shown using this method, but with prolonged external immobilisation and often initial skeletal traction.[13-16]

Wire fixation was used to secure the bone graft and assist in stability whilst awaiting bony fusion.[17-23] Brattstrom and Granholm added methylmethacrylate to the fusion mass to increase stability, obviating Halo immobilisation post-operatively.[24] This technique was adopted by several surgeons, but has largely been abandoned due to high complication rates.[21,25-8] Zygmunt published a long-term result on 163 patients with rheumatoid arthritis and OCF with this technique, 24 requiring reoperation, and 16 suffering from wound infection.[29] A study by Grob *et al* showed a 27% non-union rate, unacceptably high.[27]

Development of wire-based systems continued, with Hartshill-Ransford loops, Luque rods, rectangular Luque-Hartshill systems and hook-claw sytems used with wire fixation with good results.[30-41] Malleable 5mm rods (upside-down "U"-shape), occipital titanium loops and threaded Steinman pins secured to the occiput with wire loops, and the cervical spinous processes or laminae, have also shown good results.[42-45]

However C2 sublaminar wiring or spine-graft block wiring has been associated with cervical redislocation and neurological deterioration after tightening.[22,28,43] Wire and cable systems also have the tendency to abrade through bone, affecting stability.[46]

Concerns over fusion rates and complications with earlier techniques led Heywood to try plate and screw fixation, with additional wire fixation reserved for long segment fusions only.[1] Limited by the technology of the time, he used a distal radius T-shaped plate from the standard "small fragment trauma set" with routine bone grafting and Halo immobilisation. In addition, he studied cadavers and identified the occiput was thickest in the midline. Twelve out of 14 patients went on to satisfactory fusion, with 1 failure in a rheumatoid arthritis patient.

Several studies on rigid plate fixation followed.[27,54-57] The main successes with this procedure were improved fusion rates and the end of the absolute need for prolonged post-operative immobilisation. This can partly be attributed to the C1-2 transarticular screw, developed by Magerl, and repeatedly shown to be superior to wire-based fixation systems.[55-7] Gluf, in a review of 353 C1-2 transarticular screw insertions for atlanto-axial instability, noted vertebral artery injury in 6 screws (1.7%), 5 malpositioned screws, yet an overall fusion rate of 98%.[58]

Modular screw-and-rod systems were developed on the success of rigid plate fixation.[59-61] Abumi published a series using cervical pedicle screws in a screw-rod construct, with fusion obtained in 24 of 26 patients, significant malalignment correction, and no screw insertion complications.[62] Vale described a rigid posterior OCF system, improving the occipital fixation points towards the thicker skull midline under the external occipital protuberance.[63]

Onlay bone grafting and Halo immobilisation has been shown to be an effective procedure for OCF in children and adolescents with upper cervical instability.[64-6] This is due to rapid fusion rates, but many adults find prolonged halo restriction unacceptable.

As fifty percent of the total range of motion of the neck occurs through occiput-C2 level, stable fixation remains key to successful fusion in OCF procedures.[67-8] Complete screw systems have been proven biomechanically over wire fixation methods.[69-70] C1 wire fixation to the construct significantly increased the construct's stability. Pedicle screws have an advantage over transarticular screws in that the laminae are not required for fixation, hence can be used after posterior decompression. Pedicle screws also allow easier reduction of atlanto-axial subluxation and occipito-cervical distraction than C1-2 transarticular screws.[62]

Occipital fixation has evolved from traditional wire fixation to screw fixation.[27,69] Central screw positioning, just below the superior nuchal line, has been shown to be the thickest and safest region.[1,71-3] Bicortical screws have 50% greater pullout strength than unicortical screws or occipital wires, with pullout strength directly related to the skull bone thickness, and no significant difference between cortical and cancellous screw types.[74-5] Lateral and midline occipital bicortical screw fixation, using modern rod-screw systems, show similar biomechanical properties.[76] Inside-out techniques for occipital screw fixation show biomechanical but not clinical superiority over traditional outside-in methods.[71,77-9]

More recently C1 lateral mass – C2 pedicle screw combination have been found to be superior to the C1-2 transarticular method.[80-1] Translaminar screws have been reported to be a safe alternative.[82] It reduces risk to the vertebral arteries and is recommended for patients with high riding vertebral arteries or small pedicles.

Conclusions:

OCF, whether rigid instrumented fusion or onlay bone grating and Halo immobilisation, remains a successful, safe and reliable procedure for the stabilisation of the OC junction for a variety of indications. It achieves stability and a marked improvement in pre-operative pain and neurology.

The on-lay fusion with halo immobilisation remains a good option in the paediatric group who experience rapid fusion and tolerate the halo well. In adults the advantage of rigid fixation obviating prolonged immobilisation makes it a valuable option. Modular instrumentation allows individualisation of fixation techniques to minimise and risk and maximise stability, based on patient specific anatomy. C2 screws provide excellent cervical purchase, but the surgeon should be capable of multiple techniques as this option is not possible in all individuals.

Table 1: Presenting complaints

	Paediatric	**Adult**	**Overall**
Pain / instability	6	9	15
Myelopathy	4	6	10
Traumatic instability	2	7	9
	12	22	**34**

Figure 1: Child with halo vest applied in prone position for surgery

Figure 2: inverted T plate with translaminar C2 screws

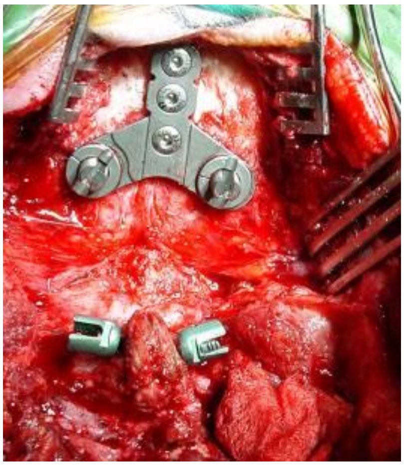


Figure 3: Occipital plate with translaminar C2 screws and bony fusion evident

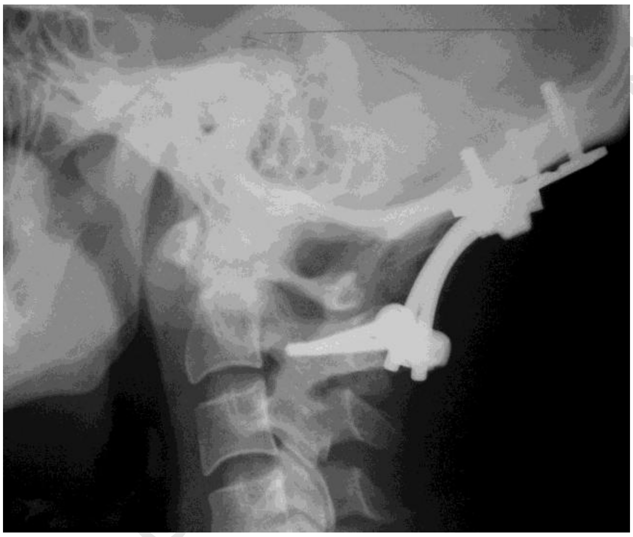
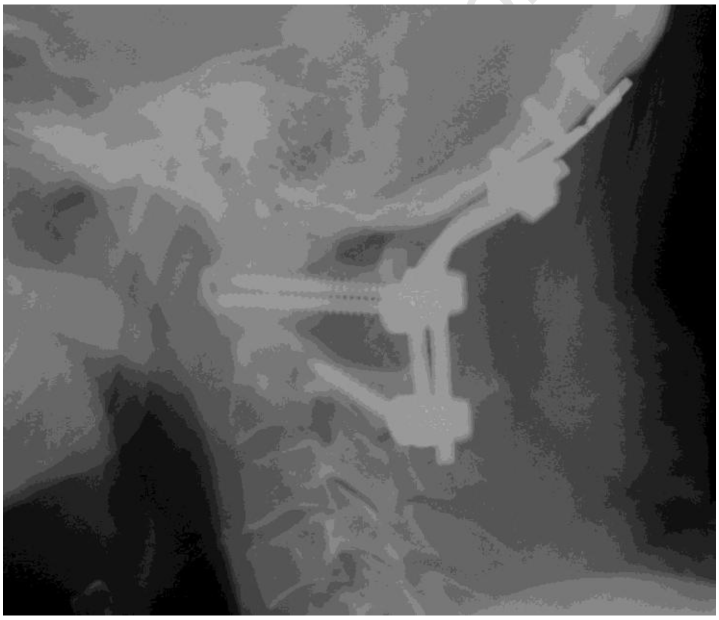


Figure 4: Occipital plate, C1 arch wire and atlanto-axial transarticular screws

Figure 5: Use of C1 lateral mass screws with C2 pedicle screws to give most stable construct and allows reduction of C1 arch.



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Part D – Supporting Documents

Instrumentation	Surname	First names	Gender	Age	Hosp No	Operation title	Date of operation	Level: top	Indication	Presenting Complaint	Surgical Time (mins)	Blood Loss (mls)	Fusion Time (months)	Follow-up Time (months)	Complication/Outcome	C2 Fixation	Bone Graft	Decompression	Trauma	Methotrexate	Hardware
None	Popoyi	Notest	Female	48	88668538	Posterior C0-3 fusion	11-Dec-02	C0	Sepsis	Myelopathy	90	100	4	12	Fusion		Auto	Nil			
PCR/Summit	Bomvu	Sipo	Male	64	88006655	Posterior C0 - C4 instrumented fusion	16-Aug-02	C0	Tumour	Pain/Instability	170	1200	0	0	Absconded	Pedicle	Allo	Nil			
None	Lu	Mikyle	Male	7	85138329	Posterior C0 to C2 fusion	20-Aug-02	C0	Congenital	Pain/Instability	45	75	2	21	Fusion		Auto	Nil			
PCR/Summit	Simpson	Verna	Female	79	59529289	Posterior instrumented C0-2 fusion and C1 decompression	04-Sep-02	C0	Inflammatory	Pain/Instability	130	300	2.5	48	Fusion	T/A	Auto	C1			
PCR/Summit	Cime	Mangubandile	Male	68	88199732	Posterior C0-2 instrumented fusion	18-Oct-02	C0	Trauma	Trauma	100	150	0	0	Absconded	T/A	Auto	Nil	C1 #		
PCR/Summit	Gaya	Nobublele	Female	41	71921217	Posterior C0-5 instrumented fusion	16-Jul-03	C0	Inflammatory	Myelopathy	150	300	6	24	Fusion	Lateral Mass	Auto	C2			Occ plate lift-off
None	Cakaca	Sandise	Male	12	88517743	Posterior C0-2 posterior decompression and fusion	28-Jan-04	C0	Congenital	Myelopathy	195	250	3	11	Fusion		Auto	C1			
None	Toni	Asanda	Male	16	60882024	Posterior C0-3 decompression & fusion	24-Mar-04	C0	Sepsis	Pain/Instability	75	300	4	36	Fusion		Auto	Nil			
None	Gordon	Janine	Female	13	76839778	Posterior C0-3 fusion	05-Jul-04	C0	Congenital	Myelopathy	120	50	0	0	Deceased		Auto	Transoral			Wound washout, rpt decompressi
	Gordon	Janine	Female	13	76839778	Posterior wound exploration and washout	10-Jul-04	C0													
None	Nkwalase	Zikhona	Female	9	414850000	Posterior C0-C2 fusion with C1 decompression	02-Jun-05	C0	Trauma	Trauma	60	100	2	2	Fusion		Auto	C1	C2 #		
PCR/Summit	Mathee	Petro	Male	59	1111	Posterior Occipito-cervical fusion and decompression (C0-T1)	06-Mar-05	C0	Inflammatory	Pain/Instability	240	1000	6	6	Fusion	Pedicle	Auto	C2-4			Occ plate lift-off
PCR/Summit	Plaatjies	Patrick	Male	38	14048045	Posterior C0-2 instrumented fusion	21-Apr-05	C0	Trauma	Trauma	100	75	3	3	Fusion	Pedicle	Auto	Nil	C1 #		
None	Fredericks	Caryn-Lee	Female	6	14455679	Posterior C0-2 fusion	20-Jul-05	C0	Trauma	Trauma	45	200	1.5	42	Fusion		Auto	Nil	AOD		
PCR/Summit	Cloete	Dina	Female	45	79163879	Posterior C0-5 instrumented fusion and C1 arch removal	14-Sep-05	C0	Inflammatory	Myelopathy	85	100	3	3	Fusion	Lateral Mass	Auto	C2			Penetration
PCR/Summit	Maboee	Bongiwe	Female	25	230505	Posterior C0-C1 instrumented fusion	23-Dec-05	C0	Trauma	Trauma	140	3300	0	0	Deceased	Lateral Mass	Allo	Nil			Vertebral art violation
PCR/Summit	De Lange	Dora Joan	Female	76	94157	Posterior Occipito-cervical fusion	03-Aug-06	C0	Trauma	Trauma	115	250	3	3	Fusion	Translaminar	Allo	C1	C2 #		
PCR/Summit	Broderick	AA	Male	74	99373	Posterio C0-6 instrumented fusion	14-Sep-06	C0	Trauma	Trauma	155	700	5	12	Fusion	T/A	Auto	Nil	C2 #		
PCR/Summit	Jones	Hazel	Female	60	53904298	Posterior C0-2 decompression & instr fusion	19-Sep-07	C0	Inflammatory	Pain/Instability	110	200	7	25	Fusion	Lateral Mass	Auto	C1			Penetration
Axon	Kennis	Kathleen	Female	61	53293007	Posterior C0-2 instrumented fusion	16-Oct-07	C0	Inflammatory	Myelopathy	120	800	6	12	Fusion	Translaminar	Auto	C1			Penetration
Axon	Zizi	Nobathembu	Female	30	88956859	Posterior C0-2 instrumented fusion	17-Oct-07	C0	Inflammatory	Pain/Instability	90	500	12	12	Fusion	Translaminar	Allo			Yes	Penetration
Axon	Smith	Tom	Male	43	20080805	Posterior C0-C2 fusion	05-Aug-08	C0	Trauma	Trauma	275	800	6	6	Fusion	Lateral Mass	Auto		C1 #		Penetration
None	Daames	Erin	Female	5	14081053	Posterior C0-C2 uninstrumented fusion	08-Aug-08	C0	Congenital	Pain/Instability	75	100	4	6	Fusion		Allo				
Axon	Petersen	Denver	Male	31	86402641	Posterior C0-2 instrumented fusion	27-Aug-08	C0	Trauma	Trauma	100	300	3	12	Fusion	Translaminar	Auto		C1 #		Penetration
Axon	Baron	Heinreich	Male	16	89176580	Posterior C0-C2 instrumented fusion	29-Oct-08	C0	Congenital	Pain/Instability	120	250	10	10	Fusion	Translaminar	Auto	C1			Penetration
Axon	Alfreds	Dora	Female	48	56821820	Posterior C0-2 decompression / fusion and C4-6 decompression	10-Dec-08	C0	Inflammatory	Myelopathy	125	300	0	1.5	Absconded	Translaminar	Auto	C1			
Axon	Easton	Denise	Female	59	53802609	Posterior C0-2 decompression and fusion	18-Mar-09	C0	Inflammatory	Pain/Instability	100	200	5	8	Fusion	Translaminar	Auto			Yes	Penetration, minor inf
Axon	Arendse	Anthea	Female	44	64049034	Posterior C0-2 instrumented fusion	09-Sep-09	C0	Inflammatory	Pain/Instability	125	500	7	7	Fusion	Lateral Mass	Auto	Nil			
Axon	Nelson	Magdalene	Female	68	85264380	Posterior C0-2 decompression / instr fusion	30-Sep-09	C0	Inflammatory	Myelopathy	110	100	3	3	Fusion	Lateral Mass	Auto	C1		Yes	Wound washout, DVT, penetration
Axon	Kasolo	Karabo	Male	8	103630588	Posterior C0-2 instr fusion	02-Oct-09	C0	Congenital	Pain/Instability	115	200	0	0	Absconded	Lateral Mass	Auto	C1			
Axon	Schultz	Jennifer	Female	59	938385	Posterior occipital to T1 decompression and instr fusion	12-Nov-09	C0	Inflammatory	Pain/Instability	175	700	3	3	Fusion	Pedicle	Allo			Yes	Superf inf, penetration
None	Jones	Jaden	Male	9	86401502	Posterior C0-2 fusion	13-Nov-09	C0	Congenital	Pain/Instability	40	100	4	4	Fusion		Allo				
Axon	Hoffman	Jacqueline	Female	43	52448578	Posterior C0-2 fusion	2-Dec-09	C0	Inflammatory	Pain/Instability	120	400	3	3	Fusion	Lateral Mass	Auto			Yes	Penetration
Axon	Van Nieuwenhuizen	Danika	Female	1	105418313	Posterior C0-2 instrumented fusion	25-Mar-10	C0	Congenital	Myelopathy	240	100	0	1.5	Ongoing	Pedicle	Auto	C1			
Axon	Twaku	Kirstohn	Male	1	107711533	Posterior C0-3 instrumented fusion	03-Mar-10	C0	Congenital	Myelopathy	120	100	0	1.5	Ongoing	Suture	Auto	C1			