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ORIGINAL ARTICLE

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A technique for frameless stereotaxy and placement of transarticular screws for atlanto-axial instability in rheumatoid arthritis

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Abstract The aim of the present study was to outline a new surgical technique and describe how, in a clinical setting, computer-generated image-guidance can assist in the planning and accurate placement of transarticular C1/C2 screws inserted using a minimally invasive exposure. Forty-six patients with atlanto-axial instability due to rheumatoid arthritis underwent posterior stabilisation with transarticular screws. This was achieved with a minimal posterior exposure limited to C1 and C2 and percutaneous screw insertions via minor stab incisions. The Stealth Station (Medtronic Sofamor Danek, Memphis, Tenn., USA) was used for image guidance to navigate safely through C2. Reconstructed computed tomographic (CT) scans of the atlanto-axial complex were used for image guidance. It was possible to perform preoperative planning of the screw trajectory taking into account the position of the intraosseous portion of the vertebral arteries, the size of the pars interarticularis and the quality of bone in C2. Screws could be inserted percutaneously over K-wires using a drill guide linked to the image-guidance system. Preoperative planning was performed in all 46 patients and accurate registration allowed proposed screw trajectories to be identified. Thirty-eight patients had bilateral screws inserted and eight had a unilateral screw. A total of 84 screws were inserted using the Stealth Station. There were no neurovascular injuries. This technique for placing transarticular screws is accurate and safe. It allows a minimally invasive approach to be followed. Image guidance is a useful adjunct for the surgeon undertaking complex spinal procedures.

Keywords Atlanto-axial · Cervical · Image guidance · Instability · Screws

Introduction

The atlanto-axial complex is the most mobile section of the spine, and treatment for instability of this region is technically challenging. In 1987, Magerl and Seemann [19] introduced transarticular screw fixation of the atlanto-axial joint and this procedure has gradually increased in popularity amongst spinal surgeons. The indication for surgical intervention is instability with the potential for neural or vascular compromise and pain. Such instability may result from rheumatoid arthritis, fractures of the odontoid, fracture dislocation or involvement of the odontoid with tumour. The technique of transarticular screw fixation may also be suitable for patients who would otherwise be unable to tolerate a halo jacket [15]. The technique of transarticular screw fixation is hazardous from a number of perspectives and usually is contraindicated in the presence of abnormal anatomy.

There is the potential to cause neural damage in addition to traumatising the vertebral arteries, with all of the inherent consequences that would involve [26]. Also, torrential haemorrhage from the surrounding venous plexuses can occur. A further complicating factor relates to the quality of bone stock for placement of the screws, which may be less than optimal in the case of metabolic bone disease, tumour invasion or trauma [17, 26].

It is well recognised that accurate preoperative assessment of the region radiologically is essential prior to embarking on surgery [9, 17, 20]. Thin-section computed tomographic (CT) scans of the C1/C2 region can be examined to evaluate the bony morphology.

Foley et al. [11] have demonstrated that applying the Stealth Station (Medtronic Sofamor Danek, Memphis, Tenn., USA) to reconstruct CT images can provide useful information regarding the proposed trajectory of the screws and any hazards likely to be encountered; for example, anomalous vertebral arteries. Accurate spinal image guidance has recently been applied to a number of techniques, including anterior cervical surgery, lateral mass plating and pedicle screw insertion [3, 4, 5].

This paper describes an in vivo technique for the image-guided insertion of C1/C2 transarticular screws. To date no clinical series involving the use of image guidance in C1/C2 has been described.

Materials and methods

In our neurosurgical unit we have applied image-guidance surgery using the Stealth Station to 46 patients with rheumatoid arthritis affecting the atlanto-axial complex associated with gross instability for placement of transarticular screws. In 31 cases, this was identified during preoperative screening for other orthopaedic procedures. A further six patients presented with myelopathy, and nine experienced pain of cervical spinal origin. All cases were associated with atlanto-axial subluxation. The key role for image guidance in transarticular screw fixation of C1/C2 is for planning and guiding the appropriate trajectory for safe screw passage through C2. The aim is to avoid the intraosseous course of the vertebral arteries, and to prevent breech of the cortex into the spinal canal or encroachment onto the C2 nerve root.

The Stealth Station (Medtronic Sofamor Danek, Memphis, Tenn., USA) is a computerised surgical navigation system that can reconstruct CT or magnetic resonance images in any of three planes, or produce three-dimensional images (Fig. 1). Surgical tools are tracked in relation to fixed reference arms using light-emitting diode (LED) arrays. The position of the tip of the instruments and a projected virtual trajectory are displayed on a screen giving the operating surgeon real-time information that can be of assistance during the procedure [11] (Fig. 2). Computer-guidance systems for spinal surgery have been shown to have a registration accuracy of less than 1.5 mm and a mean orientation of 1.5° [1, 10].

Preoperative planning for stabilisation using CT images of the C1/C2 complex are taken and reconstructed using the image-guidance system for each patient. Images are obtained with zero gantry angle tilt, an axial slice thickness of 1.5 mm and no overlap of slices. The raw data are transferred via ethernet to a Stealth Station. Three-dimensional reconstruction of the data is performed on the Stealth Station, and points are selected for later point matching during the registration process. From these images, it is possible to plot the proposed optimal trajectory for placement of bilateral transarticular screws, taking into account the dimensions of the pedicles, the course of the vertebral arteries and the quality of bone stock.

Surgical technique

A limited exposure of only C1 and C2 is undertaken based on the technique of McGuire and Harkey [20]. The reference frame with LED array detectable by the infrared camera is attached to the

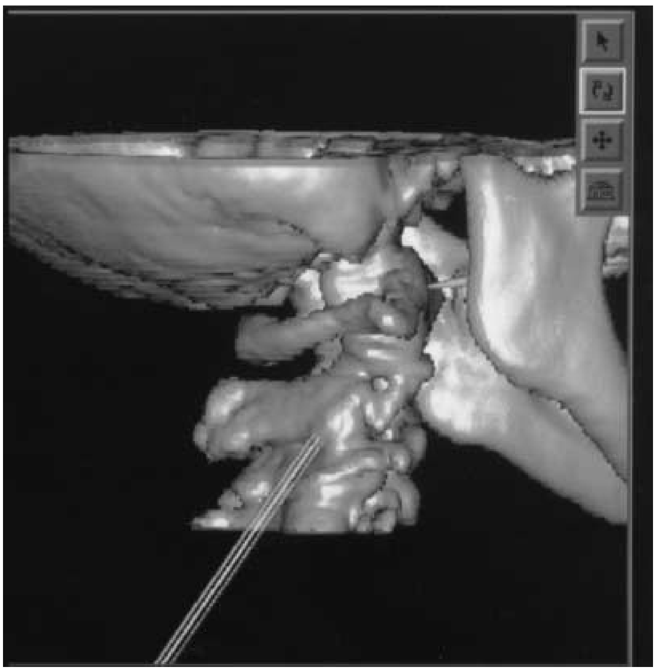

Fig. 1 Three-dimensional reconstructed image illustrating proposed entry point on C2 for transarticular screw insertion

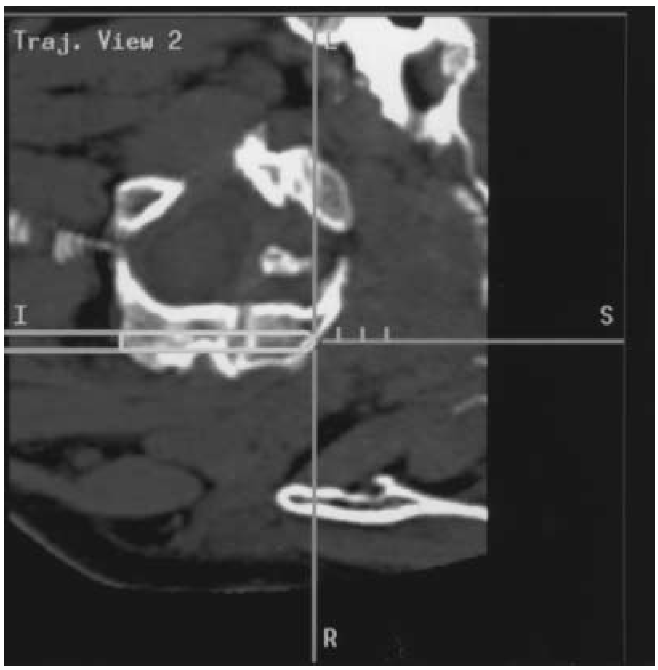

Fig. 2 Two-dimensional image showing proposed screw trajectory past the vertebral artery groove in C2 into the anterior arch of C1

spinous process of C2, and the Stealth Station is registered to C2 alone. Registration is achieved by matching five points on the posterior arch of C2 with pre-selected concordant points identified on the preoperative images. The exact points selected vary from patient to patient, and are dependent on individual patient anatomy. Any point that is visible on both the actual arch of C2 and the preoperative scans is acceptable. However, best results are achieved if the points are as widely separated as possible. Suitable points include the tips of the spinous process and the borders of the C2/C3 articular joints. This is combined with a surface matching registration. A registration accuracy of under 1.5 mm is accepted for image guidance application. Careful dissection along the medial border of the C2 pedicle exposes the C1/C2 joint on each side. The joint is curetted to remove cartilage, and bone graft inserted. Two small stab wounds are made at locations identified by image guidance to give the necessary trajectory for screw insertion. A drill guide with LED array attached is inserted. The drill guide internal diameter is capable of delivering percutaneously to the posterior arch of C2 not only the drill, but all other tools necessary for the procedure, including screws and screw drivers. K-wires are inserted through C2 via the drill guide. Tracking the drill guide rather than the K-wires or drill itself ensures that any movement error associated with K-wire bending is eliminated. Drill holes are tapped and 4-mm cannulated screws are passed over the K-wires and screwed through the pars interarticularis under image guidance control along the preoperatively determined path, avoiding the course of the vertebral arteries whilst simultaneously avoiding breach of the cortex of the vertebrae into the spinal canal. In cases where C1 is subluxed and can be manually reduced back onto C2, the C-arm image intensifier is used to obtain adequate reduction of C1 on C2. Reduction can be achieved by gentle traction on C1 while simultaneously pushing on the C2 arch, or in more difficult cases, by insertion of a Watson-Cheyne into the C1/C2 joint and levering C1 back onto C2. The image intensifier is used to assist in the final guidance of the transarticular screws through the anterior border of C1. Prior to closure, the intra-articular bone graft is supplemented with posteriorly applied graft to the C1/C2 arch. Postoperatively, all patients are placed in a Philadelphia collar and radiographs of the fixation taken. Patients were clinically evaluated at 6 weeks, 3 months, 6 months, and 2 years. Antero-posterior and lateral radiographs were taken at 6 weeks, 3 months and 6 months. Flexion-extension radiographs were taken at 6 months and 2 years.

Results

Preoperative planning allowed selection of the appropriate screw length and diameter for navigation through the pars interarticularis of C2. In all cases, an accurate registration of less than 1.5 mm was achieved to permit intraoperative guidance. Thirty-eight patients received bilateral 4-mm transarticular screws. Eight patients received a unilateral transarticular screw, because of an enlarged vertebral artery groove in C2 reducing the available diameter for screw insertion, the stabilisation being completed using an adjunctive technique. This involved Apofix clamps (Medtronic Sofamor Danek, Memphis, Tenn., USA) and/or sublaminar wiring of the arches of C1 and C2. Hence image guidance was used in the planning and placement of 84 transarticular C1/C2 screws.

There was no clinical evidence of vertebral artery injury such as haemorrhage or cerebrovascular ischaemic episodes postoperatively, and no new neurological deficits. In particular, there was no evidence of injury to the C2 nerve root. Plain radiographic assessment of screw position was undertaken postoperatively and independently reported by a consultant radiologist. Results confirmed good screw position in all instances, according to criteria defined by Madawi et al. [18] (see Table 1). In particular there was no breech of the vertebral foramina or of the spinal canal, and all screws projected less than 5 mm through the anterior cortex of C1.

In this series, there were no operative deaths. At follow-up (6–48 months, mode 24 months) there have been no instances of construct failure, re-operation or movement on evaluation by plain radiography flexion/extension films.

Table 1 Definitions of radiological assessment of transarticular screw position according to Madawi et al. [17]

Well positioned
The screw passes through both lateral masses of C1 and C2 vertebrae.
The screw crosses the joint in between C1 and C2.
The screw protrudes through the anterior cortex of C1 by less than 5 mm.
Malpositioned
The screw is too short.
The screw is too long, i.e. projects by greater than 5 mm out of the C1 cortex.
The screw is too high, i.e. points to the basiocciput.
The screw misses the lateral masses of C1 by pointing too low, too lateral or too medial.

Discussion

Dickman and Sonntag [6] have described frameless stereotaxy in association with C1/C2 transarticular screw fixation. We believe the present study is the largest clinical series using image-guidance technology for transarticular screw fixation, and confirms the safety and accuracy of using such a system. Our results confirm that computer assistance with image guidance surgery can have a useful application when performing complex cervical spinal surgery. The complications of variant anatomy of the vertebral artery have been well described, as have techniques for preoperative planning of a safe trajectory through the lateral mass of C2 [17, 18, 23]. Preoperative planning can be time consuming, not to mention in some instances trigonometrically complex. The Stealth Station allows preoperative planning that provides unique information on the exact dimensions of bony structures and gives an indication of the quality of bone for instrumentation for an individual patient. A planned trajectory can be assessed for its suitability and the pathway stored on computer until surgery can take place. In theory and in practice one can select the appropriate length and diameter of screw to avoid unwanted complications. Our experience has shown that, even when challenged intra-operatively with complex anatomy or deformity, alternative screw placements can be made confidently whilst minimising any associated risks. It is important to note that image guidance is only used to allow accurate three-dimensional navigation of the C2 pars. The relationship between C1 and C2 is not indicated by the guidance system, and the position of C1 is verified with the C-arm. Most neurovascular damage and complications arise in navigating C2 and not C1. An image guidance system allows for three-dimensional orientation in C2. If the C-arm alone is used, there is no information in relation to C2 anatomy or to three-dimensional information concerning the screw trajectory.

We have used a technique outlined by Dickman et al. [7] for placing cannulated screws over K-wires that allows for easy repositioning to facilitate optimal screw placement. Foley et al. [11] have clearly shown that it is necessary to be able to adapt ones technique to the anatomy of an individual patient, since there are no unique optimal linear or angular parameters for ideal screw placement. Image guidance provides the surgeon with a versatile tool for assessing individual patient variation and determining the trajectory for screw placement. The advantages in accuracy of screw placement using computer-assisted surgery have been demonstrated by Amiot et al. [2, 3].

We believe that a computer image-guidance system offers new possibilities and potential advantages beyond the conventional technique for screw insertion through C2 using a C-arm alone. It provides a three-dimensional orientation for a three-dimensional problem. A screw trajectory can be selected and tailored to an individual patient's unique anatomy. Furthermore, it permits the surgeon to insert screws even if there is an incomplete reduction of C1 on C2. Using a conventional technique, an incomplete reduction would be a contraindication to transarticular screw placement, since the anterior border of C1 is used as the target point for a screw's trajectory. A subluxation of C1 on C2 would result in a tendency for the trajectory to drop and encroach on the vertebral artery groove [17]. Using image guidance, navigation specifically through C2 can be achieved without relying on the position of C1. An additional benefit can be envisaged for the training of spinal surgeons, where computer-generated images can clarify the surgery both in the principal aims and practice of a technique.

Transarticular screw fixation for atlanto-axial instability has been demonstrated to be biomechanically superior to alternative fixation methods [8, 13, 14]. In addition the pseudarthrosis rate as described by Grob et al. [12] for this technique is minimal. Although curetting and bone grafting of the C1/C2 joint is not essential to the image-guidance technique, we feel it is advantageous to obtain bone grafting in compression, to assist in the stabilisation of the construct. This is supplemented with graft placed between the arches of C1 and C2. By contrast, Ranawat et al. [22] showed a much higher non-union complication rate with alternative techniques.

This large series of rheumatoid patients reflects our regional referral patterns, but is similar to other units that undertake upper cervical spine surgery [16, 17].

Paramore et al. [21] demonstrated that 18–23% of patients might not be suitable for C1/C2 transarticular screw placement on at least one side, due to the position of the vertebral artery. Our experience shows a modification of technique (unilateral screw insertion with posterior stabilisation) was required in 18% (8/46) of cases, because of variations in the diameter of the C2 pars. This highlights the incidence of potential problems that surgeons may encounter with this procedure if adequate preoperative planning is not undertaken. Computer guidance can help the surgeon rapidly evaluate where to place a screw through the pars interarticularis of C2, especially in borderline cases (i.e. cases with a reduced pars diameter).

In our series we employed additional fixation in cases of unilateral transarticular screw placement. Song et al. [24] have demonstrated that even unilateral transarticular fixation combined with a Philadelphia collar alone can produce excellent results.

Conclusions

Transarticular screw fixation has been reported to provide good relief of pain [25] and improved biomechanical stability [14, 24].

When combined with image-guidance systems, preoperative planning is facilitated, and the surgeon can operate with more confidence. The system clearly permits safe operating and, in experienced hands, is a versatile and adaptable tool for the challenges offered by abnormal anatomy. Traditionally, abnormal anatomy of C2 would be a contraindication to C1/C2 screw insertion. However, a computer-guidance system allows the surgeon to accurately assess the abnormality in the context of planning the most appropriate fixation technique tailored to the individual patient.

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