

Surgical Considerations of Rheumatoid Disease Involving the Craniocervical Junction and Atlantoaxial Vertebrae

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1. Introduction

Rheumatoid arthritis is a progressive systemic erosive inflammatory polyarthropathy causing symptoms both as a result of disease progression, (Zikow et al 2005, Gorter et al 2010, Klarenbeek et al 2010), and as result of medical management of the disease process itself (Haugeberg et al 2003). It affects synovial joints in 1% of the world's population (Matteson 2003), with more than 50% of those affected experiencing involvement of the cervical spine (Cabot & Becker 1978, Yurube et al 2011, Garcia- Arias et al 2011) It is characterised by an erosive synovitis, causing destruction of the articular joint surfaces, joint capsules and supporting ligaments for the joints. The atlantoaxial joint is the most commonly affected (Dreyer et al 1999). Though the disease process can cause horrendous morphological change to the cervical joints, with concomitant changes to joint function and stability, neurological dysfunction is surprisingly uncommon. The importance of regular neurological assessment and rapid intervention lie in the rapid progression to disability with the onset of neurological deficits (Rana 1989), allied with a significantly increased mortality rate (Mikulowski et al 1975, Paus et al 2008).

Great strides in the development and evolution of spine surgery techniques and instrumentation have been made treating individuals with cervical and craniocervical junction dysfunction. The complexities encountered when approaching the craniocervical junction of a severe rheumatoid neck, and the anatomical variability of the neural and vascular structures that may be iatrogenically breached (Bruneau 2006) mandate the use of image guidance techniques and/or conductivity detection devices (Kelleher et al 2006) to limit intraoperative risk (Kotani et al 2003, Aryon et al 2008).

The vertebrae of the region most commonly affected by rheumatoid degenerative disease, namely the craniocervical junction and the atlantoaxial joints, have a very complex anatomical relationship with traversing nerves, vessels, and of course the spinal cord (Oliveira et al 1985), and an appreciation of the structure and function of the components of these joints (including how degenerative changes alter the kinematics and structural integrity) is integral to safe surgery in the region.

The most common causes for surgical review of the cervical spine of rheumatoid patients include basilar invagination, atlantoaxial instability and subaxial subluxation (Boden et al 1993). Despite an improvement in spine surgical techniques and technology, rheumatoid

disease of the cervical spine remains a challenging opponent for the modern day spine surgeon. The challenge lies in both the poor general medical condition of most rheumatoid patients with cervical spine dysfunction (Skues & Welchew 1993), and the bone destruction and ligamentous laxity that make instrumentation difficult in all but the most specialists of practices. A predilection for developing post-operative infections also contributes to an understandable wariness on the part of non-specialist neurosurgical/orthopaedic surgeons of embarking on major instrumentation without having ready access to the necessary back-up should complications arise (Lidgran 1973, Grennan et al 2001).

2. Epidemiology of upper cervical spine involvement in rheumatoid disease

Rheumatoid arthritis has a mean age of onset at 50 years old. The first documented case of rheumatoid involvement of the cervical spine was reported by Garrod, who noted clinical evidence of rheumatoid disease in the cervical spines of 36% of his 500 rheumatoid patients. It is a ubiquitous condition, and has a male: female incidence ratio of 1:3. Initiation of combination drug therapy of disease-modifying-agents (e.g. sulfasalazine, methotrexate, hydroxychloroquine, prednisolone) at an early stage in the disease process, before extensive cervical or systemic damage has been caused, has been shown to retard the development of upper cervical subluxations (Neva et al 2000). It has been estimated that cervical involvement occurs in over 60% of rheumatoid cases (Dickman et al 1997), with atlantoaxial subluxation occurring in almost 70% of these cases (Boden et al 1993). Whilst basilar invagination and cranial settling are less commonly seen, the associated neurological deficits can be dire, with wide ranges of associated neurological deficits are reported (Zeidman & Ducker 1994), resulting in an estimated cost per case to the taxpayer of over €9500 per annum in late cases (Westhovens et al 2005). Initiation of combination drug therapy of disease-modifying-agents (e.g. sulfasalazine, methotrexate, hydroxychloroquine, prednisolone) at an early stage in the disease process, before extensive cervical or systemic damage has been caused, has been shown to retard the development of upper cervical subluxations (Neva et al 2000).

3. Cellular / molecular factors

Analysis of synovial tissue specimens taken from affected knee joints reveals a typical finding of 2 distinct cell types: Type A cells contain Golgi complexes and resemble macrophages, whose function is predominately one of phagocytosis, and Type B cells contain a proper nucleus and rough endoplasmic reticulum, whose function is mainly protein synthesis (Rooney et al 1988). The histological analysis of affected tissue in the cervical spine demonstrates that the histopathological process of late rheumatoid progression may be different compared with that of the joints of the appendicular skeleton (O'Brien et al 2002). Analysis of chronic rheumatoid disease in the craniocervical junction reveals ligamentous and bony destruction allied with a replacement of rheumatoid synovium of atlantoaxial and subaxial joints with fibrous tissue. Gross mechanical instability at the heavy-weight-bearing craniocervical junction and atlantoaxial joints is caused by bony destruction and replacement of ligamentous structures, as opposed to the acute rheumatoid inflammatory processes commonly seen in appendicular joints. Craniocervical junction chronic rheumatoid arthritis may be considered to be a progressive mechanical disabling process, as opposed to the metabolically active prevalent in other locations.

4. Radiological assessment of the rheumatoid craniocervical junction and atlantoaxial joint

The most commonly used radiological screening tool in nonspecialist units are x-rays of the cervical spine in maximum flexion and extension. However, many cases of subluxation will only reveal themselves on maximum pain-free flexion and extension views.

Computed tomography (CT) is vital when considering which surgical approach to use when fusing posteriorly with a rod and screw fixation. Anomalies such as anomalous courses of vertebral arteries, the presence of arcuate foramina, a small pars interarticularis of C2, or a small lateral mass of C1 can all be appreciated on review of 3D-reconstruction of contiguous axial images stretching from the inion to C4, with added benefit of being suitable for use also for neuronavigation-aided screw placement (Mayer 2005). Soft tissue windowing allows evaluation of pannus. CT is also the ideal imaging modality for evaluation of rotatory subluxations (Rahimi et al 2003).

Magnetic resonance imaging (MRI) is of particular use when reviewing patients with multilevel rheumatoid involvement or in evaluating cases of cranial settling. When compared with CT, MRI is more accurate in evaluating soft-tissue and pannus. It does however have serious limitations when attempting to evaluate bony anatomy. We have performed dynamic flexion MRIs in the past as suggested by some authors, but haven't found it to be of significantly more use than conventional static MRI (Reijnierse et al 2000) in the majority of cases. It may be suitable for a small number of cases where stability or compression is in doubt. In cases being considered for surgical intervention we advocate x-rays, CT, and MR imaging.

No matter which modality is presented to the clinician, he/she must be aware of the various radiographic measurements used when determining cranial settling and atlantoaxial subluxation. However, these measurements are now largely of academic interest, having been replaced in day to day practice by the direct visualisation of the anatomical structures with MRI. Projection of the odontoid peg tip above McRae's Line is considered abnormal, as is projection of the odontoid peg tip more than 3mm past Chamberlain's line. A Ranawat's distance of less than 13mm is also suggestive of cranial settling (Smoker 1994). Whilst the anterior atlantodental interval has been shown to be of great use when assessing non-rheumatoid patients for the presence or absence of spinal cord compression, rheumatoid cases are quite different. In this group of patients the pannus surrounding the odontoid peg can be quite large, and use of the anterior atlantodental interval may in fact underestimate the amount of spinal cord compression. An atlantodental interval of greater than 10mm suggests an incompetent transverse ligament (Dickman et al 1996). The transverse ligament may be lax, as in rheumatoid patients, or may be breached as is more commonly seen in trauma cases (Dickman. et al 1991). The posterior atlantodental interval has been shown to be a greater predictor of space available for cord, and of severity of neurological dysfunction (Boden et al 1993). Posterior atlantodental intervals of 14mm or more are considered to be the lower limit of normal (Oda, et al 1995). Post-operative radiographic images should be interpreted in the setting of such radiographic and craniometric measurements.

The ease of use and ready availability of MRI scanning to directly visualise the neural elements has largely superseded these measurements.

5. Upper cervical spine anatomy as it applies to screw placement and kinematics in rheumatoid patients

An in-depth knowledge of the unique anatomy in the region of the craniocervical junction and the atlantoaxial joint is mandatory when assessing neck pain or myelopathy of rheumatoid patients, and especially when considering surgical fixation of the region. The thirty two synovial lined joints of the cervical spine make this region of the body especially susceptible to becoming floridly symptomatic in individuals affected by rheumatoid arthritis. The occipitocervical and atlantoaxial motion segments have different biomechanical properties conferred on them through their bony and ligamentous relationships respectively.

5.1 Occipital bone

The occipital bone extends from the clivus anteriorly to the lambdoid suture posteriorly, its embryologic origins being four primary cartilaginous centres laid down in the chondrocranium around the foramen magnum, and a fifth membranous element (Shapiro & Robinson 1976). The superior nuchal line serves as a rough guide for the location of the transverse sinus, and the inion, found in the midline along this line, approximates the torcula herophili. The insertion of the semispinalis capitis may be the most accurate landmark for the confluence of the sinuses (Martin et al 2010). Awareness of the presence of these venous structures lurking beneath the surface of the occipital bone is paramount when placing occipital screws to avoid poor screw purchase and a devastating egress of blood if screw removal is attempted (Roberts et al 1998). The occipital bone is thickest in the midline, with the raised osseous keel being an ideal place to position screws of high pull-out-strength, compared with the thinner more inconsistent lateral portions. Safe regions for locating screws close to the occipital keel are 2cm off the midline at the nuchal line, with an 8mm occipital bone depth being usual, this "safe-zone", however, decreases in width from the midline as one approaches the opisthion (Ebraheim et al 1996). The greater occipital nerve of Arnold is found 15mm off the midline, the importance of preservation through a strict subperiosteal surgical approach lying in posterior scalp numbness or neuralgia should the nerve be damaged (Vital et al 1989).

The occipital condyles, which function as skull-base weight-bearing facets, angle medially and inferiorly at average angles of 55 and 117.5 degrees when viewed from behind (Konig et al 2005). These shape of these condyles positioned on either side of the foramen magnum allow the skull articulate with the cervical spine, whilst the angles prevent excessive axial rotation at the craniocervical junction (Noble & Smoker 1996).

5.2 Atlas

The atlas has its origins in the fourth occipital and first cervical sclerotomes. It is unique among vertebrae in not having a body, is formed from three ossification sites: the anterior arch or centrum, and two neural arches which fuse in later life to become a unified posterior arch, thereby completing the osseous ring which surrounds the spino-medullary junction (Kim et al 2007). An appreciation that this ring is incomplete in up to 5% of patients is important if one is to avoid causing a durotomy or spinal cord injury when approaching the craniocervical junction posteriorly (Torriani & Lourenco 2002, Denaro et al 2010).

The ring of the atlas consists approximately of one-fifth anterior arch, two-fifths posterior arch, with the remaining two-fifths being contributed by the lateral masses (Gray 1918). The

longus colli muscles and the anterior longitudinal ligament, which contribute to anterolateral flexion and resistance to hyperextension of the cervical spine respectively, are attached to the anterior tubercle found in the midline on the anterior arch. Two important membranes also arise from this portion of the atlas: the anterior atlantooccipital membrane connecting the atlas to the occipital bone, and the anterior atlantoaxial ligament extending from the atlas to the axis immediately inferior. The anterior atlantal arch is usually directly opposed to the odontoid peg of the axis. The lateral masses of the atlas have a mean width of 15mm (Dong et al 2003), providing both an adequate avenue for potential instrumentation by the spine surgeon, and allowing support of the weight of the head. Atlantal lateral masses have both a superior articular facet and an inferior articular facet. These true synovial joints allow articulation with the occipital condyles and the axis respectively. The atlantooccipital joints orientation at caudal angles of 129 degrees from lateral to medial limits the rotation possible, compared with the atlantoaxial joint with a cranially biased angulation of between 130-135 degrees, where much greater rotation is possible (Konig et al 2005). A posterior tubercle is found in the midline posteriorly providing attachment for the rectus capitis and the ligamentum nuchae. The posterior atlantooccipital membrane extends from the superior border of the posterior arch of the atlas, to the anterior surface of the rim of the foramen magnum (Fitzgerald et al 2002).

5.3 Axis

The axis is formed from five ossification centres: one in the body, one in each vertebral arch, and two in the odontoid process (Lustrin et al 2003) . It acts as a pivot around which the atlas rotates; the odontoid peg which rises perpendicularly from its body, allowing this unique functionality. The pars interarticularis is found directly adjoining the lateral mass-laminar junction. Successful placement of C2-pars screws mandates appreciation of the borders of this continuous bony area by the operating surgeon. The atlantoaxial joint is

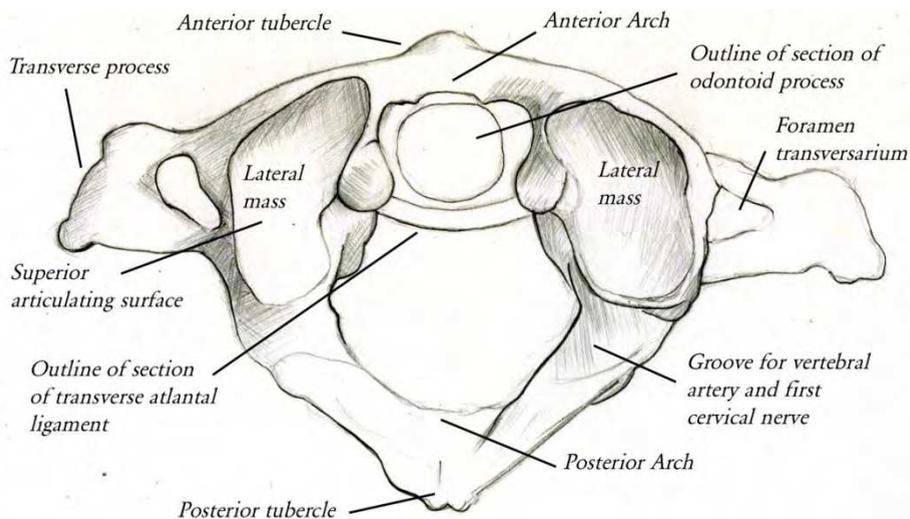


Fig. 1. The Atlas with the odontoid process being restrained by the transverse atlantal ligament.

usually angled 35 degrees oblique in the coronal plane, thereby allowing a consistently safe trajectory stretching from the caudal aspect of the lamina of the axis, through the pars interarticularis of the axis into the atlantoaxial joint, finishing in the lateral mass of the atlas. Pre-operative confirmation of the course of the vertebral artery prior to undertaking any such screw placement will be stressed later in the chapter.

5.4 The vertebral artery

The vertebral artery ascends rostrally through the foramina transversaria from C6 to C2. Prior to entering the foramen at C2 the artery passes under the pars of C2 where it is vulnerable to injury from placement of C2 OR C1/C2 screws. The vertebral artery exits the superior aspect of the axis, and then passes laterally, to pass through the C2 foramen. The vessel at this stage courses posteromedially over the superior aspect of the atlas, where it is vulnerable to injury from overly aggressive dissection by an inexperienced surgeon, before piercing the dura close to the midline and coursing cephalad to the foramen magnum. The left vertebral artery is deemed dominant in 35% of patients, whereas the right side is dominant in 23%. Equivalent vertebral arteries are present in 41% of cases (Menendez & Wright 2007, Tokuda et al 1985). . Particularly in rheumatoid patients the vertebral artery groove is variable in diameter and may encroach sufficiently on the C2 pars to render safe placement of C2 screws impossible.

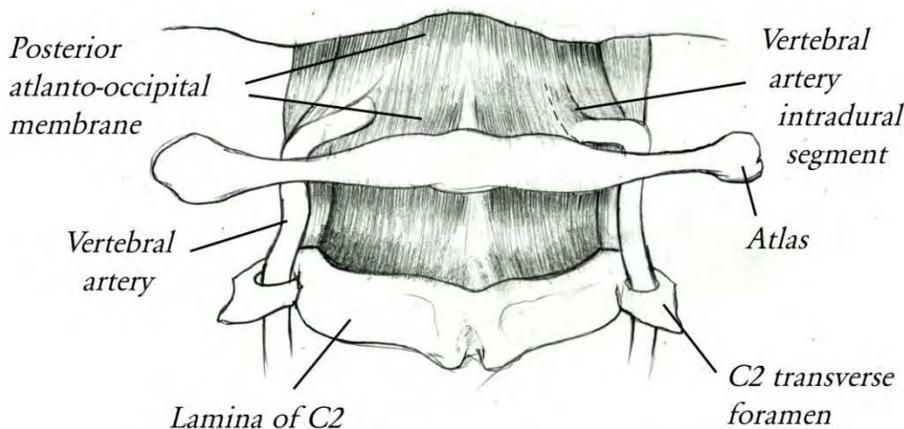


Fig. 2. The anatomy of the vertebral artery during its course from the C3 transverse process to its entry into the spinal dural canal at the level of C1

5.5 Ligaments

The osseous structures described in detail above articulate with each other through synovial joints, muscles, ligaments, and membranes. The slowly destructive process of rheumatoid arthritis is wrought on all of these, but its effects on the regions ligaments are probably the most important of all. A thorough understanding of the role that ligaments play in providing both flexibility & stability to the upper cervical spine is of vital importance when considering whether a patient would benefit from internal fixation, and also when deciding on the optimum approach to be used. The ligaments of the craniovertebral junction may be broadly divided into an extrinsic group consisting of fibroelastic membranes, the

ligamentum flavum between the atlas and axis, and the ligamentum nuchae, and the intrinsic group which consists of the tectorial membrane, the accessory atlantoaxial ligament, the cruciate ligament, the odontoid apical and alar ligaments, and the anterior atlanto-occipital membrane. Our discussion will focus primarily on the intrinsic group due to their importance in appreciating instability in cases of rheumatoid arthritis.

The apical ligament is found in the midline between the anterior atlanto-occipital membrane, has a triangular shape and extends from the tip of the odontoid peg to the anterior most lip of the foramen magnum (Tubbs et al 2000). Though reported to be absent in up to 20% of cadaveric case series, its absence or laxity is not thought to be of functional or structural significance if such abnormality occurs in isolation. The Ligament of Barkow (Tubbs et al 2010) present in 92% of studied cases inserts anterior to the alar ligaments and is often adhered to the anterior atlantooccipital membrane. Its primary function is thought to be in resisting extension of the atlantooccipital joint, acting synergistically to achieve this with the anterior atlantooccipital membrane.

The cruciform ligament is composed of both a longitudinal part (running from upper surface of the clivus to the posterior surface of the body of the axis) and a transverse part (running between the medial sides of the lateral masses of the atlas) arching behind the odontoid peg (Debernardi et al 2011). Its thickness of 2.5mm accounts for its reputation as the strongest ligament in the entire spine (failure strength of 350N), and is composed almost exclusively of collagen fibres arranged in a special lattice arrangement (Miyamoto et al, 2004, Dvorak et al 1988). This ligament functions as the major stabiliser of the atlas, tightly constraining the odontoid peg against the ring of the atlas, thus allowing axial rotation and lateral bending of the C1/C2 junction, whilst restricting flexion. When reviewing trauma radiographs or sagittal MRIs if an increase in the anterior atlantodental space above 3mm is noted, or reduction of the posterior atlantodental distance below 13mm, the clinician must assume that the transverse ligament is not intact.

A pair of alar V-shaped ligaments run from the upper one-third of the dens, where the origin is quite narrow, laterally to insert more broadly on the lateral masses of C1 & the occiput. The mainly horizontal alignment of the collagen fibres and their failure strength at about 200N allow them to restrict axial rotation in the craniocervical junction. The left alar ligament restricts axial rotation to the right, and vice-versa. The tensile strength of the alar ligaments account for the forced coupled rotation of the axis during lateral rotation.

The importance of the great strength of these ligaments is clear when one considers that an intact dorsal ring of the atlas is not required for stability. Instead an intact ventral ring of atlas and intact transverse and alar ligaments suffice for stability at the atlantoaxial junction.

The tectorial membrane is a cranial extension of the posterior longitudinal ligament running from the axis body to the basilar groove of the occipital bone. The central portion of the membrane merges with the dura mater, whilst the lateral portions merge with Arnold's ligaments (Tubbs 2007). A higher proportion of elastic fibres compared with other previously discussed ligaments account for its lack of tensile strength & its minimal contribution toward the stability of the craniocervical junction.

The accessory atlantoaxial ligament runs from the lateral mass of the atlas to the dorsal aspect of the body of the axis and to the occiput. Differences remain in the literature regarding whether this ligament is a part of or separate to Arnold's ligament (Tubbs 2004, Brodin & Halldin 2004). It is thought to play an important role in restricting craniocervical rotation.

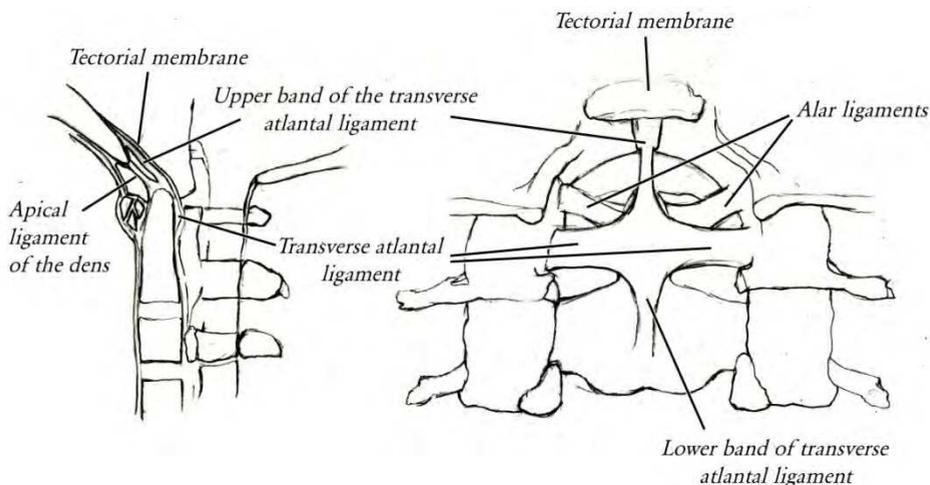


Fig. 3. (a) and (b): The ligaments of the craniocervical junction

(a) Sagittal view showing the posterior longitudinal ligament continuing rostrally as the tectorial membrane

(b) View of the cruciate ligament and alar ligaments, the main stabilisers of the craniocervical junction

5.6 Nerves & their role in causing pain assoc with RA

The greater occipital nerve is the name by which the medial branch of the dorsal primary ramus of the second cervical spinal nerve is better known by. It arises between the atlas and axis, passing between the inferior oblique and semispinalis capitis muscles, through the trapezius muscle, before innervating the posterior scalp. The lesser occipital nerve innervates the lateral scalp posterior to the ear, and is composed of fibres from both the second and third cervical nerves. Occipital neuralgia refers to sharp, shooting pain arising at back of the head or upper neck, and spreading either to the top of the skull, or to the temple region. It may be present bilaterally, and arises usually in rheumatoid patients due to atlantoaxial subluxation or to C2 nerve root impingement by thickened ligaments. Published series have reported incidence rates as high as 30% in rheumatoid patients (Conroy et al 2010). C1 lateral mass screws have been reported as being an iatrogenic cause of such a syndrome also, and needs to be considered in the post-operative period (Conroy et al 2010). The use of nerve stimulators have been associated with a mean reduction of 96% on the visual analogue score (Magown et al 2009), and are the treatment of choice in our institution (in the absence of atlantoaxial instability) post-successful diagnostic occipital nerve blocks.

6. Biomechanics of the upper cervical joints and the influence of rheumatoid changes on joint kinesiology

The atlantooccipital joint's main motion is one of flexion-extension of the head. Extension is limited by the tectorial membrane, and flexion is limited in turn by the dens meeting the foramen magnum lip. Lateral bending averages 4 degrees per side (one-sixth that possible in

flexion-extension at the same joint), and is limited by the atlanto-condylar joint angulation and also by the alar ligaments (Panjabi et al 1988, Bogduk & Mercer 2000, Steinmetz et al 2010). The atlantoaxial joints on the other hand allow significant axial rotation due to the biconvex nature of the joint. Much less flexion is possible at the atlantoaxial joint compared to the occipitocervical joint due to the presence of the transverse ligament (Dvorak et al 1988), whilst extension is limited by the tectorial membrane and the atlantoaxial joint structure itself. Anterior sagittal translation of C1 on C2 is resisted by a combination of the transverse ligament, the alar and capsular ligaments, with the main resisting strength coming from the former (Dvorak et al 1987, Panjabi et al 1991). In the non-pathological state, adult anterior sagittal translation is limited to 3mm at most (Hung 2010).

Significant compromise of the integrity of the transverse ligament-odontoid peg unit is commonly seen in the rheumatoid arthritis patient. Enzymatic degradation causing erosion of the odontoid process have been shown to occur (Scutellario & Orzincolob 1988, Mancur & Williams 1995), a biomechanical process of osteolysis occurring at the odontoid peg base which also causes bony resorption. This phenomenon, consistent with Wolff's Law, occurs in rheumatoid patients due to transverse ligament laxity resulting in significant odontoid peg stress reduction and resultant localised osteopenia (Puttlitz et al 2000). This ligamentous laxity-odontoid osteopenia cycle results in the commonly seen atlantoaxial instability in rheumatoid patients. Puttlitz's study (Puttlitz et al 2000) of a validated fully three-dimensional finite element model of rheumatoid development and progression also suggests a biomechanical mechanism underlying the resorption of lateral masses of rheumatoid atlases. An alteration in the contact force data, resulting in an unloading of the lateral aspects of the atlantoaxial and occipitoatlantal joints will result in localised resorption and osteopenia. The decreased articular joint force transmission is compensated to some extent at least by increased loading of the capsular ligaments, resulting over time in capsular ligamentous laxity through direct mechanical stretching of the capsule fibres. Much greater flexion-extension motion is allowed at an atlantoaxial joint with severe transverse ligamentous laxity, further eroding the lateral joint surfaces through joint range movement beyond the normal limits.

Whilst atlantoaxial ventral sagittal subluxation is a relatively early development in rheumatoid arthritis, cranial subluxation tends to occur at a much later stage (Slatis et al 1989). Ligamentous laxity can on its own result in ventral subluxation, whereas osseous destruction is required in addition to earlier ligamentous derangement, to cause cranial subluxation. A partial collapse of the atlantoaxial facet-joint complexes results in a cranial subluxation of the odontoid process into the foramen magnum. This process of progressive contact of the odontoid peg with the medulla is known as cranial settling when occurring as a result of rheumatoid disease (El-Khoury et al 1980). Identification of the onset of cranial settling is especially important, as it serves as a surrogate marker for patients prone to poorer outcome (Sherk 1978).

Lateral atlantoaxial subluxation occurs in 20% of cases of documented rheumatoid subluxation at the C1-C2 level (Lipson 1984), and is a clear indicator of asymmetric destruction of an atlantoaxial joint. Differing degrees of bone loss result in differing ranges of lateral subluxation. A limit of 2.5mm atlantal lateral subluxation is possible with 1mm loss of atlantal lateral mass or C2 articular surface subchondral bone, whereas if the bone loss depth increases more than 1mm, the lateral slippage can reach up to 5mm, being stopped at this limit only by the odontoid peg reaching the medial surface of the atlas lateral mass.

Posterior dislocation is found in less than 10% of cases of confirmed rheumatoid atlantoaxial dislocation (Lipson 1985). Destruction of the odontoid peg through a combination of previously described biomechanical and enzymatic means, results in the atlas subluxing posteriorly on the axis. The incidence of neurological deficit is very high due to the end position of the posterior arch of the atlas becoming wedged anterior to the spinous process of C2.

Rotatory dislocation is a less studied entity in the setting of rheumatoid disease. It is thought to occur in the setting of unilateral atlantoaxial joint destruction coinciding with severe transverse ligament laxity or destruction (Bouchaud & Liote 2002).

It is rare when assessing a rheumatoid patient to find that the anatomical abnormality can be neatly pigeon-holed into one of the described entities. Far more commonly, patients will have subluxed in a number of axes and directions, a concept of importance when considering instrumenting such cases. As a rough rule of thumb, anterior atlantoaxial dislocation occurs first, followed by cranial settling, before subluxation of C3-C7 occurs in advanced cases (Paimela et al 1997).

7. Indications for surgical intervention

A common question posed at both rheumatology and spine conferences is whether rheumatoid disease of the cervical spine is a surgical entity or not. Most clinicians would agree that the answer to this lies in the precise neurological and radiological findings at time of presentation. The three principal agreed indications for surgical intervention in rheumatoid patients are spinal cord compression, debilitating pain, or significant dislocation on radiology imaging (King 1985, Bland 1990, Bouchaud & Liote 2002).

Spinal cord compression may be noted on either clinical or radiological examination as detailed previously in this chapter. It is indisputable that spinal cord compression visible on radiological examination, in a patient medically fit for anaesthesia and not bedbound, mandates urgent spinal cord decompression and arthrodesis in the presence of neurological deficit. Indeed some authors have stated that such spinal cord compression in patients with neurological deficits is the only indication for surgical decompression (Pellicci et al 1981).

Intractable pain secondary to compression of the greater occipital nerve or the exiting two most cranial nerve roots, or perhaps true neck pain caused by irritation and strain of the synovial joint capsules and joint ligaments, can become debilitating despite maximal medical management (Pellicci et al 1981). Decompression, stabilisation and fusion of the cervical spine is indicated in this group of patients also. We do, however, advise a thorough assessment by a pain specialist and psychologist before embarking on surgical intervention in such cases (Borghouts et al 1998, Edwards et al 2006).

The last, and in our view the most difficult group to gain universal agreement on, are those rheumatoid patients without significant signs or symptoms, but who do display significant subluxation on radiology imaging. Some authors have noted spontaneous radiological fusion occurring on serial follow up, but a significant proportion of these "auto-fused" patients will progress to displaying neurological deterioration. Though the timing of, and indications for, surgical intervention in such individuals remain controversial, many authors advocate decompression and arthrodesis, on the basis that the degree of neurological compromise often does not correlate with the degree of radiological subluxation (Rana et al 1973, Bland 1990, Oostveen et al 1999). Further, arthrodesis with the appropriate technique has been shown to prevent progression, particularly in relation to C1/C2 subluxation

progressing to basilar invagination. Early intervention in these cases may obviate the need for later trans-oral decompression, a much more invasive procedure (Crockard et al 1986). Each case needs individual consideration both of the risks associated with surgical intervention, and also with the substantial risk of neurological compromise and mortality associated with conservative non-operative management (Sunchara et al 1997). Our practice advocates aggressive surgical management of such cases, in the belief that delaying intervention only places patients with impending neurological deficits at an unacceptably high risk of neurological compromise (Matsunaga et al 1976, Pellicci et al 1981, Casey et al 1996), whilst the patient's overall medical condition and mobility deteriorates, thereby raising the risk of inevitable surgical intervention.

Identification of asymptomatic patients likely to progress to neurological deterioration without arthrodesis relies on the experienced spine surgeon liaising with his rheumatology colleagues, and facilitating quick decompression and stabilisation should signs of early myelopathy become apparent. An atlantoaxial dental interval of greater than 10mm is certainly an indication for surgical intervention (Rana et al 1973), though intervals between the 5mm and 10mm need to be considered in the setting for the potential for progression to neurological dysfunction. Conventional trauma-based measurements cannot be extrapolated to rheumatoid patients, given that 5mm AADI is often seen in rheumatoid spines, as opposed to the 3mm limit of normal in unaffected adult individuals (Oda et al 1991, Shen et al 2004). We routinely favour the use of the posterior atlantodental interval as a more accurate screening mechanism for such patients, using a cut-off of 14mm as favoured by Boden et al, to stratify those at high risk of impending neural damage (Boden et al 1993). However, in our opinion, the overriding radiological measure is the presence of significant compromise on MRI imaging.

8. Peri-operative considerations in rheumatoid patients undergoing arthrodesis

A complete assessment of the patient by an internal medicine physician and an anaesthetist is vital prior to the patient undergoing general anaesthesia. Cardiological manifestations such as pericarditis, arrhythmias, and valvular incompetence occur at much greater incidence in this cohort when compared with their peers (Conlon et al 1966, Del Rincón. et al 2001). Similarly rheumatoid patients have twice the mortality rate from pulmonary disease (Gonzalez-Juanatey et al 2003). We do routinely monitor these patients in a high dependency setting postoperatively, until they are stable enough to be transferred to a low dependency and rehabilitation setting. Anaemia is a common finding in patients with well established rheumatoid arthritis (Doyle et al 2000), though in our experience pre-operative transfusion is the exception as opposed to the rule. It is our practice to continue intravenous antibiotics for a period of 3 days post-operatively, with the initial dose being administered at time of induction, due the patients tendency to develop both early and late infections (Maury et al 1988, Wimmer et al 1998, Carpenter et al 1996).

A particularly difficult issue for surgeons to grapple with is the question of when to discontinue disease modifying drugs. Though a recent trial failed to show any significant difference (Grennan et al 2001), these medications had previously been shown to delay wound healing, a most undesirable complication in an already vulnerable group of patients (Abhilash et al 2002, Hamalainen et al 1984). Our practice is to discontinue such medications four weeks prior to surgery, having discussed the case with the patient's rheumatologist.

Such disease-modifying agents are recommenced after a period of 12 weeks to allow the maximum bony fusion to occur around the arthrodesis. The one exception in the disease modifying drug group is glucocorticoids. Rheumatoid patients have commonly been receiving oral glucocorticoids as a adjunct to other agents for a few decades by the time surgical intervention is recommended. By such a stage the hypothalamic-pituitary-adrenal has been completely suppressed, placing them at risk of an Addisonian crisis if such medications are not administered. A large bolus of steroids is usually administered at the same time as that of antibiotics, with "stress-doses" continued for 3 days post-operatively. Due to the severity of the subluxation and deformity seen in the spines of these patients, along with accompanying cricoarytenoid and temporomandibular arthritis (Chen et al 2005, Paulsen 2000), the anaesthetists fibreoptically place the endotracheal tube whilst the patient remains awake.

9. Pre-operative traction

The practice in our unit for a number of years has been to initiate preoperative traction using an MRI compatible HALO ring (Oda et al 1991). This traction is then maintained during the surgical procedure to prevent the loss of valuable millimetres gained during the preceding days in traction, when the patient is being transferred to the operating table. Such millimetres may prove vital in cases of cranial settling and basilar invagination, in improving the degree of medullary compression. Should adequate reduction be possible with the traction, we proceed with a posterior-only decompression and fusion. Adequate and maintained reduction is successful in the majority of cases of rheumatoid atlantoaxial subluxation, as opposed to cases of basilar invagination with concurrent Chiari malformations (Caird & Bolger 2005). In cases of inadequate reduction, we believe our decision to proceed with an anterior odontoidectomy, and subsequent posterior stabilisation, is strengthened despite the slightly greater risks associated with such an approach. Placement of pre-operative tracheostomy and gastrostomy tubes facilitate healing of such anterior approach wounds, whilst allowing regular respiratory toilet and enhanced caloric intake, reducing risks of pneumonia or catabolism.

Rod and screw instrumentation is our favoured method of treating instability in the upper cervical spine. Techniques such as sublaminar wiring, loops or autologous grafting do not provide immediate stability, thereby mandating prolonged use of impractical HALO-vests or hard collars. A rapid return to mobilisation achievable through use of a variety of rod and screw arthrodeses will optimise the chances of a full return to independent living in this vulnerable patient cohort.

The goal with all of the surgical techniques used to treat rheumatoid cervical disease is to restore or preserve neurologic function. The precise technique used by the surgeon to achieve this will depend both on the individual radiological findings and on surgeon preference.

10. C1C2 Transarticular screws

In cases of atlantoaxial subluxation, without evidence of cranial settling, we advocate stabilisation of the C1-C2 segment through the use of transarticular screws (Krauss et al 2010). Careful scrutiny of preoperative CT imaging will identify cases where such screw trajectories are dangerous or impossible, such as abnormal positioning of the transverse

foraminae or aberrant vertebral artery (Ebraheim et al 1998, Golanki & Crockard 1999, Nagaria et al 2009). We routinely use stealth neuronavigation when planning screw trajectories to minimise the risk to both vertebral arteries and neural structures. In our experience myelopathic patients who have successful reduction and immobilisation of the C1/C2 segment will not require laminar decompression. In cases of aberrant vertebral arteries we place a unilateral transarticular screw, with a lateral mass screw in C1 and a pars screw in C2 being placed on the "aberrant" side, if safe to do so, however, an aberrant vertebral artery can also preclude safe C2 pars screw insertion and we have not experienced any failures over a 15 year period with unilateral screw placement. Though some authors routinely reinforce their constructs with a Gallie or Brooks fusion, this has not been our practice. Successful placement of bilateral transarticular screws provides 38mm of fixation which more than adequately stabilises the segment (Yoshida et al 2006), without the added 5 - 7% risk of neurologic injury associated with wire constructs (Ebraheim et al 2000).

Having applied the Mayfield skull clamp either to the skull or to the halo ring itself if previously applied, an image intensifier is used to confirm correct alignment of the atlantoaxial joint and the subaxial cervical spine. A midline posterior incision from C1 arch to C2/C3 spinous interspace level is followed by a subperiosteal exposure of both atlas and axis, and of the occiput itself in cases of occipitocervical fusion. The posterior arches of C1 and C2 are exposed at C1 as far laterally as the medial border of the lateral mass and inferiorly as far as the C2/3 joint avoiding disruption of the joint itself. The destruction wrought by the rheumatoid inflammatory process on the normal anatomical landmarks of the atlas and axis makes placing C1-C2 screws without the use of neuronavigation hazardous at best, and foolhardy in some cases. The pars of C2 is exposed subperiosteally as far as the C1/C2 joint remaining anterior to the traversing C2 root. Blunt dissection along the superior aspect of the C2 lamina allows the operator to appreciate the medial aspect of the C2 pedicle. Successful identification of the C2 pedicle and the pars as it extends superiorly toward the C1-C2 articulation, allows a safe entry into the C1-C2 joint. It is important in this area to maintain a subperiosteal approach with a sharp dissector to avoid venous haemorrhage. The joint may be entered, curetted and graft inserted directly. This step may be facilitated with the use of an operating microscope. It has been our practice to perform this additional step where the space between the articular surfaces of C1 and C2 allow it, particularly in those cases with incomplete reduction of C1 on C2. The approximate entry point for transarticular screw placement is 2mm lateral to the medial border of the C2-C3 facet joint. Stab incisions as per image guidance bilaterally allow the desired screw trajectory aiming toward the upper half of the C1 anterior tubercle. Use of neuronavigation to confirm screw trajectory minimises the danger of encountering either the vertebral artery (which may easily be damaged with a lateral or inferior trajectory (Geremia et al 1985) or the spinal cord. The vertebral artery is most at risk from a trajectory that is too low rather than one that is too lateral. This is especially important in cases when incomplete reduction of C1 and C2 has been achieved where an anterior target above the tubercle of C1 should be chosen. In these cases the choice of the anterior tubercle of C1 as a target causes a low trajectory through C2 with the risk of cortical perforation inferiorly. If this is kept in mind, incomplete reduction of C1 on C2 does not preclude C1/C2 transarticular screw fixation. An image-guided drill-guide is passed percutaneously to the posterior arch of C2, and aligned with the planned entry point on the neuronavigation. A guide K-wire is drilled

into C2 using the drill-guide, and using lateral fluoroscopy to identify the trajectory to C1 through the C1-C2 joint toward the anterior tubercle of C1. Self-tapping screws are passed over the K-wire, which is then safely removed. In cases of incomplete reduction, lag screws (partially threaded screws) may be used to improve the reduction.

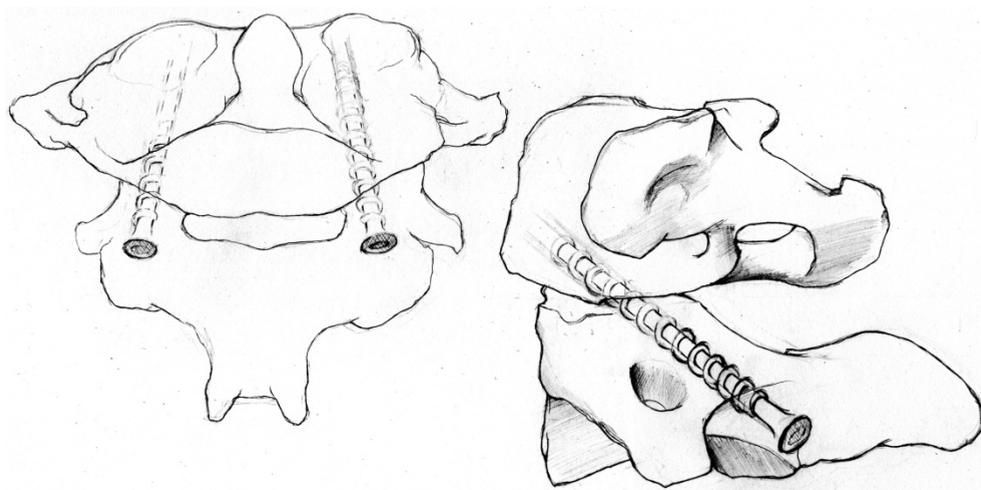


Fig. 4. Trajectory of transarticular screws aiming toward the upper anterior.

Given that up to one-fifth of patients will not be suitable for bilateral safe placement of C1/C2 transarticular screws due to abnormal vertebral artery position (Wright & Laurysen 1998), all available technologies to reduce the risk of potentially catastrophic vascular injury must be made available to the operating surgeon. The first clinical series involving the use of image guidance in C1/C2 transarticular screws demonstrated no neurovascular injuries in a series of 84 screws (38 bilateral and 8 unilateral) performed in 46 patients with atlantoaxial instability due to rheumatoid arthritis (Paramore et al 1996). Preoperative planning using the contiguous axial images allowed careful planning of the screw trajectory; keeping in mind the position of the intraosseous portion of the vertebral arteries, the diameter of the pars interarticularis and the quality of bone in the axis.

Independent review of postoperative radiographs by consultant radiologists confirmed good screw position in all instances. In 8 cases pre-operative assessment demonstrated a pars diameter which precluded the safe placement of a C2 pars screw, so alternative posterior stabilisation methods were undertaken on the reduced pars diameter side. Such is the biomechanical strength of a properly placed transarticular screw, however, that both in our own practice and those of other authors excellent results have been achieved with a unilateral transarticular screw and Philadelphia collar (Wigfield & Bolger 2001).

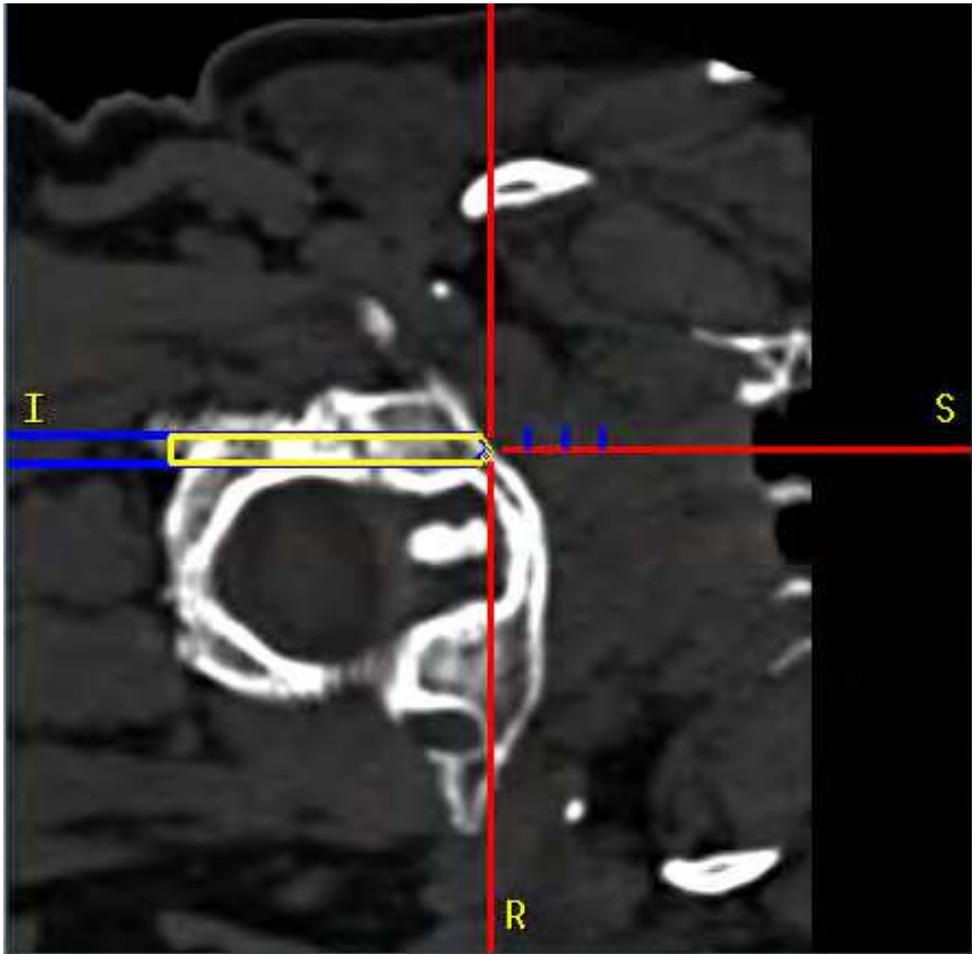


Fig. 5. Neuronavigation trajectory planning of a C1 screw



Fig. 6. Lateral radiograph demonstrating bilateral C1C2 transarticular screw placement

11. Occipital-cervical fusion

The occipitocervical junction (consisting of the occipitoatlantoaxial complex) is a multi-joint complex of 4 synovial joints. An important biomechanical nuance to be overcome when fusing this joint complex is the sharp angle between the occiput and the upper cervical spine readily appreciable on lateral x-rays or MRI sagittal views. This sharp angle makes access to the joints quite challenging in rheumatoid patients and also contributes, along with the 5kg weight of the head, to a large moment arm necessitating the most rigid of constructs. Unfortunately fusion and immobilisation of this junction will eliminate up to 50% of the normal range of motion of the head and neck. Our main indication for such "drastic" reduction in mobility in rheumatoid patients is in cases with a large ventral pannus causing cord compression.

The most common complications, other than infection and persistent neck pain, are fixation of the patient's head in an excessively flexed or extended position, thereby increasing the risk of falls in an already vulnerable and sometimes unsteady patient cohort. Our practice of placing these patients pre-operatively in a HALO-brace will accomplish the dual goals of checking whether the ventral compression is relieved on distraction (through visualisation of CSF anterior to the cord on MRI), and will allow the physiotherapists to check patient safety on mobilising.

Though historically the cervical fixation was achieved with interspinous wiring or lateral mass wiring in combination with preformed rods such as the Ransford loop, our practice is to use lateral mass or transarticular screws, with off-set connectors if necessary as the bony anatomy is commonly distorted in rheumatoid patients. These more modern techniques have demonstrated higher fusion rates (Shad et al 2002, Kelleher et al 2008) and lower pseudoarthrosis rates (Abumi et al 1999) when compared to their wire-based predecessors.

Surgeons now have a choice of 2 types of occipital fusion systems. The older "Grob-style" plating system utilises the thick keel-like midline portion of the occipital bone, with the inverted Y-shaped plate being fixed to the occipital midline through a set of predetermined screw positions. The greater thickness of the bone in this location increases the pull-out resistance. We favour such plating systems where the occipital bone is intact. Our practice, however, involves treating patients who have commonly undergone previous suboccipital decompression, with loss of this midline portion of occipital bone. In such cases we more commonly utilise an "all-in-one" cervical rods with integrated occipital plates which are secured to the previously placed lateral mass/transarticular screws with locking cap screws. This construct allows the use of bicortical polyaxial screws of differing length, and also allows the surgeon to vary the screw position and trajectory. This 2-plate occipital fixation provides more rotational stability than the mid-line only Grob-plate occipital fixation. A variation on this solution is the use of modular plate rod constructs allowing a further degree of surgical screw-placement freedom.

No clear biomechanical data exists regarding where the caudal-most screw fixation point ought to be placed. Our practice is to have at least 3 solid lateral mass screws or a transarticular screw and 2 lateral mass screw fixation points on each side of the subaxial spine to. The published literature does not give any guidance on which patients may be treated with constructs that end at the axis, and which patients require subaxial stabilisation as part of an occipitocervical fusion. Martin et al's (2010a) cadaveric study suggested that occipital plate and transarticular screw constructs restricted motion equally well whether or



Fig. 7. Occipitocervical fusion utilising transarticular screw fixation of the axis

not subaxial fixation were included as part of the construct. Criticisms such as the female-only nature of the cadaveric specimens and the use of non-contiguous subaxial fixation points have been robustly refuted by the authors as being of limited clinical relevance.

Nowhere in spine surgery is the concept of ultimate mechanical fatigue and subsequent failure of greater importance than at the occipitocervical junction. The large moment arm generated with an adult head and the steep angles required in excessively lordotic porotic rheumatoid cervical spine account for these high failure figures. We use a combination of the autologous bone-chippings on the decorticated bone surfaces, and osteoconductive and osteoinductive bone void-fillers superimposed on our construct to maximise the chance of securing bony fusion. Osseous fusion is necessary for ultimate success of this procedure, as in its absence metal fatigue and subsequent catastrophic construct failure is virtually guaranteed. Rigid internal fixation at time of surgery obviates the need for use of post-operative HALO-bracing, though a custom-fitted Miami-J collar beneath the patient's chin will prevent premature excessive neck flexion and screw pull-out. Careful adherence to a professionally devised and supervised nutrition programme is also part of any follow-up



Fig. 8. Occipitocervical fusion using a transarticular screw fixation of the C1C2 complex, and lateral mass fixation of C3-C7. The construct was extended into the upper thoracic levels. Note that single screws were only possible at the C3 and C4 levels

schedule after such fusions to enhance healing rates. Despite poor bone quality we have not encountered any incidents of screw pull-out or construct-failure in our published series of rheumatoid cervical fusions (Heller et al 1991).

12. C1 Lateral mass screw placement

Though we prefer to use C1/C2 transarticular screws, anatomical or surgical circumstances pertaining to this challenging patient cohort occasionally mandate the use of C1 lateral mass screws. C1 lateral mass screws are technically demanding, but we do use them regularly in cases of rheumatoid C1-2 fusions. These may be inserted in cases in which transarticular screws are contraindicated because of anatomic constraints. Such cases include patients with anomalous vertebral arteries, though in such cases it is essential to show on 3D CT that placement of a C2 pars screw is possible. Seventeen (18%) of 94 patients had a high-riding transverse foramen on at least one side of the axis that would prohibit the placement of conventional C1/C2 transarticular screws (Mummaneni & Haid 2005, Nagaria et al 2009). C1 lateral mass screw-rod constructs are preferred over conventional atlantoaxial transarticular screws by certain authors due to a variety of factors (Paramore et al 1996, Currian & Yaszemski 2004). The C1 lateral mass screws can be inserted before reduction of the atlantoaxial joints, thereby enabling the surgeon to use the screws as method of achieving a reduction. The screws do not violate the C1-2 joints, and therefore they can be used for temporary immobilization in trauma patients; however this is not a consideration in the rheumatoid patient. C1 lateral mass screws can also be used when the C1 arch is deficient. The presence of an arcuate foramen (ponticulus posticus) in the atlas, seen in up to 18% of cases, through which the vertebral artery and first cervical nerve traverse, precludes the use of this technique (Gunnarsson et al 2007).

Beginning the passage of C1 lateral mass screw can be quite a challenge due to the almost constant presence of a venous plexus at the insertion site caudal to the posterior lateral arch of the atlas. We use a combination of Surgicel and thrombin glue to achieve haemostasis, and a slightly more rostral entry point, on the posterior lateral arch itself using a pneumatic drill to drill away the undersurface of the posterior lateral arch. Using such an entry point, in conjunction with neuronavigation, allows one to avoid the vertebral artery and spinal cord, whilst also avoiding the worst of the bleeding from the venous plexus. Such an approach is possible in over 85% of cases (Huang & Glaser 2003). The internal carotid artery and hypoglossal nerve lie over the anterior aspect of the lateral mass of the atlas and are at risk from bicortical C1 lateral mass screws. Some authors have advocated use of unicortical C1 lateral mass screws in order to avoid such potential complications. Such opinions are supported by biomechanical data showing greater pull-out strength of both unicortical and bicortical C1 lateral mass screws compared with subaxial lateral mass screws. Our practice however is to aim for bicortical purchase, given the absence of adequate comparative data for rheumatoid patients, and the greater risk of screw pullout due to the tendency of the underlying rheumatoid disease to cause osteoporosis of the vertebrae (Wordsworth et al 1984, Lee et al 2006).

13. Anterior approaches

The most common indication historically for anterior approach to the craniocervical junction in rheumatoid patients was to perform a transoral odontoidectomy in cases of brainstem

deformity caused by a fixed kyphotic deformity. Recent authors have published their series demonstrating that such an approach is not necessary if pre-operative traction is successful in reducing the kyphosis, given that the pannus causing the deformity resolves after a posterior immobilisation procedure (Martin M. et al 2010, Nagaria et al 2009). We reserve odontoidectomy for such cases of failed reduction with traction, concentrating on eliminating the medullary kink through resection of the odontoid itself, the body of C2 and a portion of the clivus, if necessary. Our practice is to confirm adequate medullary decompression with a post-operative MRI, before proceeding to a posterior stabilisation as a second procedure. Rheumatoid patients unfortunately are often unsuitable for this transoral approach to such ventral pathologies, due to an inability to open their mouths the required minimum of 2.5cm, or perhaps due to a fixed flexion deformity of their unstable cervical spine precluding adequate surgical access. Advantages of this approach include the presence of pannus usually being within 1.5cm of the midline (Grob et al 1997). The preparatory work and initial steps involving adequate neck extension in traction, use of Crockard transoral retractors to minimise swelling of tongue and lips, along with the midline posterior pharyngeal incision are described elsewhere (Fessler & Sekhar 2006). We often use a posterior pharyngeal flap allowing for greater exposure and less mucosal trauma from retraction.

A few salient anatomical points related specifically to removal of the rheumatoid pannus are warranted however. Direct incision over the tubercle of the atlas is vital as a first step to avoid straying off the midline, and placing neighbouring neural and vascular structures at significant risk. Once the anterior arch of C1 is removed, we dissect laterally to fully identify the borders of the Peg prior to beginning removal. In this way anatomical awareness is maintained throughout the procedure. Many authors advocate separating the peg inferiorly and delivering the upper end by pulling the, disarticulated, inferior end out, towards the surgeon. However we think that this practice is potentially dangerous with the tendency for the superior end of the peg to be displaced posteriorly into the medullary tissue during the manoeuvre. Our practice is to directly expose the upper end of the peg so it may be immobilised prior to any extraction manoeuvre.

Other authors stress the importance of closing the pharyngeal structures in 2 layers (Crockard et al 1986). We have found this almost impossible to achieve, due to the poor quality of the mucosa in these patients, particularly after prolonged retraction. We have routinely closed the posterior pharyngeal mucosa in a single layer without complication.

14. Subaxial instability & lateral mass screws

Inclusion of subaxial points of fixation as part of an occipitocervical or atlantoaxial fusion may be required depending on the individual case. Post-operative follow-up is of the utmost importance in rheumatoid patients. Nowhere is this demonstrated more readily than in severe rheumatoid patients who have undergone craniocervical fusions involving only the atlas and axis. Such constructs whilst immobilising the spine at the upper motion segments, will accentuate the stresses experienced in the subaxial levels, and accelerated adjacent level breakdown may be seen (Smith et al. 1972). The ligamentous laxity so commonly seen in these patients, allied to uncovertebral joint synovitis, further promotes a rapid degenerative process. Due to this tendency we advocate extending the level of fusion to the upper thoracic spine. Our practice is to extend the construct to T2 at least if we encounter a cervical spine that has undergone significant degenerative change; should the

subaxial spine be relatively intact, and the subluxation be confined to the atlantoaxial joint, then we advocate simply performing a single level fusion. Avoiding including the very heavy skull and inferior subaxial levels will accomplish the dual goals of eliminating atlantoaxial subluxation, whilst also avoiding the creation of a very large moment arm about the fusion endpoint. If fixation to the skull is necessary we may extend the subaxial fixation as far as C4, but any longer fixation mandates extension of the fixation to T2. An intermediate level of fixation will produce a large moment arm with almost certain failure of the construct at its lower end. Our own series of 37 consecutive rheumatoid patients, with a minimum follow-up of 7 years post transarticular screw placement for atlantoaxial subluxation, demonstrated a 90% success rate in relief of neck pain and occipital neuralgia symptoms (Nagaria et al 2009). In our case series we defined "success" as at least a 50% reduction in the VAS. Both the Myelopathy Disability Indices and the Ranawat myelopathy score showed significant postoperative improvement. Bony fusion and stability was noted in 97% of cases on follow-up CT imaging and flexion/extension radiograph views of the C1/C2 motion segment.

Though described initially by Roy-Camille slightly more than thirty years ago (Nagaria et al 2009), lateral mass screws have been the posterior fixation method of choice for the majority of spine surgeons for the past 20 years. Lateral mass fixation has the advantage over wiring or laminar screw techniques in that it may be used in conjunction with laminectomies or laminoplasties. A disadvantage is the proximity of the vertebral artery, the exiting spinal nerve root, and indeed the cord itself. In the original description, Roy Camille proposed an entry point in the middle of the lateral mass, and a drill/screw trajectory 10 degrees lateral from the parasagittal plane. In an average patient, a screw length of 14-16mm will achieve the bicortical purchase so important in these commonly osteoporotic patients. A number of variations on the concept, involving slightly different entry points and trajectories have been described, but the end-results are biomechanically broadly similar (McKibbin 1979, Xu et al 1998), and all techniques have at their core an emphasis on placing the screw trajectory away from the nerve root and vertebral artery.

The Magerl technique describes the entry point as being 1mm medial to the centre of the lateral mass, and then angling the drill 20 degrees cephalad and 30 lateral trajectory. The vertebral artery usually lies anterior to the longitudinal depression or valley found in all cervical vertebrae between the laminae and lateral masses. Placing your entry point medial to the centre point of the lateral mass will lessen the risk of encountering the vertebral artery and nerve roots, whilst also maximising your screw length, thereby increasing the overall stability of your construct. Further variations of this original technique include the Anderson technique with entry point also 1mm medial to the mid-point and trajectory 10 degrees lateral in a rostrocaudal plane parallel to the facet joint.

Our lateral mass screw placement and trajectory is slightly different to these previously described techniques, with our focus being on achieving the longest possible bicortical screw placement through the lateral mass, whilst avoiding the nerve root or vertebral artery. To this end, we make our entry point at least 3 mm medial to the lateral mass midpoint, commonly along the lamina-lateral mass junction "valley", and then steeply angle laterally and caudally at angles of 30 degrees and 45 degrees respectively. Resting the drill guide on the spinous process of the inferior vertebra is a reasonable rule-of-thumb for the required trajectory (Varrey et al 2004), though in deformed rheumatoid patients especially this rule may not be completely reliable. In our experience it is often necessary to remove the tops of the spinous processes to achieve the required "back-and-out" drill slant. Previous

biomechanical studies have shown the more laterally divergent screws of the Magerl technique to have greater pull-out strength compared with the 10 degree Roy-Camille screw (Chin et al 2006), and we believe that our own variation on this with increased screw length at least partly accounts for our success in achieving fusion despite significant comorbidities (Heller et al 1991).

Inclusion of the C7 lateral mass may be required in a minority of cases. In such instances the surgeon's task is eased somewhat by the absence of the vertebral artery from the vertebral foramen, but it must be borne in mind that the C7 lateral mass is the smallest of all in the cervical spine. For this reason placement of a C7 pedicle screw with a 30 degree medial and perpendicular rostrocaudal trajectory is our usual practice. Should the occiput be included in such constructs however we advocate inclusion of at least T1 and T2 in the construct due to the dangers (screw pull-out and kyphosis) of stopping such a large moment arm at a transition junction. Careful review of 3D CT cervical spine pre-operatively will allow the surgeon to gauge pedicle size, and also recognise any aberrant vertebral artery anatomy.

15. Use of PediGuard™

Misplacement and breach of pedicle cortex occurs in approximately 20% of attempted screw placements. Given the much softer consistency of rheumatoid bones, and the importance of avoidance of creating any false tracts down narrow pedicles, it is of utmost importance to ensure that each "screw placement counts". A screw which breaches the pedicle will not be able to contribute its required resistance to flexion, extension or torque forces, and so will significantly weaken the entire construct, perhaps even placing the patient at risk of



Fig. 9. PediGuard™ Picture

developing a significant neurological morbidity. Our practice when placing pedicle screws in such patients is to utilise the Pediguard™, a device which doubles both as a hand-held awl and which also detects changes in electrical conductance at the device tip. Variation of conductivity occurs when passing between different media, such as exiting the osseous pedicle into surrounding soft-tissue, as occurs during an iatrogenic pedicle perforation. Our series demonstrated a sensitivity of >98% in detecting breaches, more than twice the rate reported by surgeons performing the same surgeries (Bolger et al 2007, Anzhsn 2011).

16. Conclusion

Rheumatoid arthritis affecting the craniovertebral junction and subaxial cervical spine remains a challenging surgical entity despite recent technological advances. Such cases need a pre-operative assessment by a multi-disciplinary team to ensure adequate medical optimisation prior to such invasive procedures, thereby limiting the risk of post-procedure medical deterioration. Symptomatic instability may require instrumentation, and success in such cases depends on the specialist knowledge of the unique altered bone morphology and the plethora of traversing neural and vascular structures. An appreciation of the biomechanical forces which instrumented constructs in this area experience is mandatory if a safe solid pain-free end-result is to be achieved.

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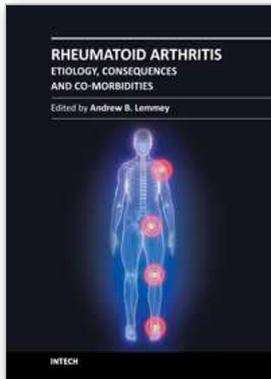
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The purpose of this book is to provide up-to-date, interesting, and thought-provoking perspectives on various aspects of research into current and potential treatments for rheumatoid arthritis (RA). This book features 16 chapters, with contributions from numerous countries (e.g. UK, USA, Japan, Sweden, Spain, Ireland, Poland, Norway), including chapters from internationally recognized leaders in rheumatology research. It is anticipated that Rheumatoid Arthritis - Etiology, Consequences and Co-Morbidities will provide both a useful reference and source of potential areas of investigation for research scientists working in the field of RA and other inflammatory arthropathies.

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