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Safety Ranges in V3 Segment of the Vertebral Artery for Surgical Procedures at the Craniocervical Junction

Rangos de Seguridad en el Segmento V3 de la Arteria Vertebral para Procedimientos Quirúrgicos en la Unión Craneocervical

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SUMMARY: The aim of this study was to establish safety ranges for the third vertebral artery segment (V3) for craneocervical procedures. Injury to V3 represents a potentially catastrophic complication. Its tortuous path and complex relationship with neighboring structures, increasing the risk. Ten male adult cadavers (20 vertebral arteries) with arterial infiltration of red latex were studied. The length, angles and anatomical measurements were obtained between the selected surgical landmarks and the portions of V3 segment. The horizontal portion has a length of 32.7 ± 3.6 mm with an angulation of 115.1 ± 8.3 degrees. The mean distances of the horizontal portion were: from the midline to the V3 groove of C1 posterior arch (24.7 ± 6.3 mm); from C1 pars interarticularis to the V3 distal loop of V3 (8.9 ± 1.4 mm). The vertical portion has a length 32.5 ± 5.6 mm with an angulation of the proximal loop of 113.6 ± 5.8 degrees. The mean distances between the C2 spinous process to the medial surface of the distal loop (43.8 ± 4.2 mm); from the C1-C2 joint to the V3 vertical portion (9.5 ± 1.5 mm); from C2 pars interarticularis to V3 in the C2 transverse foramen (6.5 ± 3.4 mm); from C2 pars interarticularis to V3 in the C1 transverse foramen (17.5 ± 4.5 mm). We reported four potential sites where V3 can be injured during four different surgical procedures: exposure of the posterior arch of C1, and pars interarticularis of C1 in the horizontal portion and exposure of the C1-C2 joint, and placement of C1-C2 transarticular screws one in the vertical portion. We provide measurements of redundancy and safety ranges to reduce the risk of injury to the V3 segment during craniocervical surgical procedures.

KEY WORDS: Anatomy; Vertebral artery; V3 segment; Cervical spine; Spine surgery.

INTRODUCTION

Injury to the vertebral artery (VA) during craniocervical procedures represent potential catastrophic complications (Hsu *et al*., 2017). The VA is divided into 4 segments: The first segment (V1) extends from its origin in the posterior-superior surface of the subclavian artery to its entry into the C6 transverse foramen. The second segment (V2) is the artery from the C6 up to the C2 transverse foramen. The third segment (V3) exits from the C2 transverse foramen until it enters the skull through the posterior atlanto-occipital membrane. The fourth segment (V4) is the intracranial portion of the artery until it anastomoses with the contralateral VA forming the basilar artery (Neo *et al*., 2005; Fassett *et al*., 2008; Lunardini *et al*., 2014; Yeom *et al*., 2013). The V3 is the most tortuous and has the most complex bone relationships, making it the segment of greatest interest in surgical procedures (de Souza *et al*., 2011; Khanfour & El Sekily, 2015; Hsu *et al*.).

The V3 segment itself is subdivided in three portions: a vertical portion (VP) between the transverse foramens of C1 and C2, a horizontal portion (HP) from the C1 transverse foramen to the vertebral groove of the atlas, and an oblique portion (OP) from the vertebral groove of the atlas to penetrate the posterior atlanto-occipital membrane (Chytas *et al*., 2018). Each portion has a curvature on its axis that allows it to form loops which as it become more pronounced,

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increases the redundancy, making it the most mobile segment. The VP curves laterally forming the proximal loop, while the HP extends posteriorly forming the distal loop (Inamasu *et al*., 2005; Duan *et al*., 2009).

The pathologies that affect the craniocervical junction and the supra-axial spine are classified into different types: traumatic, degenerative diseases, neoplasms, and congenital malformations (Akar *et al*., 2016). Most common surgical procedures in which the V3 segment is susceptible to injury are: suboccipital craniectomies with osteotomy of the C1 posterior arch, posterior instrumentation of the C1-C2 vertebrae, "far lateral" type approaches in which an osteotomy of the occipital is required, retro-mastoid approaches, and trans-condylar approaches (Fassett *et al*.; Khanfour & El Sekily). Vertebral artery injury has been reported in spinal surgery in 5.4 % in laminectomies, 11.7 % in posterior region exposure, and 32.4 % in C1-C2 spine fixation, from this 9.5 % in C1-C2 transarticular screws and 8 % in pedicle screws (Khan *et al*., 2007; Yamaguchi *et al*., 2008; Lunardini *et al*.; Shafafy *et al*., 2017; Hlubek *et al*., 2018). These may have neurologic repercussion in 0.2 - 14.25 % of cases (Fassett *et al*.; Ulm *et al*., 2010). Injuries include not only bleeding, but also complications, such as pseudoaneurysm, arteriovenous fistula, vertebrobasilar insufficiency, posterior fossa infarction, and even death of the patient (Fassett *et al*.; Shafafy *et al*.).

There is evidence indicating that neurosurgeons with less experience have an increased risk of vascular injuries during surgeries of the craniocervical junction (Khan *et al*.). The analysis of anatomical relationships of the VA to identifiable bone elements to suggest safety ranges for procedures would be of great value (Abd el-Bary *et al*., 1995; Gupta, 2008). There are studies that report differences in safety ranges amongst American, Asian, and Middle-Eastern populations, however data on Hispanics is lacking. The objective of the present study was to complete a morphological analysis of the V3 as well as safety ranges for the most frequent surgical procedures of the craniocervical junction.

MATERIAL AND METHOD

A descriptive, observational, transversal and non-comparative study was performed, evaluating the V3 segment of the VA in relation to specific landmark of the craniocervical junction. We used adult male cadavers of Mexican origin, fixed in formaldehyde and with previous arterial latex infiltration, provided by the Human Anatomy Department from the school of medicine, Universidad Autónoma de Nuevo León. The study complies with the regulations, standards of confidentiality, and ethics requested by the institution. No distinction was made in terms of age of the bodies. None of the bodies had a known history of chronic-degenerative pathology. Those with a history of surgical procedures or trauma in the cervical spine or craniocervical junction were eliminated from the study.

Anthropometry of height and cephalic perimeter were measured; subsequently the dissection of the posterior cervical region was performed (Fig. 1). In prone position and previous occipital trichotomy, the cervical alignment was checked by fluroscopy. A bilateral horizontal incision was made 3 cm posterior to the upper edge of the auricular pin and a vertical incision from the external occipital protuberance to T1 spinous process (Fig. 1A). Muscle planes were dissected from C1 posterior tubercle to C7 spinous process to access the plane of the suboccipital triangle (Fig. 1B), continued with a subperiosteal dissection by curettage to expose the laminae and the spinous processes and transverse processes of C1-C7. The dissection was continued laterally to the C1-C7 inter-facetary joints, to achieve full access of the cervical spine in its posterior region. The microdissection was also performed with magnification (between x 0.6 - 2.5) with the use of a surgical microscope (Carl-Zeiss OPMI 1FC) for the V2 in the cervical spine and V3 in- and out-side the suboccipital triangle (Fig. 1C). A digital vernier (Mitutoyo Absolute IP 67) was used to quantify the distances between the VA and the previously determined bone landmarks (Fig. 2). Loop angulation was measured in situ with a goniometer (with a 0.5º precision). 3-0 nylon sutures were used to mark the transition sites between each VA segment. Finally, the artery was then extracted for direct measurement of V3 (with the use of vernier).

Eleven variables (Table I) were grouped into four sets based on the utility during surgery in four different surgical maneuvers: exposure of the posterior arch of C1 (Fig. 2A), exposure of the C1 pars articularis (Fig. 2B), exposure of the C1-C2 joint (Fig. 2C), and placement of C1-C2 transarticular screws / C2 pars screws / C2 pedicle screws (Fig. 2D).

The data were captured and analyzed using Microsoft Excel 2016 for Windows 7. Descriptive statistics were performed reporting mean and standard deviation. The comparison of means between left and right was made to find significant differences with a value of $p \leq 0.05$.

The present study complies with the regulations, standards of confidentiality, and ethics requested by the institution. This was approved by the ethics committee and local research committee with the approval number AH13-001. The authors declare no conflict of interest for the realization and publication of this work.

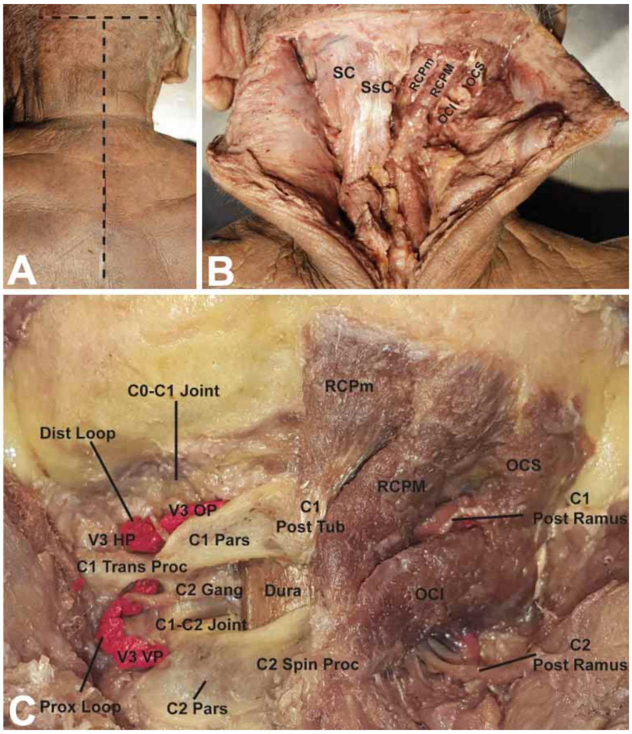

Fig. 1. Dissection in cadaver of the craniocervical region and the cervical spine in a posterior view. (A) The body in prone position and a trichotomy of the occipital region. The segmented line marks the incision made 3 cm posterior to the superior margin of the auricular pin bilaterally and a vertical incision from the external occipital protuberance to the spinous process of T1. (B) Dissection of the craniocervical area, with the trapezius muscle and the sternocleidomastoid muscle removed from their insertion in the skull, and removal of the semispinalis capitis muscle and splenius capitis muscle to access the suboccipital triangle. (C) V3 segment, atlas (C1), and axis (C2) dissection. Microdissection of the vertical portion (VP) next to the posterior branch of the C1 nerve and in its horizontal portion (HP) together with the posterior branch of the C2 nerve. Subperiosteal dissection by curettage to expose the spinous processes and the laminae of C1-C7, followed by a lateral dissection on the atlanto-occipital joint and the C1-C7 facets joints, the ganglia and spinal nerves of C1-C8 as well as the transverse processes.
Dist Loop = distal loop; Dura = dura mater; Gang = ganglion; HP = Horizontal Portion; OCI = obliquus capitis inferior muscle; OCS = obliquus capitis superior muscle; PAOM = posterior atlanto-occipital membrane; Post Tub = posterior tubercle; Prox Loop = proximal loop; RCPm = rectus capitis posterior minor muscle; RCPM = rectus capitis posterior major muscle; SC = splenius capitis muscle; SsC = semispinalis capitis muscle; SpC = spinalis cervicis muscle; Spin Pr = Spinous Process; Trans Pr = Transverse Process; VP = Vertical Portion.

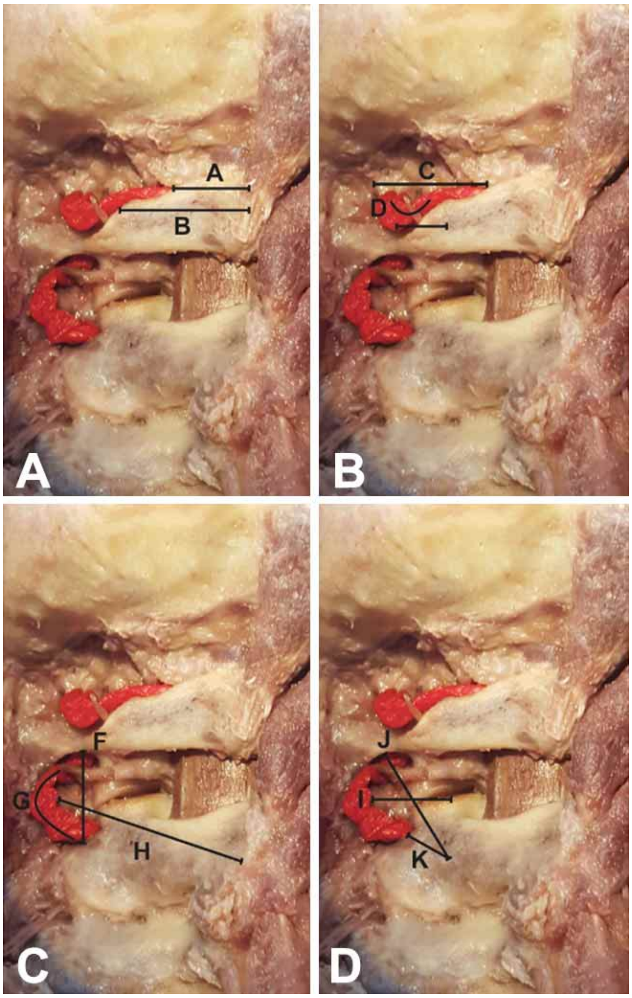

Fig. 2. Ilustration of variable measurements. Cadaveric dissection of the craniocervical junction and supraxial spine (Posterior view). A and B show the variables of the vertebral artery in its third segment (V3) with the atlas (C1), while C and D show the variables of the vertebral artery in its third segment (V3) with the axis (C2). The letters in figures correspond to the variables according to Table I.

RESULTS

A total of 10 cadavers (20 vertebral arteries) were evaluated, with a mean age of 56.7 ± 11.80 years. The anthropometry was a mean height of 174.6 ± 5.14 cm with a cephalic perimeter of 56.5 ± 2.46 cm. The variables had no significant difference when comparing right and left, so the data were grouped to analyze a total of 20 vertebral arteries in situ. The results are shown in Table II, this was grouped based on the HP and OP, and the VP of V3 and the surgical utility of each.

Table I. Variable classification by Surgical Application.

Surgical Procedure	Variable	Description
Exposure of C1 posterior arch	A	Distance from C1 midline to the entrance point of VA in the posterior atlanto-occipital membrane
	B	Distance from the C1 midline to the VA as it passes through the vertebral groove in C1 posterior arch
Exposure of C1 pars articularis (Lateral Mass Screws and Far-Lateral)	C	Length of the horizontal and oblique portion of V3
	D	Angle of the distal loop of V3
	E	Distance from the C1 pars articularis to V3 where it enters in the C1 transverse foramen
Exposure of C1-C2 joint	F	Length of the vertical portion of V3
	G	Angle of the proximal loop of V3
	H	Distance from the C2 spinous process to the medial surface of the proximal loop of V3
Placement of C1-C2 transarticular screws, C2 pars, C2 pedicle	I	Distance from the C1-C2 joint to the medial surface of the vertical proximal loop of V3
	J	Distance from the C2 pars articularis to V3 where it enters in the C1 transverse foramen
	K	Distance from the C2 pars articularis to V3 where. it leaves the C2 transverse foramen

Table II. Mean length of variables.

	Surgical Procedure	Variable	Mean ± SD
Oblique and horizontal portion	Exposure of C1 posterior arch	A	19.6 ± 3.1
		B	24.8 ± 6.3
	Exposure of C1 pars articularis (Lateral Mass Screws and Far-Lateral)	C	32.5 ± 2.1
		D	115.1 ± 8.3
		E	8.9 ± 1.4
Vertical portion	Exposure of C1-C2 joint	F	36.6 ± 1.9
		G	113.6 ± 5.8
		H	43.7 ± 4.2
	Placement of C1-C2 transarticular screws, C2 pars, C2 pedicle	I	6.5 ± 3.4
		J	17.5 ± 4.5
		K	9.5 ± 1.4

Data reported: Mean and SD (±).

The usefulness for posterior arch osteotomy and exposure of the atlanto-occipital joint was studied in the HP and OP. For the osteotomy of C1 posterior arch, two safety margins were quantified using the midline of C1 as reference. The first one was represented by the entrance of V3 to the posterior atlanto-occipital membrane, resulting in a mean distance of 19.6 ± 3.1 mm; while the distance to V3 as it passes over the vertebral groove in C1 posterior arc had a mean of 24.7 ± 6.3 mm. For the exposure of the atlanto-occipital joint the redundancy of the artery was assessed by a length of 32.7 ± 3.6 mm, with an angulation in the distal loop of 115.1 ± 8.3 degrees laterally to the articular facet of C1. The relation of the central point of the pars articularis of C1 with the most prominent point of the distal curvature resulted in a mean distance of 8.9 ± 1.4 mm.

The analysis of the VP for the exposure of the C1-C2 facet joint and the placement of the trans-articular screws C1-C2 / C2 pars. Related to de exposure of the C1-C2 facet joint the artery redundancy was assessed and showed a mean length of 32.5 ± 5.6 mm, with an angulation in the proximal loop of 113.6 ± 5.8 degrees. The distance between C2 spinous process towards the medial edge of the most prominent point of the proximal loop was 43.8 ± 4.2 mm. For the placement of transarticular screws the distance from C1-C2 facet joint to V3 of 9.5 ± 1.5 mm. From the C2 pars articularis, two measurements were made with mean of: 6.5 ± 3.4 mm from its entrance in C2 transverse foramen, and 17.5 ± 4.5 mm towards the exit point in the C1 transverse foramen.

DISCUSSION

The anatomy of the craniocervical complex is of relevance during surgical procedures to treat traumatic pathologies, neoplasms, degenerative diseases, congenital malformations, among others. V3 has the highest risk of being injured in different procedures such as suboccipital craniectomies, "far-lateral" type approaches, and during craniocervical junction instrumentation approaches (Cacciola *et al*., 2004; Fassett *et al*.). There are several studies on the relationships and variations of the V3 segment explaining various aspects of the position of the VA with the aim of reducing the risk of injury, using different techniques, such as dry bones, fixed cadavers, and imaging studies (Abd el-Bary *et al*.; Bruneau *et al*., 2006; Fassett *et al*.; de Souza *et al*.; Elliott *et al*., 2014; O'Donnell *et al*., 2014). Our study evaluates the relationships of V3 obtaining in situ measurements on fixed bodies. In order to make the results useful and applicable to a clinical scenario, they were grouped based on their relation to specific surgical procedures. There are four points in which VA can be injured during craniocervical approaches, two related to the HP and two to the VP (Fig. 2).

Medial part of the horizontal portion of V3. The posterior arch osteotomy of C1 is performed during suboccipital craniectomies to improve decompression of the posterior fossa. Injury to the medial portion of V3 may occur during osteotomy or curettage of the bone surface of the posterior arch of C1. The relationship of V3 at the medial end of the C1 midline has been reported between 16 mm and 24 mm (Abd el-Bary *et al*.; Bruneau *et al*.; de Souza *et al*.,; Fassett *et al*.). We identified the distal portion of V3 was not at the same site as the portion that crosses the groove carved in the posterior arch of C1. Due to this, a distinction should be made when establishing a safety range for the osteotomy. Our results showed a mean of 24.8 ± 6.3 mm from the C1 posterior midline to the grovee, but 18 mm until the site where the VA enters the atlantooccipital membrane. Considering this, our recommendation is to perform the C1 posterior arch osteotomy 18 mm lateraly to the posterior C1 tubercle to decrease the potential risk of VA injury.

Lateral part of the horizontal portion of V3. The exposure of the atlanto-occipital joint and/or superior joint facet of the lateral masses of C1 is performed during the placement of Condilo-C1 screws, "far lateral", and retro-mastoid type approaches. In these procedures the lateral section of the HP, and its redundancy are of great interest. The relationship of the most prominent surface of this vessel at this level with the center point of the pars articular of C1 showed a distance of approximately 9 mm, resulting in the safety dissection range for this bony prominence. Another relevant aspect for this segment is the degree of redundancy it presents. In our study we quantified this variable using the length and angulation of the distal curvature, reporting an angulation of 115.1º, demonstrating a more obtuse angle and less redundant length than those analyzed in other population (Inamasu *et al*.; Muralimohan *et al*., 2009) (Table III). It is possible the redundancy of the V3 segment varies with the age of the patients (Gupta), since there are studies that establish blood vessels increase their tortuosity with age due to degenerative changes in the wall.

Vertical portion of the V3 segment. The procedures that expose posteriorly the atlanto-axial complex, places the vertical portion of V3 at risk in two mainly moments: during the dissection of the C1-C2 joint, and during the placement of C1-C2 transarticular, C2 pars and C2 pedicle screws.

During the initial dissection of C1 and C2, the spinous process of C2 is a palpable and the primordial reference. From here, the closest distance to the vertebral artery is approximately 4 cm. Our results demonstrate the redundancy of this segment is further, approximately 8 mm from the C1-C2 joint. This indicates these are safe references to use for dissection and exposure of posterior elements of C1 and C2 levels. The transition point where the vertebral artery changes from second segment to third segment is at C2 transverse foramen, placing it at high risk of injury during the placement of C1-C2 transarticular screws and C2 pars screws. We examined the distance between the C2 pars articularis towards the proximal loop of V3, with a mean of 9.5mm, and an obtuse angle in the proximal loop of 113.6º, differing from others reporting an angulation of 90º in 50 % of the cases, acute angles in 37.5 %, and obtuse in 12.5 % (Fassett *et al*.).

Once the C1-C2 complex is exposed, in order to perform stabilization procedures, the surgeon can choose between C1-C2 transarticular, C2 pars or C2 pedicular screws. It has been determined that the risk of injury to the vertebral artery in these procedures is similar between these techniques, although there is a greater risk of injury in case of a high-riding VA, reason why it is preferable to use transpedicular screws instead of transarticular screws (Shafafy *et al*.; Yeom *et al*.). Our results did not determine this anatomical variable. However, we define mean distances from the probable site of entry of the screw to the identifiable bony references during the procedure.

Previous studies determine the redundancy of the artery based on angulation, reporting a mean angle of approximately 90 degrees, which in comparison are more acute than our results (Table III). Because the angles have a great variation in both the proximal curvature in the VP, as well as in the distal curvature of the HP, these should be studied in greater

Table III. Comparison with other authors.

Authors & Year	A	B	C	D	E	F	G	H	I	J	K
Cacciola 2004	---	22.1 †	35.7 †	---	---	15.7 †	---	---	---	---	---
Gupta 2008	---	16.40 ± 3.44 R 16.03 ± 3.49 L	---	---	---	---	---	---	---	---	---
Muralimohan 2009	---	---	15.04 ± 1.53 †	---	---	35.57 ± 2.44 †	---	---	---	---	---
Ulm *et al*. 2010	---	23 ± 5.5 R 24 ± 5.7 L	---	---	---	---	90 ° †	30.4 ± 3.8 R 25.6 ± 3.5 L	---	---	---
Alfaouri-Kornieieva 2014	---	---	29.33 ± 2.11 R 31.01 ± 2.23 L	75.40 ° ± 1.06 R 68.80 ° ± 1.23 L	---	22.98 ± 2.52 R 24.63 ± 2.23 L	72.13 ° ± 1.48 R 75.66 ° ± 1.57 L	---	---	---	---
Khanfour 2015	---	15.30 ± 2.07 R 16.33 ± 1.98 L	---	---	---	9.70 ± 0.98 R 10.90 ± 0.78 L	---	---	---	---	---
Akar 2016	---	18.90 ± 2.48 R 18.53 ± 2.00 L	19.08 ± 2.47 R 18.66 ± 1.45 L	---	---	---	---	---	---	---	---
Present Study 2019	19.86 ± 2.95 R 19.23 ± 3.30 L	25.25 ± 6.60 R 24.29 ± 6.33 L	32.51 ± 4.23 R 32.50 ± 4.93 L	115.20 ° ± 7.00 R 114.90 ° ± 9.75 L	9.20 ± 1.49 R 8.73 ± 1.43 L	37.30 ± 1.34 R 35.95 ± 2.51 L	112.60 ° ± 5.66 R 114.60 ° ± 6.02 L	43.49 ± 5.16 R 44.00 ± 3.27 L	6.61 ± 3.53 R 6.31 ± 3.50 L	17.50 ± 4.23 R 17.48 ± 4.93 L	10.03 ± 1.42 R 9.03 ± 1.37 L

Data reported: Mean and SD (±) on the right side (R) and left side (L). † Average measure reported

detail and taken into account in surgery, due to the possible inadvertent lesion during the craniocervical instrumentation.

With the development of new technologies such as navigated procedures, anatomical references will seem less useful, however the availability of these resources is not feasible in most centers in developing countries. In addition, there are publications that show that neuro-navigated procedures have not yet surpassed free-hand procedures in safety and risk of complications (Ulm *et al*.; Alfaouri-Kornieieva & Al-Hadidi, 2014; Ha *et al*., 2014). Anatomical understanding of this region will continue to be relevant for neurosurgeons, especially for those who encounter a rising learning curve.

As a conclusion, the data provides safety ranges for the posterior approaches of the craniocervical junction and supra-axial spine. Knowledge of the V3 segment in relation to the spine provides parameters to reduce the risk of injuries in the V3 segment. The relationship of the degree of redundancy based on the age and sex of the patients should be further studied.

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RESUMEN: El objetivo de este estudio fue establecer rangos de seguridad en el tercer segmento de arteria vertebral (V3) para cirugías de la región craneocervicales. La lesión de V3 representa una complicación potencialmente catastrófica. Su tortuoso trayecto y compleja relación con las estructuras aledañas, aumenta el riesgo. Se estudiaron diez cadáveres adultos masculinos (20 arterias vertebrales) con infiltración arterial de látex rojo. La longitud, ángulos y medidas anatómicas se obtuvieron respecto a los puntos de referencia quirúrgicos y las porciones del segmento V3. La porción horizontal tiene una longitud de 32,7 ± 3,6 mm con una angulación de 115,1 ± 8,3 grados. Las distancias medias de la porción horizontal fueron: desde la línea media hasta el surco V3 del arco posterior C1 (24,7 ± 6,3 mm); desde C1 pars interarticularis hasta el bucle distal V3 de V3 (8,9 ± 1,4 mm). La parte vertical tiene una longitud de 32,5 ± 5,6 mm con una angulación del bucle proximal de 113,6 ± 5,8 grados. Las distancias medias entre el proceso espinoso C2 y la superficie medial del bucle distal (43,8 ± 4,2 mm); desde la unión C1-C2 hasta la porción vertical V3 (9,5 ± 1,5 mm); de C2 pars interarticularis a V3 en el foramen transversal C2 (6,5 ± 3,4 mm); de C2 pars interarticularis a V3 en el foramen transversal C1 (17,5 ± 4,5 mm). Informamos cuatro sitios potenciales donde la V3 puede lesionarse durante cuatro procedimientos quirúrgicos diferentes: exposición del arco posterior de C1 y pars interarticularis de C1 en la porción horizontal y exposición de la articulación C1-C2, y colocación de C1-C2 Tornillos transarticulares uno en la porción vertical. Proporcionamos mediciones de los rangos de redundancia y seguridad para reducir el riesgo de lesiones en el segmento V3 durante procedimientos quirúrgicos craneocervicales.

PALABRAS CLAVE: Anatomía; Arteria vertebral; Segmento V3; Columna cervical; Cirugía de columna.

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