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Posterior atlantoaxial screw placement in a Portuguese population: a morphometric analysis based on CT scan measurements

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Abstract

Introduction: The atlantoaxial joint stability depends on the integrity of the bone and ligament structures. Trauma, congenital malformations, neoplasms, infections, and inflammatory diseases can lead to C1-C2 instability requiring posterior atlantoaxial fixation. Hence, C1-C2 instrumentation demands profound anatomical knowledge and, besides, there are no studies providing anatomical references for atlantoaxial screw placement in the Portuguese population.

Objective: Evaluate the screw length and trajectory angles for posterior atlantoaxial fixation in a Portuguese population, through the study of cervical CT scans.

Methods: Cervical CT scans of fifty adults were measured using SURGIMAP® software according to predefined screw trajectories of C1-C2 transarticular (C1C2TA), C1 lateral mass (C1LM), C2 pedicle (C2P), C2 pars and C2 laminar (C2L) screws. For each of these trajectories, screw length and angles were measured and compared between males and females.

Results: For the C1C2TA screw trajectory, the mean length, medial and cranial angles were 34,12 ± 3,19 mm, 6,24° ± 3,06 and 59,25° ± 5,68, respectively, and for the C1LM screw trajectory were 27,12 ± 2,15 mm, 15,82° ± 5,07 and 13,53° ± 4,80. The mean length, medial and cranial angles for the C2P screw trajectory were 23,44 ± 2,49 mm, 27,40° ± 4,88 and 30,41° ± 7,27, respectively, and for the C2 pars screw trajectory were 16,84 ± 2,08 mm, 20,09° ± 6,83 and 47,53° ± 6,97. The mean length, lateral and cranial angles for the C2L screw trajectory were 29,10 ± 2,48 mm, 49,80° ± 4,71 and 21,56° ± 7,76, respectively. The comparison of these parameters between males and females revealed that there were no gender differences except for the C1C2TA (p=0,020) and C2L (p=0,001) screws length, which was greater in males than in females.

Conclusion: This study provides anatomical references for the posterior atlantoaxial fixation in a Portuguese population. This detailed data is essential to aid spine surgeons to achieve safe and effective screw placement.

Key words: Cervical spine, posterior atlantoaxial fixation, screw placement, atlantoaxial morphometry, Portuguese population

Resumo

Introdução: A estabilidade da articulação atlantoaxial depende da integridade das estruturas ósseas e ligamentares. Trauma, malformações congénitas, neoplasias, infeções e doenças inflamatórias podem levar à instabilidade desta articulação, requerendo fixação atlantoaxial posterior. Assim, a instrumentação de C1-C2 exige um profundo conhecimento anatómico e, para além disso, na bibliografia atual, não existem referências anatómicas para a colocação de parafusos atlantoaxiais na população portuguesa.

Objetivo: Avaliar o comprimento e os ângulos dos parafusos para a fixação atlantoaxial posterior numa população portuguesa, através do estudo de tomografias cervicais.

Métodos: Tomografias axiais computorizadas cervicais de 50 adultos foram analisadas e realizaram-se medições no software SURGIMAP® de acordo com trajetórias pré-definidas para os parafusos da massa lateral de C1 (C1LM), C1-C2 transarticulares (C1C2TA), C2 pars, C2 pedicular (C2P) e C2 laminar (C2L). Para cada uma destas trajetórias foram avaliados o comprimento e os ângulos de trajetória, comparando-os entre o sexo masculino e feminino.

Resultados: Para a trajetória do parafuso C1C2TA, a média do comprimento e dos ângulos medial e cranial foi de 34,12 ± 3,19 mm, 6,24° ± 3,06 e 59,25° ± 5,68, respetivamente, e para a trajetória do parafuso C1LM foram 27,12 ± 2,15 mm, 15,82° ± 5,07 e 13,53° ± 4,80. O comprimento médio e os ângulos medial e cranial da trajetória do parafuso C2P foram 23,44 ± 2,49 mm, 27,40° ± 4,88 e 30,41° ± 7,27, respetivamente, e para a trajetória C2 pars foram 16,84 ± 2,08 mm, 20,09° ± 6,83 e 47,53° ± 6,97. O comprimento médio e os ângulos lateral e cranial da trajetória do parafuso C2L foram 29,10 ± 2,48 mm, 49,80° ± 4,71 e 21,56° ± 7,76, respetivamente. A comparação destes parâmetros entre o sexo masculino e feminino revelou que não houve diferenças entre géneros, exceto no comprimento dos parafusos C1C2TA ($p=0,020$) e C2L ($p=0,001$) que foi maior nos homens do que nas mulheres.

Conclusão: Este estudo fornece referências anatómicas para a fixação atlantoaxial posterior numa população portuguesa. Estes dados detalhados são importantes para auxiliar os cirurgiões de coluna na colocação segura e eficaz dos parafusos.

Palavras-chave: Coluna cervical, fixação atlantoaxial posterior, colocação de parafusos, morfometria atlantoaxial, população portuguesa

Abbreviation list

C1- Atlas

C1-C2- Atlantoaxial

C1C2TA- C1-C2 transarticular

C1LM- C1 lateral mass

C2- Axis

C2L- C2 laminar

C2P- C2 pedicle

CT- Computed tomography

CTA- Computed tomography angiography

ICA- Internal carotid artery

MRI – Magnetic resonance imaging

VA- Vertebral artery

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Introduction

The atlantoaxial (C1-C2) joint has a close relationship with several vascular and neural structures, such as the vertebral artery (VA), atlas (C1) and axis (C2) nerve roots, which emerge superiorly to the respective vertebrae, and the vertebral venous plexus.[1] The VA emerges from the transverse foramen of C2, ascending through the C1 transverse foramen, where it runs medially along the VA sulcus in the C1 posterior arch. Often, there may be a small bony bridge in the atlas between the lateral mass and the C1 posterior arch named *ponticulus posticus* with a foramen that retains the VA, known as the arcuate foramen. The C2 nerve root emerges from the spinal cord at the lower edge of the C1 posterior arch, superior to the pedicle of C2. Surrounding the C2 nerve root and the vertebral artery is the vertebral venous plexus.[2]

The C1-C2 complex contributes with 50% of the cervical spine rotation capacity, allowing lateral inclination and flexion-extension movements and is formed by three joints. These are the atlanto-odontoid joint and the lateral atlantoaxial joints. These joints together with the cruciform ligament, alar, and apical ligaments are responsible for the stability of the atlantoaxial complex. Without this ligament stability there may be excessive movement between the atlas and axis, causing spinal cord compression which may lead to serious complications such as tetraparesis or even sudden death.[3]

Trauma, congenital malformations, neoplasms, infections, and inflammatory diseases, such as rheumatoid arthritis[4] and ankylosing spondylitis[5], have been implicated in the development of C1-C2 instability.[4] Even though conservative management can be appropriate for some patients, surgical intervention is often necessary. The indications for surgery are refractory pain, neurologic deficits, and/or radiographic evidence of significant instability characterized as an atlantodens interval greater than 5 mm on flexion/extension lateral radiographic views.[3]

Trauma is the most common cause of atlantoaxial instability.[6] Traumatic bone injuries such as Jefferson's C1 fractures associated with transverse ligament rupture and unstable fractures, as type II odontoid fractures, can result in atlantoaxial instability.[7,8] Proposed treatments for bone fractures include traction, cervical collar, halo-vest immobilization, and anterior odontoid fixation or posterior C1-C2 fixation.[9-11] Although treatment of odontoid fractures remains controversial,[3,12] posterior atlantoaxial fixation is an accepted treatment option, especially in certain cases such as in elderly patients or in fractures with inappropriate angulation for osteosynthesis.[10] Besides, obese patients and patients with thoracic kyphosis or barrel chest prevent the appropriate angle for the anterior placement of an odontoid screw and should be treated with a posterior C1-C2 stabilization procedure.[10]

There may be instability of the C1-C2 complex in the absence of fractures, namely in the rupture of the transverse ligament, which usually occurs due to acute hyperflexion of the cervical spine, caused by a fall or direct trauma to the occiput.[3] In rheumatoid arthritis, exuberant synovitis occurs with the destruction of the osteoarticular and ligamentous structures with consequent atlantoaxial subluxation, migration of the odontoid apophysis, instability and spinal cord compression.[3,13] Also, congenital conditions such as Down syndrome and skeletal dysplasias (p.e. Moquio or Goldenhar syndromes) predispose to atlantoaxial instability due to ligamentous laxity and bony abnormalities such as *os odontoideum.*[3,14]

Several posterior atlantoaxial fixation techniques were utilized until the development of the screw-rod technique widely used today.[2] This advancement in surgical techniques has led to a better safety profile and a higher fusion rate.[15] However, due to the anatomical proximity to vascular and neural structures, posterior atlantoaxial fixation with screws is associated with potentially serious complications, depending on the choice of the surgical technique. The complications that may occur include vascular and neurological injuries, bony nonunion, screw breakage, and surgical site infection.[4]

The VA is at high risk of injury during these procedures, due to its close relationship with the entry point and trajectory of the screws.[4] The unidentified VA anomalous course or the presence of a *ponticulus posticus* increases this risk.[4,10] Postoperative C2 neuralgia can occur due to nerve root manipulation when the screw is placed in the atlas.[2] The internal carotid artery (ICA), spinal cord, vertebral venous plexus, and hypoglossal nerve may also be injured during surgery.[4] Thus, it is important that spine surgeons are familiar with the different posterior atlantoaxial fusion techniques, along with in-depth anatomical knowledge, to minimize the complications inherent to the surgery.

The goal of this study was to assess the length and trajectory angles for posterior atlantoaxial screw placement in a Portuguese population, through the study of cervical CT scans performed at Centro Hospitalar Universitário do Porto.

Methods

This study included all patients in the SECTRA IDS7® (version 17.3.2086) database who performed a cervical computed tomography (CT) scan, from October 10 2020 to January 11 2021, at Centro Hospitalar Universitário do Porto and was approved by the local ethics committee (REF.ª 2021.042(035-DEFI/036-CE)).

A total of 217 clinical files were analysed and 167 were excluded for having incomplete CT scans, cervical fractures, bone neoplasms, cervical degenerative diseases including disc herniation, presence of osteophytes and spondylolisthesis, cervical scoliosis, history of cervical surgery, and inflammatory diseases such as rheumatoid arthritis and ankylosing spondylitis. The remaining 50 CT scans were analysed using the Surgimap® software (v2.3.2.1, Nemaris Inc., New York, NY).

The measurements were performed based on pre-defined screw trajectories of C1-C2 transarticular (C1C2TA), C1 lateral mass (C1LM), C2 pedicle (C2P), C2 pars, and C2 laminar (C2L) screws. All screw measurements were made by two investigators to reduce bias.

According to the trajectory being evaluated, the screw length, medial, lateral, and cranial angles were measured on the right side of C1 and C2 vertebrae. All screws were placed unicortically with the maximum length allowed without crossing the vertebrae anterior cortex and it was ensured that the bone height and width could safely accommodate a 3.5-mm diameter screw.

The medial and lateral angles, in the axial plane, were obtained by measuring the angle formed by the intersection of the pre-defined screw trajectory and the longitudinal midline of the respective vertebra. In the sagittal plane, the cranial angle for the C1LM screw trajectory was the angle between the endplate of C1 and the screw trajectory line. For the C1C2TA, C2P, C2 pars, and C2L screw trajectories the cranial angle was the angle made by the screw trajectory line and the line parallel to the C2 inferior vertebral body border.

C1-C2 transarticular screw

The starting point used for the C1C2TA screw trajectory was 3 mm lateral and 3 mm superior to the medial border of the C2-C3 facet joint. The trajectory was directed medially in the axial plane and toward the C1 anterior arch in the sagittal plane (Figure 1).[16]

C1 lateral mass screw

For the C1LM screw trajectory, the starting point used was at the intersection of the lower edge of the C1 posterior arch with the midpoint of the C1 lateral mass. The trajectory was convergent towards the C1 anterior arch and parallel to the C1 posterior arch in the sagittal plane (Figure 2).[17]

C2 pedicle screw

For the C2P screw trajectory, the starting point used was the midpoint between the superior and inferior C2 articular processes. The trajectory was directed medially and cranially to the C2 anterior cortex (Figure 3).[15]

C2 pars screw

The starting point used for C2 pars screw trajectory was 3 mm lateral and 3 mm superior to the medial border of the C2-C3 facet joint. The trajectory was directed medially and cranially, parallel to the C2 pars in the sagittal plane and parallel to the medial border of the pars in the axial plane (Figure 4).[15]

C2 laminar screw

For the C2LS trajectory, the starting point used was at the junction of the C2 spinous process and the lamina with the screw trajectory being directed parallel to the downslope of the contralateral lamina (Figure 5).[18]

Statistical analysis

An inter-observer reliability analysis using the Cohen's Kappa statistic was performed to determine the agreement among investigators.

Additionally, the mean length and angles for each gender were calculated. To identify statistically significant differences between gender, a statistical analysis of the data was performed using a t-test for independent samples, considering a p-value <0.05 as significant.

Data was collected in Microsoft Excel® (Version 2013, Microsoft Inc, Redmond, WA, USA) and analysed using SPSS® (Version 26, IBM, Armonk, New York, USA) for statistical analysis.

Results

This study included a total of 50 patients with a mean age of 42,62 ± 15,25 at the date of data collection. There were 26 male and 24 female patients (52% vs 48% respectively). In males, the mean age was 40,08 ± 15,81 and, in females, the mean age was 45,38 ± 14,45 (Table I). There was good inter-observer agreement (K>0.4) for all measurements except for the C1LM screw length (Table II). The mean length and angles for each screw trajectory is described in Table III. The comparison of screw measurements by gender (Table IV) demonstrated that the mean screw length in males was higher for the C1C2TA and C2L screw trajectories. There were no significant statistical differences between genders for the C1LM, C2P, and C2 pars screws length (p>0,05). Also, there were no gender significant statistical differences for all trajectory angles.

C1-C2 transarticular screw

For the C1C2TA screw trajectory, the mean screw length was 34,12 ± 3,19 mm. In males it was 35,15 ± 2,66 mm and in females was 33,00 ± 3,39 mm, a difference that was statistically significant (p= 0,020). The mean medial and cranial angles were 6,24° ± 3,06 and 59,25° ± 5,68, respectively. In males they were 5,71° ± 2,78 and 58,79° ± 5,21 and in females were 6,81° ± 3,30 (p= 0,207) and 59,75° ± 6,23 (p= 0,555).

C1 lateral mass screw

For the C1LM screw trajectory, the mean screw length was 27,12 ± 2,15 mm. In males it was 27,69 ± 2,09 mm and in females was 26,50 ± 2,09 mm (p= 0,050). The mean medial and cranial angles were 15,82° ± 5,07 and 13,53° ± 4,80, respectively. In males they were 16,46° ± 5,26 and 13,12° ± 4,78 and in females were 15,13° ± 4,86 (p= 0,357) and 13,98° ± 4,90 (p= 0,531).

C2 pedicle screw

For the C2P screw trajectory, the mean screw length was 23,44 ± 2,49mm. In males was 23,58 ± 2,58 mm and in females was 23,29 ± 2,44 mm (p= 0,690). The mean medial and cranial angles were 27,40° ± 4,88 and 30,41° ± 7,27, respectively. In males they were 27,00° ± 4,18 and 28,60° ± 7,00 and, in females were 27,83° ± 5,59 (p= 0,551) and 32,38° ± 7,18 (p= 0,066).

C2 pars screw

For the C2 pars screw trajectory, the mean screw length was 16,84 ± 2,08mm. In males it was 17,27 ± 2,29 mm and in females was 16,38 ± 1,77 mm (p= 0,131). The mean medial and cranial angles were 20,09° ± 6,83 and 47,53° ± 6,97, respectively. In males they were 18,83° ± 6,42 and 46,10° ± 6,90 and, in females were 21,46° ± 7,12 (p= 0,176) and 49,08° ± 6,85 (p= 0,131).

C2 laminar screw

For the C2L screw trajectory, the mean screw length was 29,10 ± 2,48 mm. In males it was 30,15 ± 2,29 mm and in females was 27,96 ± 2,18mm, a difference that was statistically significant (p= 0,001). The mean lateral and cranial angles were 49,80° ± 4,71 and 21,56° ± 7,76. In males they were 48,96° ± 4,58 and 20,92° ± 8,11 and, in females were 50,71° ± 4,77 (p= 0,193) and 22,25° ± 7,47 (p= 0,551).

Discussion

Posterior atlantoaxial fixation is required to provide stability, reduce deformity, and prevent neurological injury. Since the sublaminar wiring technique was introduced by Gallie, interlaminar clamps, C1-C2 transarticular screws, and screw-rod fixation have been described for the treatment of atlantoaxial instability.[19] The C1-C2 complex long-term stability depends on bone fusion which requires rigid limitation of atlantoaxial motion.[20]

Currently, the more commonly used techniques for posterior atlantoaxial arthrodesis are C1C2TA screws and screw-rod fixations which include C1LM screw combined with C2P, C2 pars, or C2L screws.[21] These procedures achieve a high fusion rate and an immediate rigid fixation, eliminating the need for postoperative external orthosis which improves patients' quality of life. [19]

There are several studies evaluating the safety and fixation strength between unicortical and bicortical placement of the C1LM and C1C2TA screws.[22-27] Cyr *et al.* concluded that there was no significant difference in the pullout strength of unicortical and bicortical purchase of C1 in the C1C2TA screw placement.[26] In contrast, Eck *et al.* revealed that there is evidence that bicortical C1LM screws provide stronger fixation. [27] This difference in fixation strength is due to the greater bone density of C1 anterior cortex compared with the lateral mass. However, no difference was found in the rates of successful arthrodesis of C1LM screws despite the uni or bicortical bony purchase.[25] Bicortical screw placement requires a longer screw length to penetrate the C1 anterior cortex thus increasing the risk of neurovascular injuries.[23] The hypoglossal nerve lies 2 to 3 mm lateral from the middle of the C1LM anterior aspect, while ICA location is variable but can lie within 1 mm from the screw exit point[26], thus being at risk of injury during bicortical C1LM and C1C2TA screws placement.[23] Although there are studies reporting that bicortical screws are relatively safe when directed medially to avoid the neurovascular structures, the unicortical screws remain safer.[23,27-29] Nevertheless, the strength of screw fixation is also associated with bone mineral density[25,27], thus in patients with osteoporosis or rheumatoid arthritis bicortical screw placement can be necessary to avoid poor screw purchase.[23,30] In these cases, due to the wide variation in ICA location relative to C1, a preoperative computed tomography angiography (CTA) should be considered to determine the screw trajectory. [23,24,31] In the current study, all screws length was measured until but without perforating the second cortex. Decision between using uni or bicortical screws should be reserved to surgeon preference and individual patient anatomy.

Although some authors have advocated the safety and accuracy of freehand technique[32,33], posterior atlantoaxial screw placement under fluoroscopy guidance represents the gold-standard procedure for all screw trajectories except for the C2L screw.[20,34] The risk of neurovascular injury is reduced with intraoperative fluoroscopy but it is not completely avoidable.[35] Therefore, several spinal navigation techniques have been developed.[36-38] Compared to fluoroscopic guidance, spinal navigation has the advantage of providing accurate 3D images, enabling the surgeon to precisely track the screw trajectory which increases the accuracy and safety of screw placement.[39] Also, it is important to mention that spinal navigation must not be considered as a substitute but as an aid to the knowledge of spinal anatomy.[36] Fluoroscopy and spinal navigation are associated with radiation exposure and increased operative time which could be avoided with the use of freehand screw placement.[32,35] However, the learning curve to perform the freehand technique is steep, requiring an experienced surgeon with precise knowledge of the anatomical landmarks.[32] Future studies comparing clinical outcomes, morbidity and mortality of freehand C1–C2 posterior fixation, fluoroscopy and navigated screw placement are needed.

The screw constructs are selected based on the patient's osseous and vascular C1-C2 anatomy, the particular pathological lesion, and the experience and comfort level of the surgeon.[40] Due to the variable bony and vascular anatomy of the C1-C2 complex, a preoperative cervical CT scan or magnetic resonance imaging (MRI) is highly recommended to determine the anatomic feasibility and safe screw trajectory to avoid complications related to the screw placement.[2]

Several authors have described the most used screw trajectories for the posterior atlantoaxial fixation, however, there is a lack of studies analysing all these screw trajectories in the same population. Besides, there are no reports of anatomical references for these screws in the Portuguese population. Hence, this study is essential to provide anatomical references, adding on to existing knowledge. The comparison between the results in this study and the international literature for each screw trajectories is described in Table V.

Transarticular screw fixation, introduced by Magerl, provides high stability and fusion rates ranging from 92% to 100%.[2] However, this technique requires reduction of the C1-C2 complex before screw placement and it is associated with a potential risk of injury to the vertebral artery, particularly in those with a high-riding VA.[41] In approximately 20% of patients C1C2TA screw can not be safely inserted due to aberrant vertebral artery anatomy which places this artery in the path of the C1C2TA screw.[20]

Nogueira-Barbosa *et al.* analysed one hundred CT scans to determine atlantoaxial bone morphometric measurements related to transarticular screw fixation technique. Their study determined that, in males, the screw length was 39 mm, the medial angle was 8° and the cranial angle was 59°. In females, the screw length, medial and cranial angles were 37 mm, 7° and 57°, respectively. [42] In the current study, the results were similar. In males, the screw length, medial and cranial angles were 35 mm, 6° and 59°, respectively, and in females were 33 mm, 7° and 60°.

Due to being less technically demanding and with a decreased risk of VA injury than C1C2TA screws, the C1 and C2 screw-rod construct techniques have become popular. [43]

To overcome the pitfalls of the transarticular fixation technique, Goel and Laheri and later, Harms and Melcher introduced a C1–C2 fixation technique using C1LM screw combined with C2P or C2 pars screws. This technique has good biomechanical strength and allows intraoperative reduction of the atlantoaxial complex.[20] Additionally, the C2P and C2 pars screws trajectories are more medially than the C1C2TA screw, thus reducing the risk of VA injury.[43] Despite these advantages, the risk of VA or neurological lesion still exists, resulting from the screw passage through the transverse foramen or the vertebral canal due to excessive lateral or medial angulation.[41]

Medial angulation of the C1LM screw maximizes the margin of safety, with any lateral angulation being unsafe, risking violation of the vertebral foramen and VA injury.[44] The C1LM screw placement may cause postoperative C2 nerve injury and massive bleeding from the venous plexus below the C1 posterior arch during exposure of the C1LM screw entry point.[15] To overcome this problem, some authors have described a higher entry point for the C1LM screw in the surface of the C1 posterior arch,[45,46] and through a notch on the underside of the C1 posterior arch. [47] However, a C1 posterior arch height of less than 4 mm precludes the insertion of the C1 screw in this entry point for approximately 8% to 53,8% of patients.[15]

Different C1LM screw lengths and angles have been described in earlier anatomic studies, depending on the selected screw entry point and each patient's unique anatomy. [17,30,48-50] Also, there is evidence that the trajectory angles have implications on screw lengths. Yong Hu et al. conducted a study to determine the optimal entry point, medial angle, and effective length for safe fixation of C1LM screws and concluded that screw lengths varied significantly depending on the medial angle of C1LM screws, with a greater medial angle implying a longer screw length. In their study it was considered that the optimal entry point was at the middle of the posterior C1 inferior articular process 2 mm above the articular surface. Regarding angles, they used a fixed 15° cephalad angle and determined that the optimal medial angle to reduce the risk of VA and spinal cord injury was 21º with a corresponding screw length of 22 mm inside the C1LM.[50] Simsek *et al.* analysed forty dried atlantal specimens to assess the feasibility of the C1LM posterior screw fixation and found that the ideal screw cranial angle was 15° using the same entry point as the current study. The screw length inside the lateral mass and the medial angle, measured on the right side of the C1 vertebra, was 20 mm and 14°, respectively.[30] However, due to the overlying C1 posterior arch, the screw length increases to allow the rod placement in the polyaxial head of the screw. Rocha et al. determined the ideal screw length with the overlying C1 posterior arch as 30 mm with screws placed bicortically. Regarding angulation, the medial and cranial angles were 17° and 22°, respectively.[49] In the current study, the C1LM screw length inside and outside the C1LM was 27 mm with 16° medial and 14° cranial angles.

The C2P screw technique has the advantage over the C1C2TA screw of requiring a less acute approach angle.[43] However, the C2 pedicle width and height limit the screw placement. Igarashi *et al.* determined that approximately 20% of C2 pedicles did not have sufficient size to accept a 3.5mm screw placement.[51]

Although with a higher incidence of VA injury[52,53], some studies claim that the C2P screw provides the highest biomechanical stability when compared with C2 pars and C2L screws.[53-55] Thus, the placement of C2 pars or C2L screws are important alternatives when the patient cervical anatomy precludes C2P screw placement such as in C2 pedicle hypoplasia or high-riding VA.[19,40,56]

In the current study, the C2P screw length was 23 mm with 27° medial and 30° cranial angles. Chin *et al.* conducted a similar study using CT scans from thirty-four patients to evaluate the ideal screw trajectory through each C2 pedicle and concluded that, on the right side, the screw length, medial and cranial angles were 22 mm, 28° and 23°, respectively.[57]

Kiran *et al.* evaluated the safety and accuracy of anatomic and lateral fluoroscopic-guided placement of C2 pars screws. They determined that screw placement was safe with a 16 mm screw length with a medial and cranial angulation of 23° and 30°, respectively.[53] In the current study, the C2 pars screw length was 17 mm with 20° medial and 48° cranial angles. Although screw length and medial angle were similar to Kiran *et al*., the cranial angle was found to be higher in this study. This difference in the cranial angle may result from using a different reference plane.

The bilateral crossing C2L screw, described by Wright, avoids the risk of VA injury since the screws are not positioned near the transverse foramen.[18] The placement of this screw is safe, easy to perform, and does not require fluoroscopy or spinal navigation. However, C2L screws have an increased risk of spinal canal injury from a ventral cortical breach.[20] Furthermore, Parker et al found that patients with C2L screw constructs had a significantly higher pseudoarthrosis rate compared to those with C2P screw.[58]

Dean *et al.* conducted a study to evaluate critical dimensions of the C2 vertebrae for the laminar screw placement through CT scan measurements and concluded that the C2L screw length was 29 mm and the lateral angle was 42°. In the current study, the screw length was 29 mm with a 50° lateral angle.[59]

To prevent the possibility of a screw ventral breakthrough toward the spinal canal, Jea et al. suggested a modification of Wright's technique, adding an exit cortical window at the facet-laminar junction.[60] A recent study evaluated the biomechanical stability of this technique in cadaveric specimens and concluded that C2 laminar bicortical screws are biomechanically superior to the C2 laminar unicortical screws and equivalent to C2P screw fixation.[21] However, more studies are needed to verify the feasibility and biomechanical superiority of this new technique and to compare it to the other atlantoaxial fixation techniques.

To the author's knowledge, the current study is the first to provide a complete description of the more commonly used screw trajectories for posterior atlantoaxial fixation in the same population. Moreover, it is the first study providing anatomical references for posterior C1-C2 screw placement in a Portuguese population.

Nevertheless, the limitations of the present study should be noted. The screw length and angles were measured only on the right side of the C1 and C2 vertebrae. Additionally, all the measurements were made manually and are investigator-dependent. Thus, to overcome this limitation, the screw length and angles were measured by two investigators, and a good agreement was obtained for all but for one measurement.

In conclusion, instrumentation in the upper cervical spine surgery can lead to catastrophic complications and extreme care must be taken to minimize these events. This study provides important atlantoaxial references that may help spine surgeons to achieve proper screw placement, especially when intra-operative navigation is not available. However, due to the anatomic variations of the C1-C2 complex, this data can act only as a rough guide and is not sufficient for safe and effective screw implantation. Thus, if screw implantation is considered, it is essential to perform pre-operative CT imaging with detailed anatomic analysis to determine the ideal screw trajectory.

Tables

Table I- Sample's age by gender.

Gender	N	Age	
		Mean	**Std. Deviation**
Male	26	40,08	15,81
Female	24	45,38	14,45
Total	50	42,62	15,25

Table II – Inter-Observer Reliability for each screw length and angulation

Screw trajectory		Inter-Observer Reliability
C1C2TA	**Length**	0,441
	Medial angle	0,598
	Cranial angle	0,674
C1LM	**Length**	0,214
	Medial angle	0,691
	Cranial angle	0,427
C2P	**Length**	0,709
	Medial angle	0,828
	Cranial angle	0,747
C2 pars	**Length**	0,573
	Medial angle	0,795
	Cranial angle	0,784
C2L	**Length**	0,593
	Lateral angle	0,605
	Cranial angle	0,651

Table III- Length and angulation for each screw trajectory

		N	Minimum	Maximum	Mean	Std. Deviation
C1C2TA	**Length**	50	28	40	34,12	3,19
	Medial angle	50	2	13	6,24	3,06
	Cranial angle	50	45	70	59,25	5,68
C1LM	**Length**	50	23	33	27,12	2,15
	Medial angle	50	4	28	15,82	5,07
	Cranial angle	50	6	25	13,53	4,80
C2P	**Length**	50	19	28	23,44	2,49
	Medial angle	50	18	38	27,40	4,88
	Cranial angle	50	18	43	30,41	7,27
C2 pars	**Length**	50	14	24	16,84	2,08
	Medial angle	50	9	33	20,09	6,83
	Cranial angle	50	31	60	47,53	6,97
C2L	**Length**	50	24	33	29,10	2,48
	Lateral angle	50	36	59	49,80	4,71
	Cranial angle	50	3,5	34,5	21,56	7,76

Table IV- Length and angulation for each screw trajectory by gender.

Screw trajectory		Gender	N	Mean	Std. Deviation	Std. Error Deviation	p-value
C1C2TA	Length	Male	26	35,15	2,66	0,52	0,020
		Female	24	33,00	3,39	0,69	
	Medial angle	Male	26	5,71	2,78	0,55	0,207
		Female	24	6,81	3,30	0,67	
	Cranial angle	Male	26	58,79	5,21	1,02	0,555
		Female	24	59,75	6,23	1,27	
C1LM	Length	Male	26	27,69	2,09	0,41	0,050
		Female	24	26,50	2,09	0,43	
	Medial angle	Male	26	16,46	5,26	1,03	0,357
		Female	24	15,13	4,86	0,99	
	Cranial angle	Male	26	13,12	4,78	0,94	0,531
		Female	24	13,98	4,90	1,00	
C2P	Length	Male	26	23,58	2,58	0,51	0,690
		Female	24	23,29	2,44	0,49	
	Medial angle	Male	26	27,00	4,18	0,82	0,551
		Female	24	27,83	5,59	1,14	
	Cranial angle	Male	26	28,60	7,00	1,37	0,066
		Female	24	32,38	7,18	1,47	
C2 pars	Length	Male	26	17,29	2,27	0,45	0,131
		Female	24	16,38	1,77	0,36	
	Medial angle	Male	26	18,83	6,42	1,26	0,176
		Female	24	21,46	7,12	1,45	
	Cranial angle	Male	26	46,10	6,90	1,35	0,131
		Female	24	49,08	6,85	1,40	
C2L	Length	Male	26	30,15	2,29	0,45	0,001
		Female	24	27,96	2,18	0,44	
	Lateral angle	Male	26	48,96	4,58	0,90	0,193
		Female	24	50,71	4,77	0,97	
	Cranial angle	Male	26	20,92	8,11	1,59	0,551
		Female	24	22,25	7,47	1,52	

Table V- Comparison between the screw measurements of the current study and those described in the international literature.

Trajectory	Current Study				International literature: Nogueira-Barbosa et al.	Young Hu et al	Simsek et al.	Rocha et al	Chin et al.	Kiran et al.	Dean et al.
	Gender	N	Mean	Total							
C1C2TA length	Male	26	35,15	34,12	38,86						
	Female	24	33,00		36,99						
C1C2TA medial angle	Male	26	5,71	6,24	7,57						
	Female	24	6,81		7,48						
C1C2TA cranial angle	Male	26	58,79	59,25	58,64						
	Female	24	59,75		57,3						
C1LM length	Male	26	27,69	27,12		21,86	19,59	30,40			
	Female	24	26,50								
C1LM medial angle	Male	26	16,46	15,82		20,86	13,50	16,70			
	Female	24	15,13								
C1LM cranial angle	Male	26	13,12	13,53		15,00	15,20	21,70			
	Female	24	13,98								
C2P length	Male	26	23,58	23,44					22,10		
	Female	24	23,29								
C2P medial angle	Male	26	27,00	27,40					27,90		
	Female	24	27,83								
C2P cranial angle	Male	26	28,60	30,41					23,00		
	Female	24	32,38								
C2 pars length	Male	26	17,19	16,8						16,40	
	Female	24	16,38								
C2 pars medial angle	Male	26	18,83	20,09						22,70	
	Female	24	21,46								
C2 pars cranial angle	Male	26	46,10	47,53						30,00	
	Female	24	49,08								
C2L length	Male	26	30,15	29,10							28,80
	Female	24	27,96								
C2L lateral angle	Male	26	48,96	49,80							42,45
	Female	24	50,71								
C2L cranial angle	Male	26	20,92	21,56							
	Female	24	22,25								

Figures

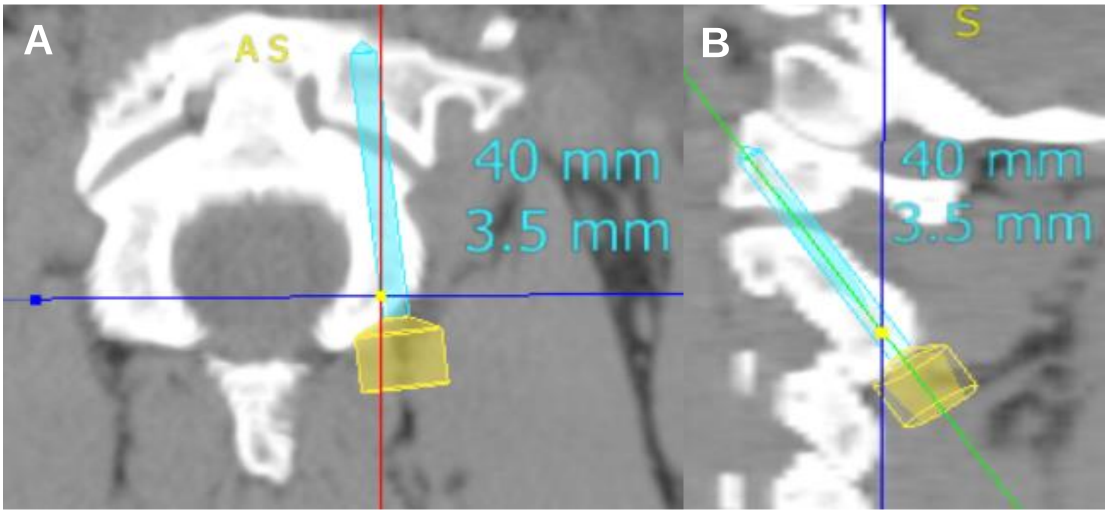

Figure 1 – C1C2TA screw trajectory measurement. C1C2TA screw in the axial plane (A) and in the sagittal plane (B).

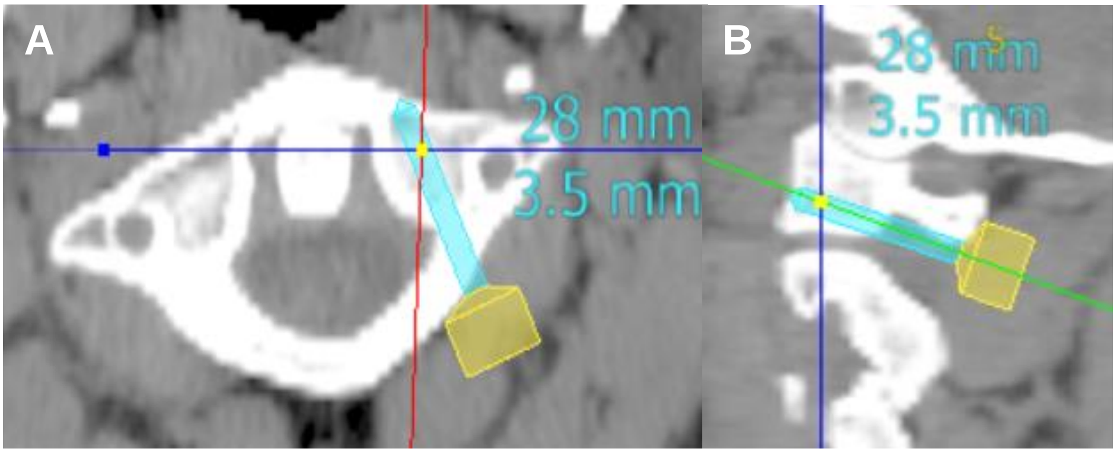

Figure 2 - C1LM screw trajectory measurement. C1LM screw in the axial plane (A) and in the sagittal plane (B).

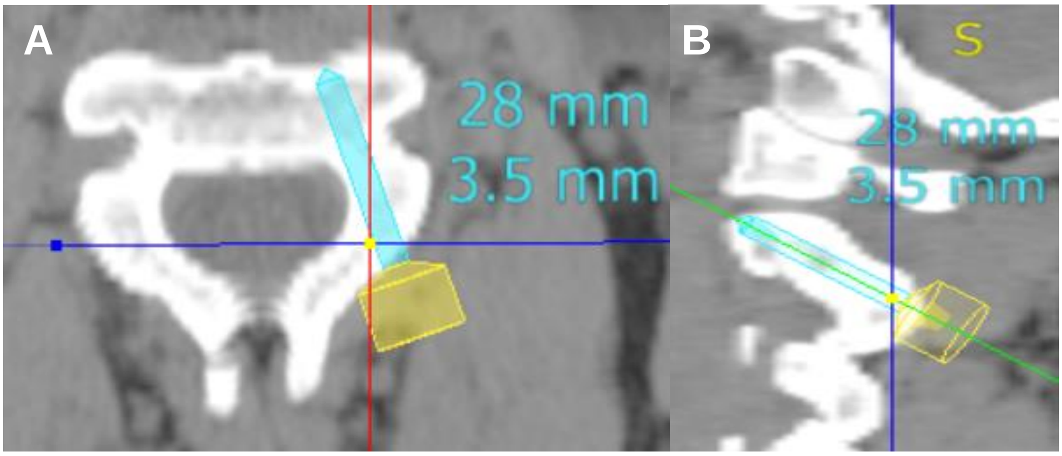

Figure 3 – C2P screw trajectory measurement. C2P screw in the axial plane (A) and in the sagittal plane (B).

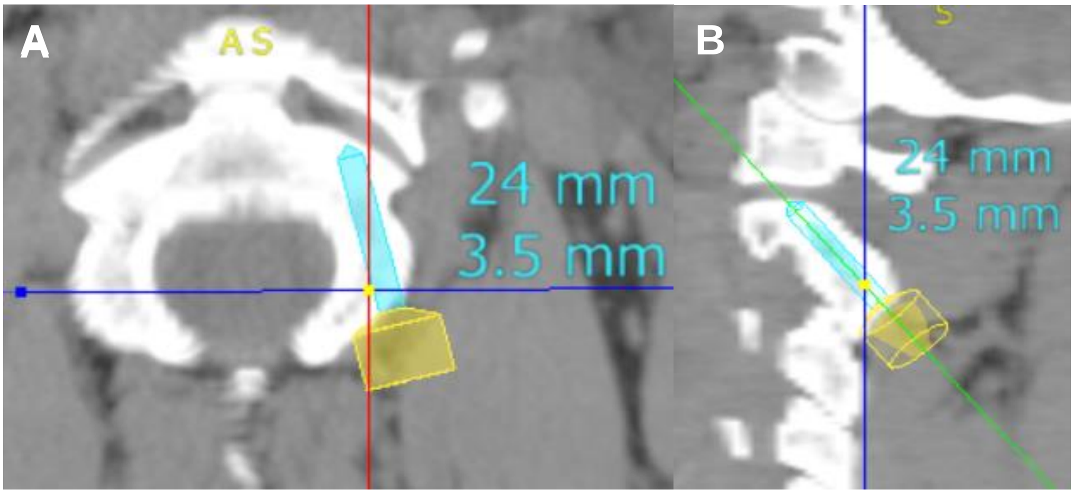

Figure 4 – C2 pars screw trajectory measurement. C2 pars screw in the axial plane (A) and in the sagittal plane (B).

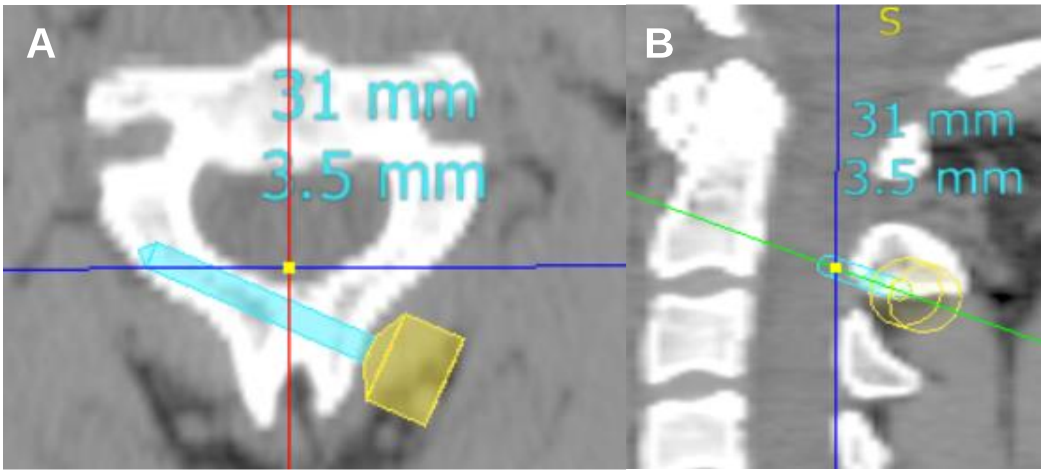

Figure 5 – C2L screw trajectory measurement. C2L screw in the axial plane (A) and in the sagittal plane (B).

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