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Intraoperative Computed Tomography for C1-C2 Stabilization by Goel-Harms: Analysis of Clinical Efficacy and a Novel Classification of Screw Placement Accuracy

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■ BACKGROUND: **The introduction of intraoperative computed tomography (iCT) could improve the surgical results of C1-C2 stabilization by Goel-Harms, especially in patients with complex deformities. This study aims to investigate the impact of iCT on the accuracy of C1-C2 screw positioning and to develop a score based on multiparametric analysis of imaging data (Cervical Screw Placement Accuracy score [CSPAs]).**

■ METHODS: **Twenty-one patients were retrospectively evaluated. The data obtained with the use of an iCT were compared with the incidence of cases of malpositioning in the literature. Multiparametric imaging criteria were developed: the 82 screw positions were evaluated using the CSPA criteria and 2 additional variables. The CSPAs was obtained from the aggregation of the CSPAs criteria: optimal (CSPAs ≥8), suboptimal (CSPAs = 6–7), malpositioned (CSPAs ≤5).**

■ RESULTS: **The average incidence of malpositioning in C1-C2 arthrodesis decreased from 13% without iCT to 1.2% with the aid of iCT, considering a monoparametric value. The CSPAs analysis shows a greater discretion and higher number of well-defined categories of the accuracy of C1-C2 screw position: optimal, 80.3%; suboptimal, 17.1%; and malposition, 2.6%. A correlation was observed between the accuracy of the positioning of both right and left screws in C2. Furthermore, the anatomic site of C2 screws was found to be a predictor of cortical invasion.**

■ CONCLUSIONS: **The results suggest that the introduction of the iCT is associated with a consistent improvement of the accuracy in the positioning of the screws. A multiparametric score (CSPAs) could improve the assessment of screw placement.**

INTRODUCTION

Many pathologic causes can lead to C1-C2 instability. Usually, they involve the C1-C2 joint and ligamentary structures. The cause is most frequently acute trauma, followed by odontoid nonunion, inflammatory disease (rheumatoid arthritis), or a tumor.[1-5]

Atlantoaxial arthrodesis, especially with posterior approaches, is technically demanding and is known to be a surgical challenge because of the proximity of neurovascular structures and wide range of motion of the joint.[3,6]

In 2001, Goel-Harms developed his technique of atlantoaxial screw fixation, introducing a stabilization based on fixation of the C1 lateral masses and C2 isthmus using polyaxial screws.[7-9]

Complications are potentially severe and can be divided as follows: damage to neurovascular anatomic structures, loss of bone continuity, and system failure (recurrence or worsening of instability). These complications are strictly related to mechanical variables such as screw trajectory and its structural characteristics. Therefore, it is advisable to monitor and evaluate the precision of the screw positioning to minimize risks and improve clinical outputs.

Key words
- C1-C2 stabilization
- Classification
- Goel-Harms technique
- Intraoperative CT scan
- Screw accuracy

Abbreviations and Acronyms
CSPAs: Cervical Screw Placement Accuracy score
CT: Computed tomography
iCT: Intraoperative computed tomography
IRLR: Ideal/real length ratio

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The recent introduction of intraoperative computed tomography (iCT) has the potential to improve procedural results, especially in patients with complex deformities.[10]

iCT is used to achieve clearer images of the regional anatomy after the patient has been positioned in a prone fashion to allow neuronavigation during the process of placing the screws and to control their correct placement even before the patient is awake, obviating a second surgery.

This study aims to investigate the impact of iCT on the accuracy of the placement of the screws in C1-C2 and to develop a score (Cervical Screw Placement Accuracy score [CSPAs]) based on multiparametric analysis of imaging data (Figures 1—3).

METHODS

A retrospective review was conducted of all patients from January 2017 to October 2019 who underwent posterior C1-C2 stabilization using iCT and neuronavigation. Four different spine surgeons with varying clinical experience performed the operations in 2 different institutes (AOU Città della Salute e della Scienza di Torino and AOU Maggiore della Carità di Novara).

The exclusion criteria were constructs with only C1 or C2 included in the stabilization, poor image quality, and C1-C2 stabilization without iCT use.

All patients underwent preoperative angio computed tomography (CT) to determine feasibility of surgery. At the beginning

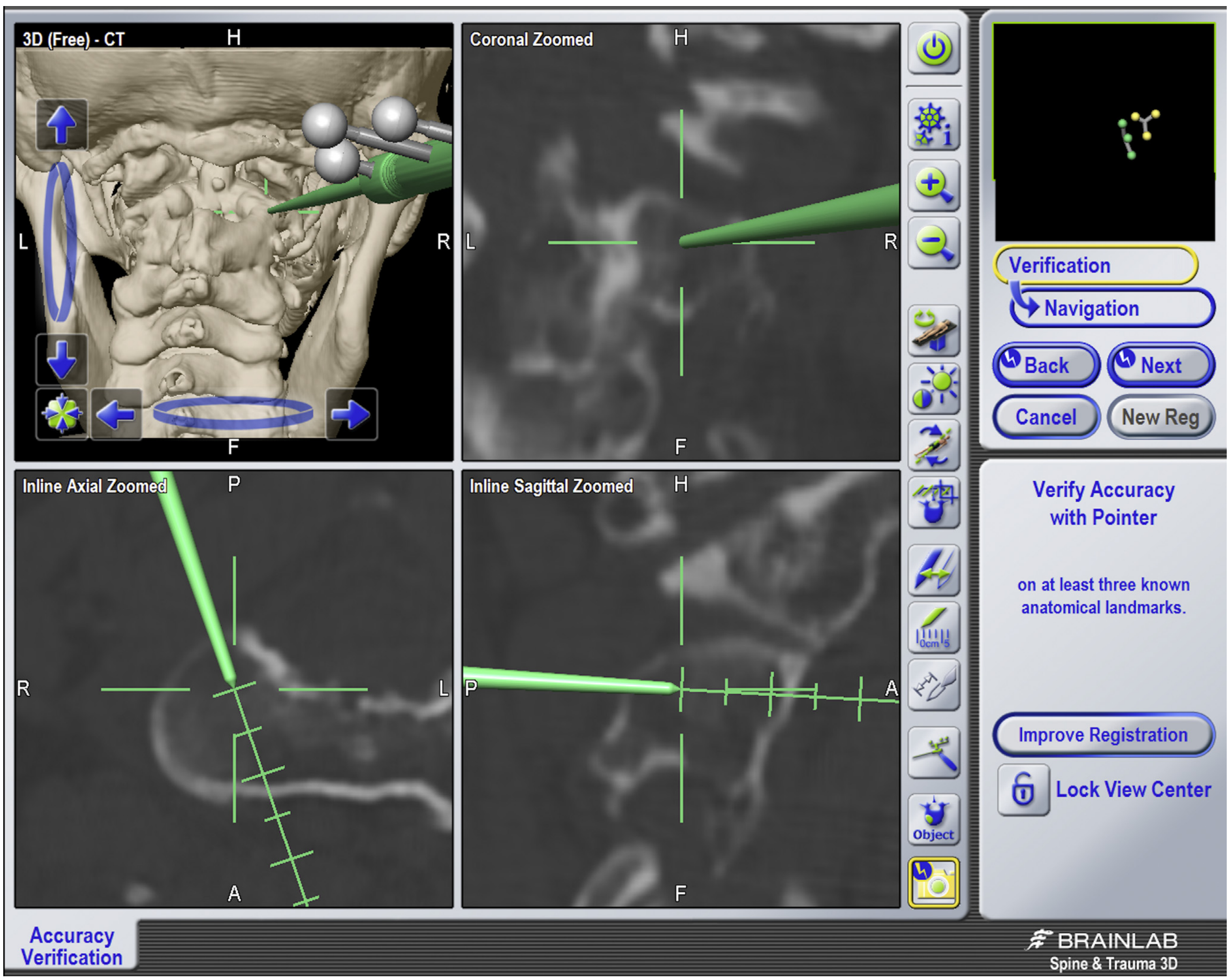

Figure 1. Neuronavigation applied to C1-C2 stabilization.

of the procedure, once the patient was properly positioned on the surgical table, a prone iCT scan was acquired for planning and stealth acquisition. After the vertebrae were skeletonized, stealth guidance (Brainlab, Westchester, Illinois, USA), was set with a point-by-point match. The screws were inserted with a customized entry point and trajectory. With the help of neuronavigation, the longest (with more bone purchase) and safest trajectory was chosen, the tip projection feature allowed for stressing screws bicorticallity safely avoiding any vertebral artery or medullary injury.

Because of reasons associated with the specific disease or anatomic variations, patients occasionally had unilateral or asymmetric C1 fixation applied. Therefore, each screw was analyzed individually and a total of 21 patients and 82 screws were evaluated. A review of the literature was conducted to assess the incidence of malpositionings (defined through a monoparametric evaluation) in C1-C2 arthrodesis without iCT aid.[10-19]

To assess the impact of iCT, the data obtained were compared with the incidence of malpositionings registered. The following clinical data were analyzed: age, gender, cause of instability, myelopathy, operative time, preoperative and postoperative neurologic status, complications, and necessity for further surgery after 3 months.

To refine the evaluation, novel multiparametric imaging criteria (CSPAs) were developed. The screw positions were then assessed using the CSPAs criteria and 2 additional variables.

The CSPAs was obtained from the aggregation of the CSPAs criteria and used to classify the accuracy of the positioning as following: optimal (CSPAs $\geq$8), suboptimal (CSPAs = 6–7), and malposition (CSPAs $\leq$5).

CSPAs Criteria

Many studies have analyzed errors in the placement of thoracic, lumbar, and cervical screws.[10] Only a few have included screws in C2[10,11] and the studies that fully investigated C1-C2 arthrodesis did not take into consideration the use of iCT.[12] No evidence was found of previous studies including analysis of C1-C2 stabilization with iCT.

Most of the studies found in the literature assess the evaluation of the placement of the screw, considering the cortex invasion as the only parameter needed.

This score takes into consideration more variables: 2 criteria for screws in C1 and 3 criteria for screws in C2 (16 different variables in total, with specific scores).

C1

A systematic review by Aude et al.[10] shows that the most widely used method to assess cortex invasion is the 2-mm increment grading system based on CT imaging. Of 37 different articles reviewed, the method described by Amato et al.[20] was chosen to report the C1A criteria.

Screw position was classified as correct when the screw was completely surrounded by the pedicle cortex, as “cortical encroachment” (questionable violation) if the pedicle cortex could not be visualized, and as “frank penetration” when the screw was outside the pedicular boundaries. Frank penetration was further subdivided as minor (when the edge of the screw thread was $\leq$2.0 mm outside the pedicle cortex), moderate (2.1–4 mm), and severe (4 mm) (Figure 4).[20]

The criteria of Amato et al.[20] were completed by entering a score useful for calculating the CSPAs score (Table 1).

Figure 2. Screws applied correctly in C1.

Figure 3. Screws applied correctly in C2.

It is also specified that penetration can take place in the following senses: medial, lateral, superior, and inferior.

Criterion C1B describes the length of the screw, which is considered correct if the anterior cortex is penetrated by a maximum of 2 mm. This criterion was added also by reaching the anterior cortex, leading to greater stability of the whole system.

Penetration >2 mm is considered incorrect because it increases the risk of damaging proximal anatomic structures (Table 2).

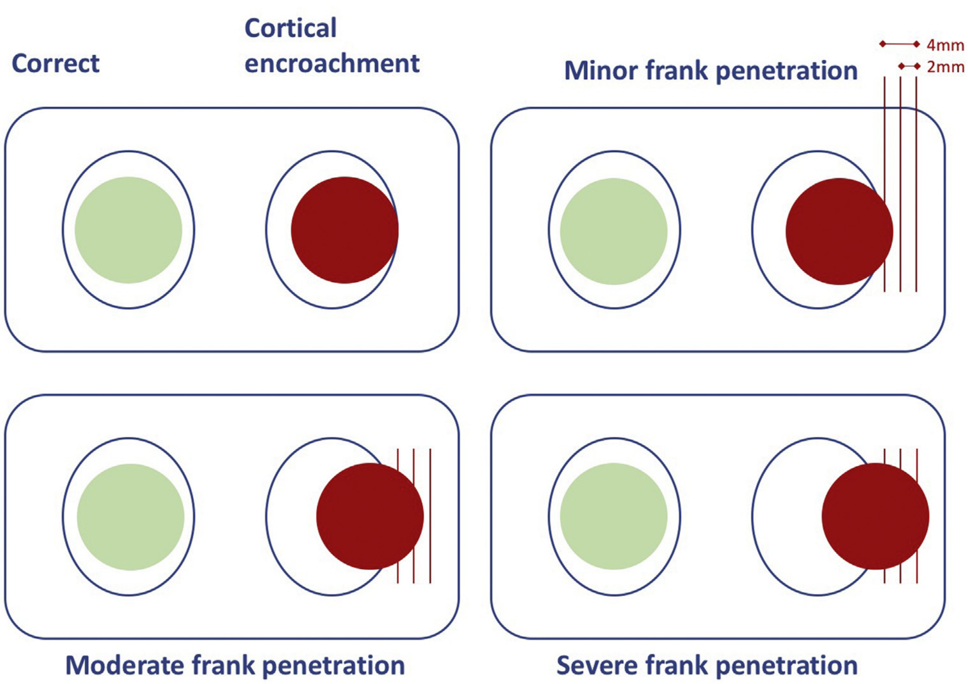

Figure 4. Cortex invasion criteria.

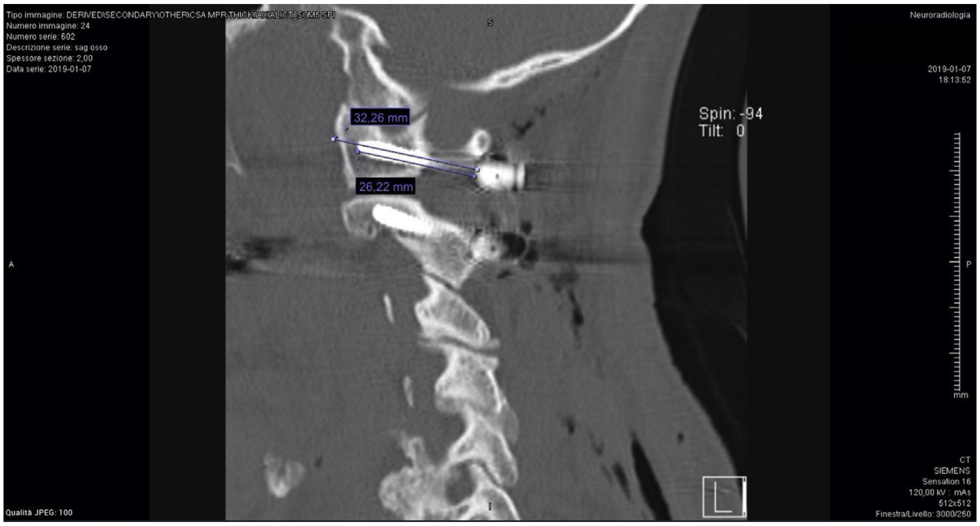

Figure 5. Ideal/real length ratio measuring.

The length of each screw was analyzed and further established a ratio (ideal/real length ratio [IRLR]) that shows more precisely by which percentage the screw is longer/shorter compared with the length of the ideal screw (**Figure 5**). The IRLR is positive when the screw is long and negative when the screw is short. It was obtained according to the formula:

$$\text{ideal screw length} : \text{real screw length} = 100 : x$$

where x is the percentual length of the real screw compared with the ideal one from which $100 - x$ is the percentage of inadequacy referred to the real screw compared with the ideal one.

C2

Criterion C2A is the same as Criterion C1A (**Table 3**). Criterion C2B was slightly modified compared with that in C1, because reaching the anterior cortex in C2 is desirable, but less important than it is in C1. The peduncular cortex guarantees major consistency of the bone compared with the lateral mass of C1 (**Table 4**).

Criteria C2C took into consideration whether the transverse foramen is violated or not (**Table 5**).

The position of the screw in C2 is highlighted: pedicle, pars interarticularis or laminar.

In cases of laminar screw, only criterion C2A can be evaluated.

CSPAs score is calculated as follows:

$$\text{C1 CSPAs} = \text{C1A} + \text{C1B}$$

$$\text{C1 CSPAs} = \text{C2A} + \text{C2B} + \text{C2B}$$

Therefore, the system was conceived using existing scores, evaluating how to divide the total amount of points in terms of free, potential, or overt derived risk for the stability of the instrumentation and/or injury to surrounding structures such as vertebral arteries (see Discussion section). The statistical analysis then gave it a scientific interpretation (**Tables 6** and **7**).

RESULTS

Twenty-one patients were retrospectively evaluated, of whom 12 were male (57.1%) and 9 female (42.9%) with a mean age of 73 years. Of these patients, 11 (52.4%) underwent surgery in Turin and 10 (47.6%) in Novara. In 13 patients (65%), a fracture of the axis dens was detected, in 4 (20%), a C1-C2 medullary compression, and in 3 (15%), general instability of the atlas-axis joint. Of the 13 patients with tooth fractures of the axis, 100% had a traumatic origin of the lesion and 61.5% were operated on at the Novara facility. Radiologic signs of myelopathy were also found in 70% of patients; the data were significantly distributed ($P = 0.002$; Cramer $V = 0.788$) among the indications for the intervention: 92.3% of patients with tooth fractures did not develop signs of myelopathy, which was present instead in 100% of patients with spinal cord compression.

The patients analyzed reported the following comorbidities: rheumatoid arthritis (10%), Down syndrome (5%), distal polyneuropathy (5%), myelodysplastic syndrome (5%), Klippel-Feil syndrome (5%), and idiopathic hypertension (10%). The remaining patients did not report comorbidities. The presence of comorbidity was more associated with a nontraumatic (degenerative, malformative, or rheumatic) cause of the lesion.

The analysis of surgical reports showed that 3 patients (14.28%) developed intraoperative complications, in 1 patient directly after malposition (perforation of the vertebral artery) as a result of a severe anatomic dysfunction; in the other 2 patients, there were

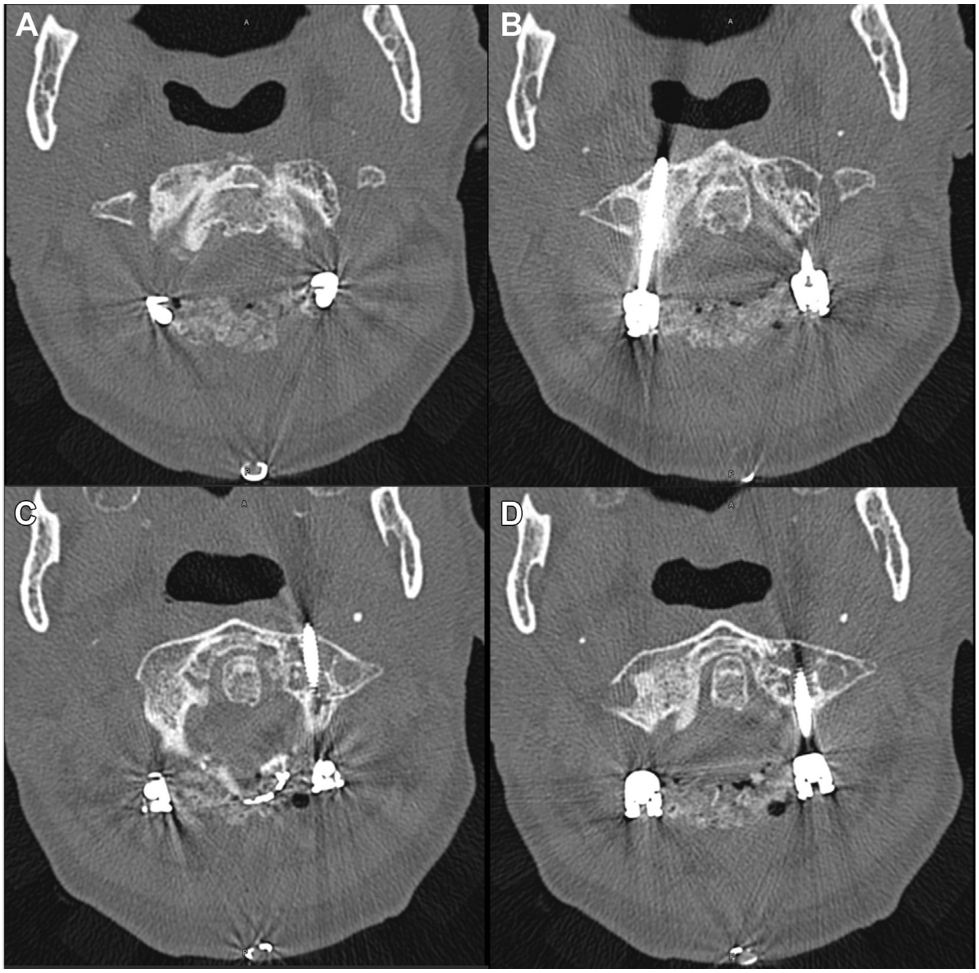

Figure 6. Screws applied correctly in C1 seen on multiple TC levels.

cardiovascular complications related to anesthesia, then not connected to instrumentation.

No need for reintervention was registered at 90 days (**Figures 6** and **7**).

SCREWS

C1—Right

As shown in the tables below, all of the screws applied to the right in C1 are classified as correct (71.4%) or as cortical encroachment (28.6%) according to criteria A, which evaluated the possible invasion of the cortex (lateral, medial, superior, or inferior invasion of the bone) (**Figure 8**). Criteria B evaluated the length and showed that 66.6% of the screws reached the anterior cortex or perforated it for a maximum of 2 mm; only the remaining 33.3% were found to be more distant from the cortex, of which 14.3% for >2 mm (**Figure 9**).

The CSPAs distribution table shows that 80.9% of the screws were classified as optimal positioning and 19.1% as suboptimal positioning. No screws were misplaced (**Figures 10** and **11**).

C1—Left

The C1 screws applied to the left are similar to those applied to the right (**Figures 12** and **13**). There are differences on the length variable: the screws on the left are further from the anterior cortex; 20% of these do not reach the cortex by >2 mm, and only 25% perforate the cortex correctly, against 33.3% of the screws on the right.

The IRLR distribution table shows us that a screw was evaluated 8% longer compared with the ideal screw; 5 screws had an

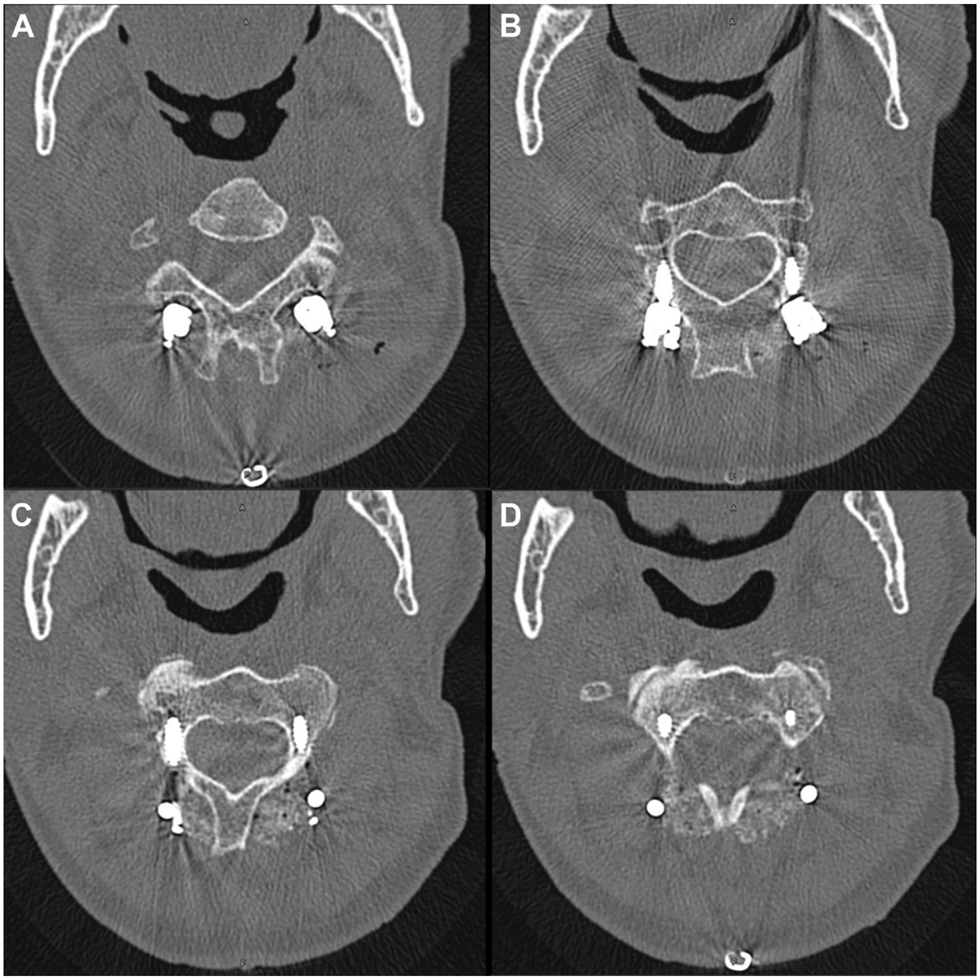

Figure 7. Screws applied correctly in C2 seen on multiple TC levels.

adequate length and the remaining 14 were shorter, for an average of 5.6% inadequacy (Figure 14).

In C1, on the left, a suboptimal positioning of 5 screws (25%) is highlighted. Because in C1 on the left a screw was not placed, 20 screws were studied, against 21 screws in C1 on the right (Figure 15).

No cortical penetrations (minor frank penetration, moderate frank penetration, or severe frank penetration) were registered in any screw applied to C1.

C2—Right

Of a total of 21 screws inserted in C2 on the right, 57% were positioned correctly and 38% were in contact with the cortex of the peduncle (Figure 16). Only 1 screw (4%) invaded and exceeded the cortex by >2 mm (Figure 17).

In the C2 screws, the length parameter seems to be distributed more evenly over the variables, compared with the same parameter evaluated on the C1 screws.

Of the screws, 5.3% have an adequate length, whereas most do not reach the anterior cortex for <4 mm.

The IRLR distribution table shows us that 1 screw was positioned "long" by 4%, 1 screw was positioned correctly, and the remaining screws were considered short, for an average percentage of inadequacy equal to 12.6%. The length parameter and, consequently, the reaching of the anterior cortex, is supposed to be less important in C2 than in C1; this led us to weigh the score for length differently between the 2 vertebrae (Figures 18 and 19).

Of a total of 19 screws, 2 were misplaced. The first screw (CSPAs = 0) invaded the peduncular cortex, was short, and violated the transverse foramen; the second (CSPAs = 5), although not

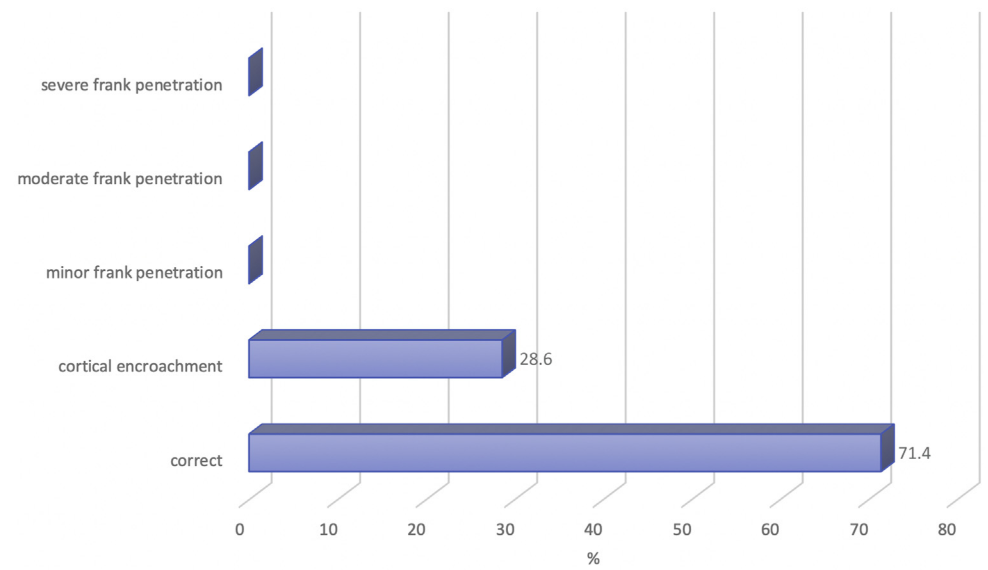

Figure 8. Right C1A—cortex invasion ($n = 21$).

invading the cortical bone, was short and invaded the transverse foramen. Overall, the data obtained show a substantial difference between the accuracy of the positioning of the screws in C2 on the right than on the left; these data are worthy of new investigations (**Figure 20**).

C2—Left

The CSPAs cannot be evaluated in cases of interlaminar screws, because the variables relating to the length and the violation of the transversal foramen cannot be verified (**Figures 21—25**). These screws are not evaluated using the score. However, they are analyzed using each valid criterion.

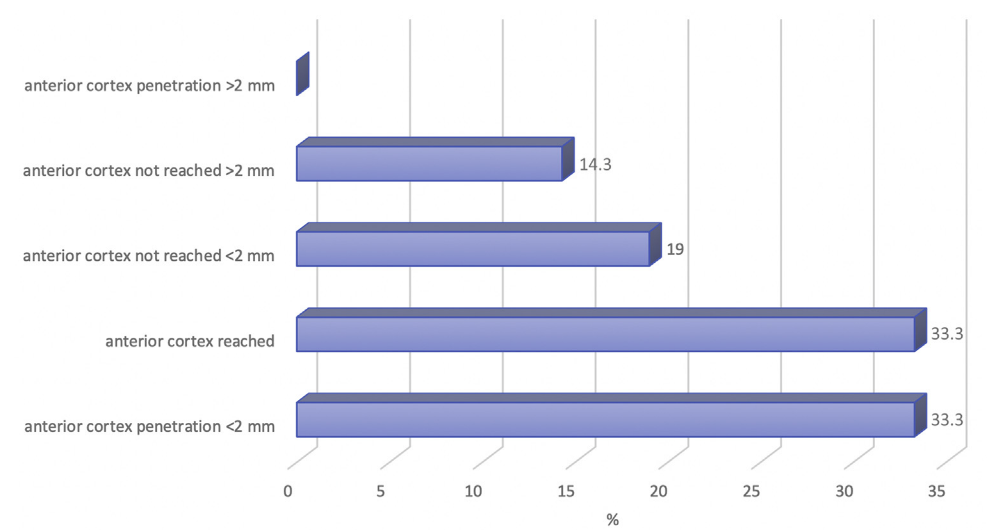

Figure 9. Right C1B—length ($n = 21$).

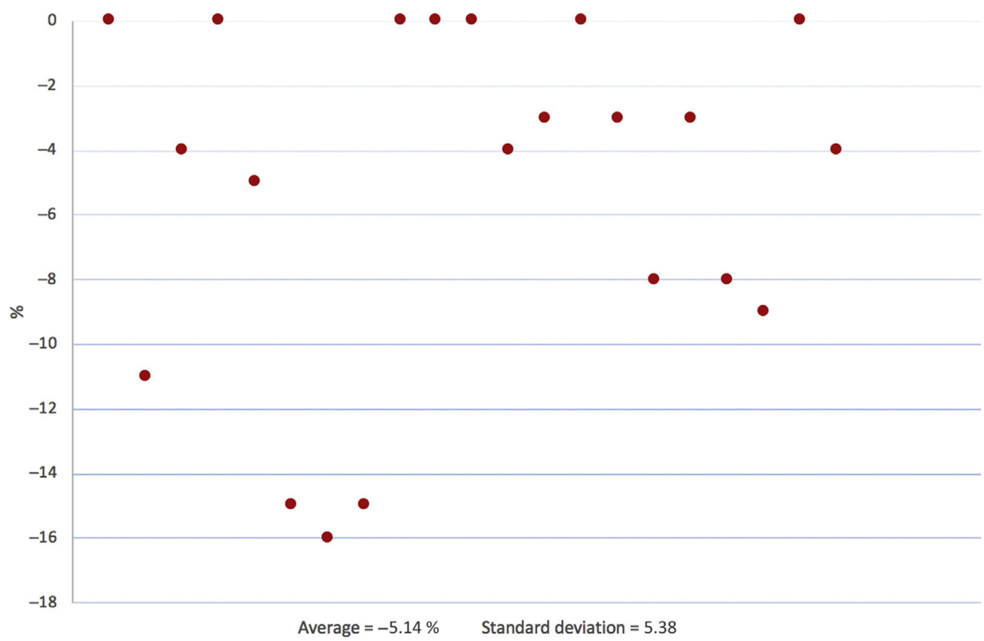

Figure 10. Right C1 ideal/real length ratio (IRLR) distribution ($n = 21$). The IRLR index provides a percentage measure of the inadequacy of the inserted screw compared with the ideal screw length. 14 screws were considered short; overall, therefore, an average IRLR of −5.14 reported that the screws in C1 on the right were positioned "short" for an average of inadequacy equal to 5.1%.

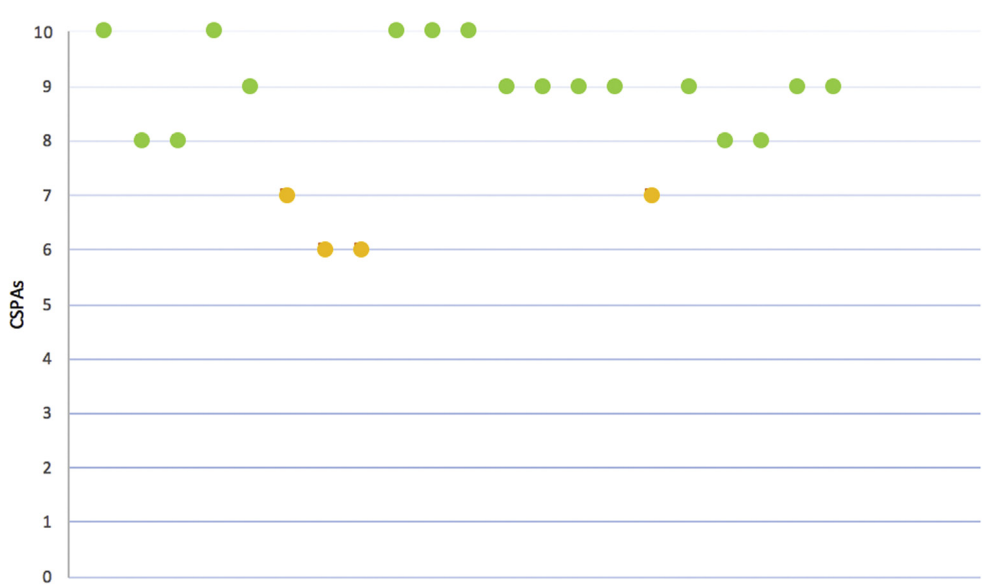

Figure 11. Right C1 Cervical Screw Placement Accuracy score distribution. Optimal placement, 17 (80.9%); suboptimal placement, 4 (19.1%); misplacement, 0 ($n = 21$).

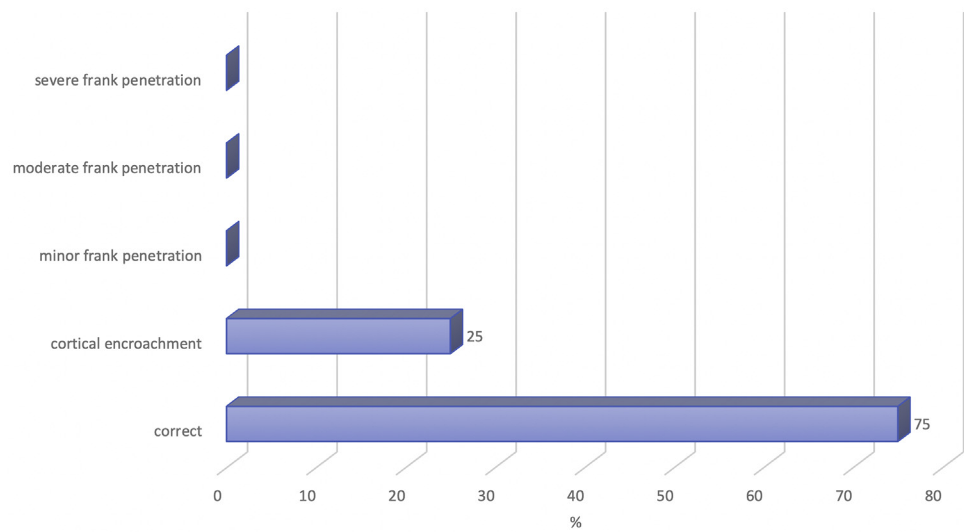

Figure 12. Left C1A—cortex invasion ($n = 21$).

C1-C2 Overview

Overall, the data analysis carried out according to the CSPAs allows a greater discrimination among the different placements, classifying them as follows: 80.3% of the vines are positioned optimally, 17% suboptimally, and 2.6% incorrectly (Figures 26 and 27).

A descriptive statistical analysis allowed us to compare the results with the literature, using the same criteria: the previous studies refer to monoparametric evaluation, mainly using the criterion that considers the invasion of the cortical bone (criterion A in CSPAs).

Taking into consideration only this parameter, it is shown that 1.2% is classifiable as "badly positioned", against 9.8% of the screws[10] (average in the literature) inserted without the aid of iCT analyzed in previous studies.

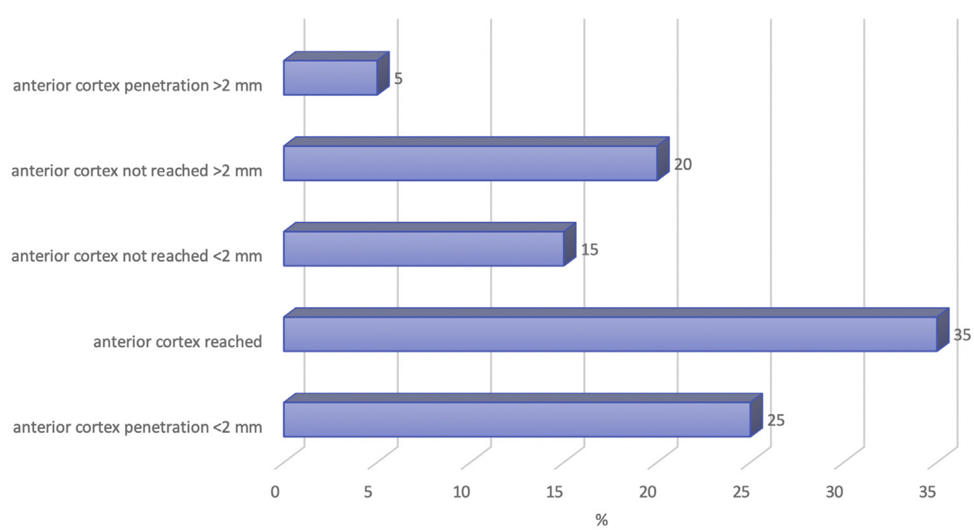

Figure 13. Left C1B—length ($n = 21$).

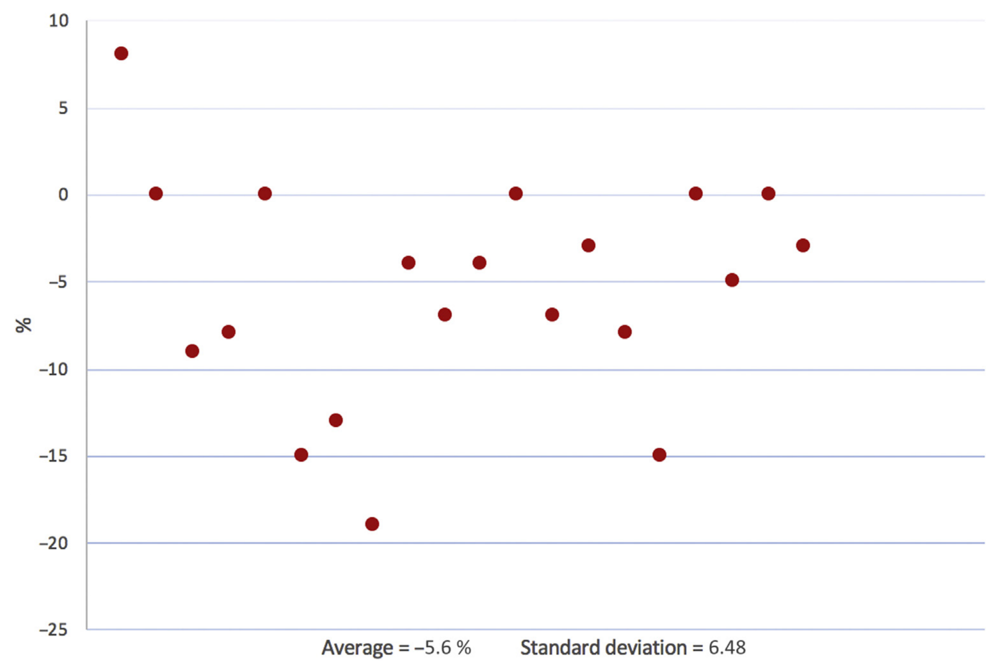

Figure 14. Left C1 ideal/real length ratio distribution ($n = 21$).

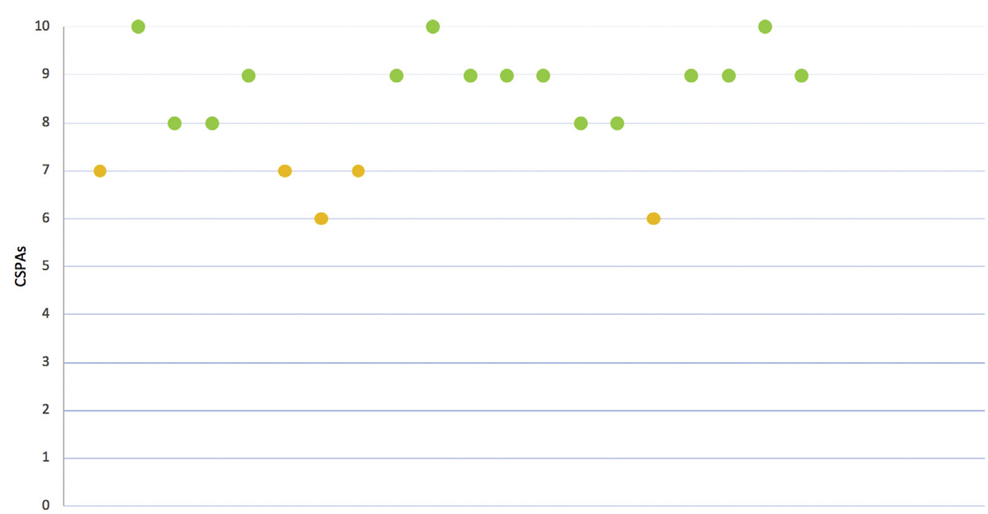

Figure 15. Left C1 Cervical Screw Placement Accuracy score (CSPAs) distribution. Optimal placement, 15 (75%); suboptimal placement, 5 (25%); misplacement ($n = 20$) (left C1 screw was not positioned in 1 patient).

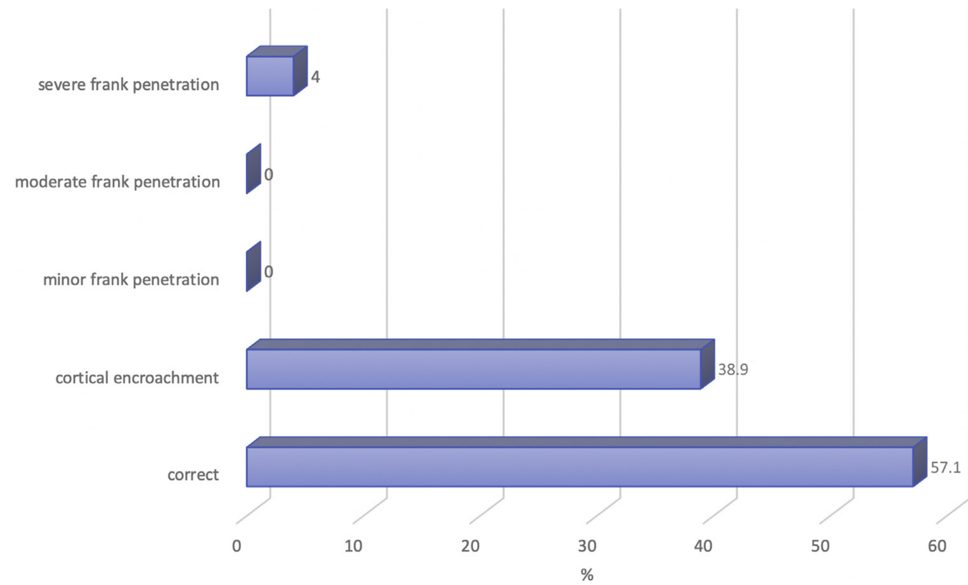

Figure 16. Right C2A—cortex invasion (n = 21).

Correlative Analysis

Possible associations and correlations among the single CSPA criterion, the CSPAs, and the clinical and intraprocedural information of patients were investigated.

The data obtained do not suggest any association between the accuracy of screw positioning in C1 and the accuracy of positioning in C2.

Instead, a correlation is noted between the invasion of the cortex in the right C2 screws and the left C2 screws ($P = 0.016$; Cramer $V = 0.643$) and in general between the CSPAs score on the right C2 screws and the CSPAs of the screws C2 on the left ($P = 0.013$; Cramer $V = 0.659$).

Furthermore, the anatomic site of the C2 screws was found to be a predictor of cortical invasion ($P = 0.010$; Cramer $V = 0.677$).

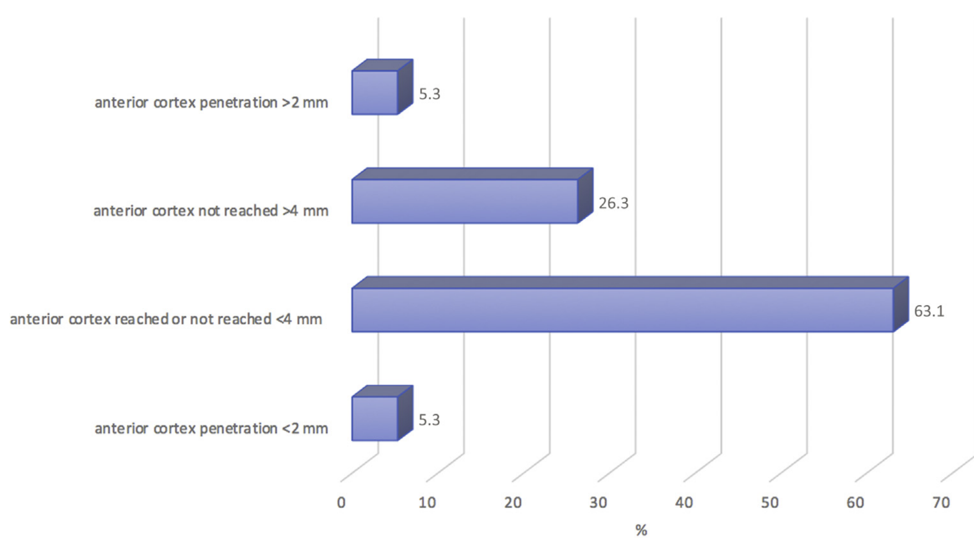

Figure 17. Right C2B—length (n = 19) (right C2 screw length could not be assessed in 2 patients because of poor image/radiologic definition).

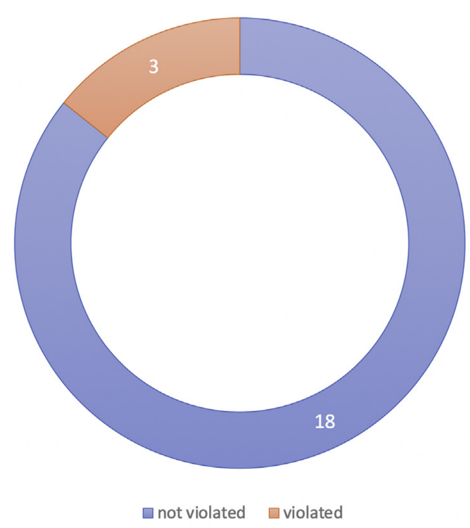

Figure 18. Right C2C—transverse foramen.

Patients were further divided based on the cause of the lesion: traumatic and nontraumatic (degenerative, rheumatic, or malformative); in this manner, a significant association trend emerged in favor of the association of nontraumatic and CSPAs <7 lesions in the screws applied in C2 to the right ($P = 0.021$; Cramer $V = 0.814$) and left ($P = 0.036$; Cramer $V = 0.779$).

DISCUSSION

This study set 2 different goals. First, the relationship between the recent introduction of iCT and the accuracy of screw placement in C1-C2 arthrodesis according to Goel-Harms was investigated.

A systematic review of the literature was carried out to evaluate the incidence of malpositioning with C1-C2 arthrodesis without the aid of iCT. A 2005 study by Aoude et al.[10] analyzed 68 articles on the different types of evaluation of accuracy in the insertion of pedicle screws, for a total of 43,305 screws. The investigators conclude by stating that the most widely used method, as well as that considered the most precise, is based on the evaluation of the possible cortical invasion, divided into 2-mm steps. Among the reported classifications, the one proposed by Amato et al.[20] was selected to analyze the data and compare them with the literature; the same classification was included in the new CSPAs evaluation criteria as criterion A and completed with scores.

The literature on C1-C2 arthrodesis suggested the use, in C1, of the same monoparametric criteria used for C2 pedicle screws.

Most investigators[10] agree that any situation in which the penetration of the cortex is <2 mm is considered risk free: in this limit fell both the “correct” and “cortical encroachment” variables of criterion A, which are summed up in 98.8% of the

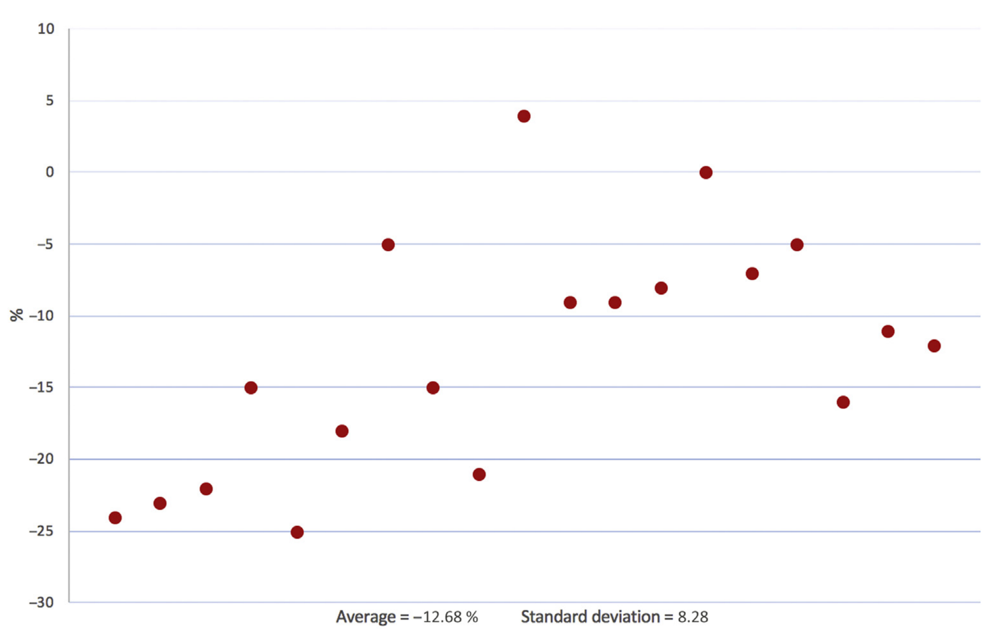

Figure 19. Right C2 ideal/real length ratio distribution ($n = 19$) (right C2 screw length could not be assessed in 2 patients).

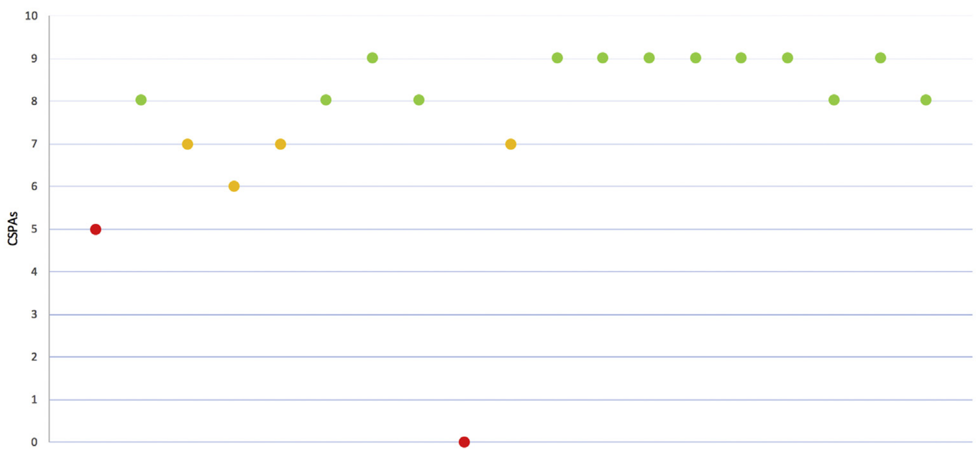

Figure 20. Right C2 Cervical Screw Placement Accuracy score (CSPAs) distribution. Optimal placement, 13 (68. 4%); suboptimal placement, 4 (21%); misplacement, 2 (10.6%) ($n = 19$) (right C2 screw length could not be assessed in 2 patients).

screws analyzed. Only 1.2% of the screws can thus be considered unsafe or malpositioned.

Therefore, it can be stated that the average incidence of malpositioning of synthesis media in C1-C2 arthrodesis procedures goes from 9.8% without the aid of iCT (average in the literature)[10-14] to 1.2% with the aid of iCT (Table 8).

The second objective of the study consisted of the development of a score (CSPAs) based on multiparametric analysis of the imaging data.

It is known that the main complications of the intervention consist of loss of bone continuity, structural instability of the system, and bleeding. In particular, the instability of the system and the bleeding correlate respectively with the length of the screws and the violation of the transverse foramen. The achievement by the screws of the anterior cortical bone guarantees greater structural stability and a lesion of the vertebral artery passing through the transverse foramen causes intraprocedural bleeding. However, in the literature, the parameters described

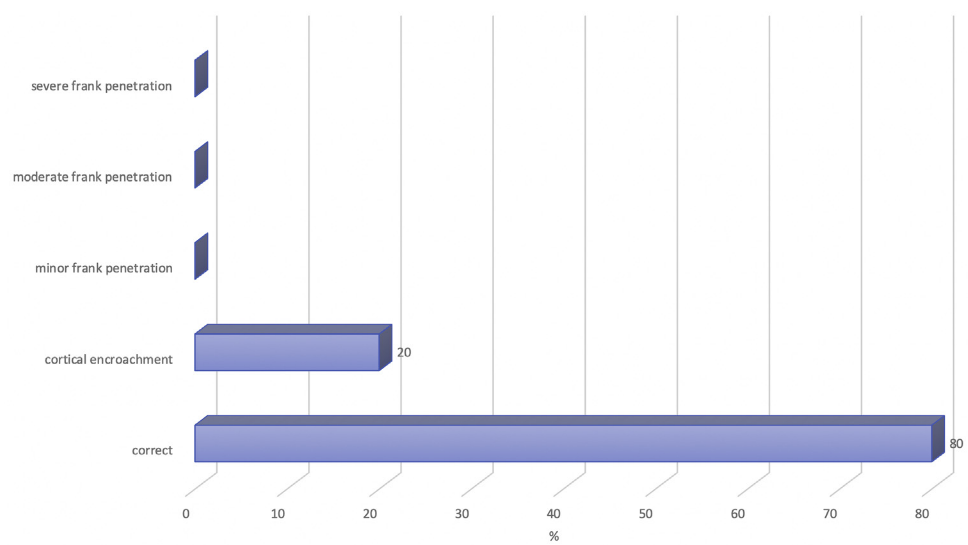

Figure 21. Left C2A—cortex invasion ($n = 20$) (left C1 screw was not positioned in 1 patient).

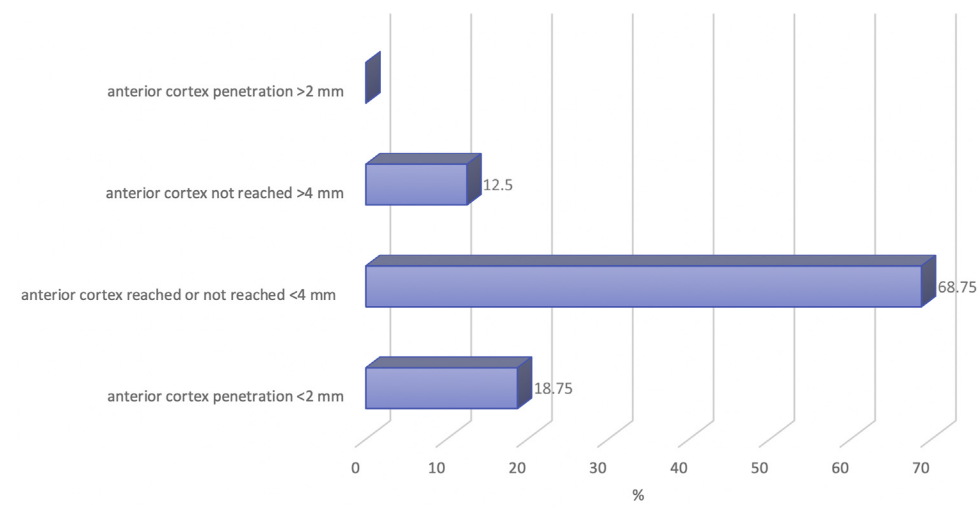

Figure 22. Left C2B—length ($n = 16$) (right C2 screw length could not be assessed in 2 patients; left C2 screw was not positioned in 1 patient; 2 patients underwent interlaminar screw positioning).

are not evaluated together; they are not weighted differently between C1 and C2 and are rarely correlated with the recently introduced iCT.

Therefore, it was appropriate to add further variables, which could analyze in detail the different characteristics of the placement.

The analysis of the data according to the CSPAs criteria and the CSPAs results in greater discrimination of the accuracy in the positioning of the screws: optimal, 80.3%; suboptimal, 17.1%; and malpositioning, 2.6%. The significance of the screws positioned according to the suboptimal positioning judgment should be contextualized case by case.

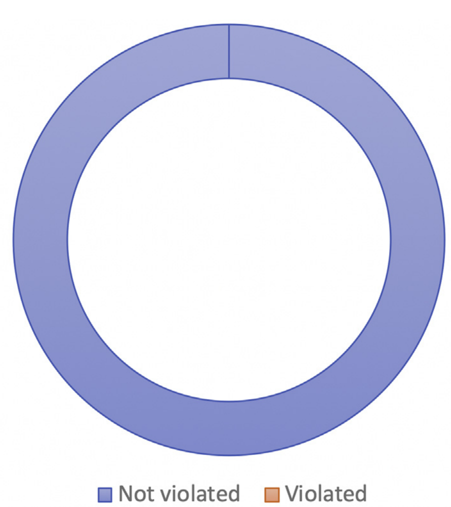

Figure 23. Left C2C—transverse foramen ($n = 18$) (left C2 screw was not positioned in 1 patient; 2 patients underwent interlaminar screw positioning).

Through the analyses carried out by means of the new proposed criteria, the variables relative to the length of the screw showed inhomogeneous results. In C1, reaching the anterior cortex is an indication of greater system stability; the results showed a greater commitment on the part of surgeons to adhere to an adequate length in C1. In C2, as shown in the proposed tables, the screws are on average shorter. The adequate length, or the perforation of the anterior cortex for a maximum of 2 mm, was reached in 4 cases. Nevertheless, in 7 cases, the screws were considered long for a percentage of inadequacy (ideal/real length ratio ≤25%).

It is therefore advisable to further discuss the role of reaching the anterior cortical bone in C2, to understand the real implication in terms of system effectiveness and to be able to standardize the procedure with reference to the parameter in question.

The appearance of a statistically significant association between the cause of the lesion and the CSPAs is also highlighted. Lesions of malformative, rheumatic, or degenerative origin are associated with lower scores. Clinical experience states that there are more difficulties in screw positioning in patients with lesions of nontraumatic origin. This relationship between the results of the study and the experience of the operators allows verification and confirmation of the correct functioning of the score proposed. The same clinical verification has been found, noticing that interlaminar screws, usually more difficult to place, resulted with lower CSPAs.

Clinical implications of the score could involve first the possibility of objectively evaluating any risk for the stability of the

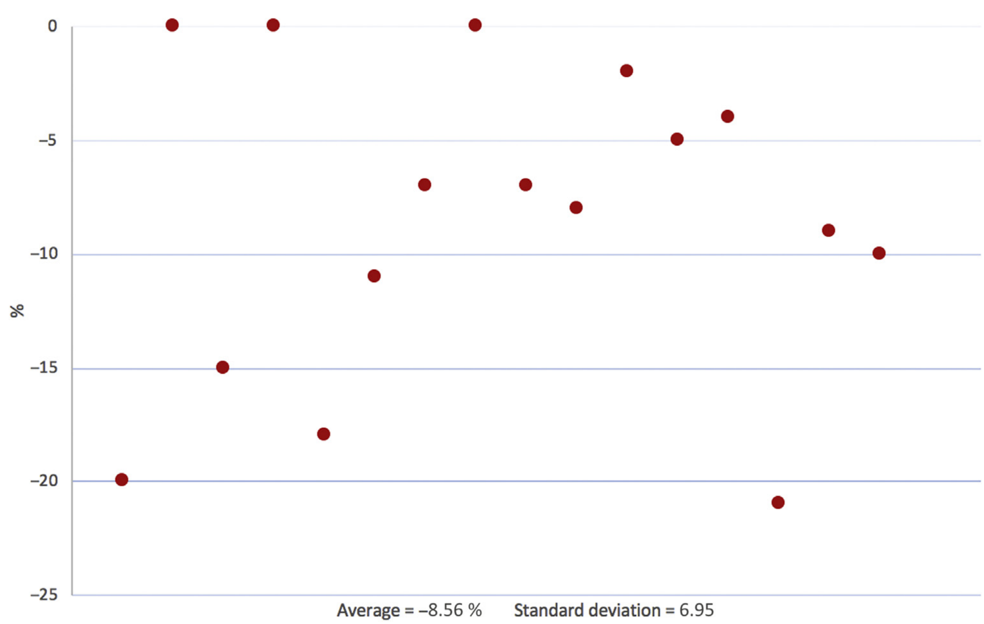

Figure 24. Left C2 ideal/real length ratio distribution ($n = 16$) (right C2 screw length could not be assessed in 2 patients; left C2 screw was not positioned in 1 patient; 2 patients underwent interlaminar screw positioning).

implant, especially considering the association noticed with the cause of the lesion, as well as other complications as discussed. Furthermore, it adds rationale to promote and objectively evaluate the use of iCT especially if compared with traditional free/hand positioning.

In future, it will be appropriate to continue to analyze candidate patients retrospectively, to increase the study population and confirm or exclude trends that have not shown statistical significance. In particular, the relationship between neuronavigation and CSPAs is worthy of further study.

CONCLUSIONS

This study presents the largest series of C1-C2 arthrodesis according to Goel-Harms performed with the aid of iCT.

Figure 25. Left C2 Cervical Screw Placement Accuracy score (CSPAs) distribution. Optimal placement, 16 (100%); suboptimal placement, 0; misplacement, 0 ($n = 16$) (right C2 screw length could not be assessed in 2 patients; left C2 screw was not positioned in 1 patient; 2 patients underwent interlaminar screw positioning).

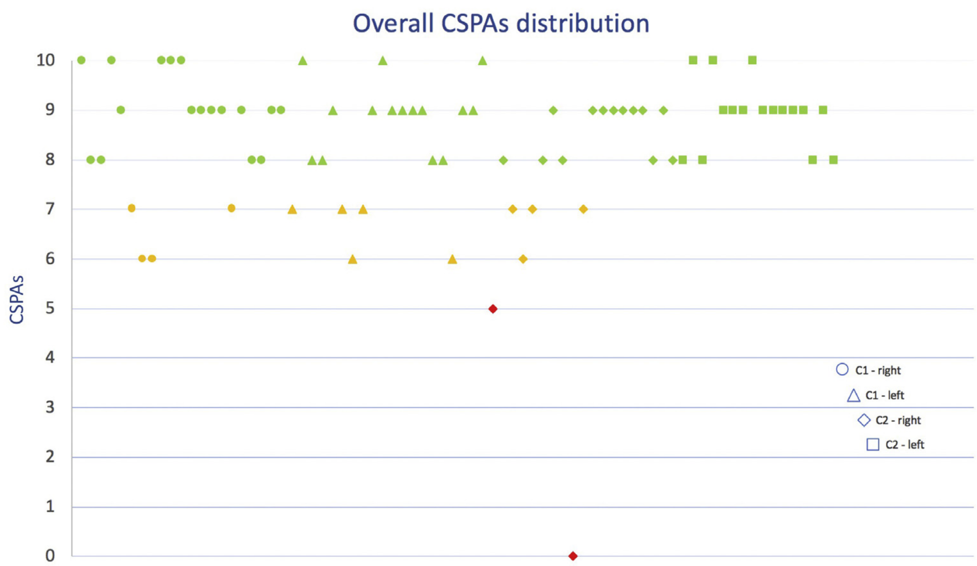

Figure 26. Overall Cervical Screw Placement Accuracy score (CSPAs) distribution.

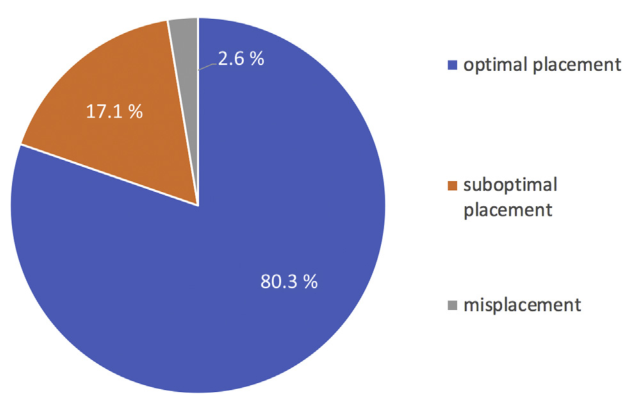

Figure 27. Screw placement accuracy according to Cervical Screw Placement Accuracy score.

Table 1. C1A—Cortex Invasion

Correct	5
Cortical encroachment	4
Minor frank penetration (<2.0 mm)	2
Moderate frank penetration (2.1—4.0 mm)	1
Severe frank penetration (>4.1 mm)	0

Table 2. C1B—Length

Anterior cortex penetration <2 mm	5
Anterior cortex reached	4
Anterior cortex not reached <2 mm	3
Anterior cortex not reached >2 mm	2
Anterior cortex penetration >2 mm	2

Table 3. C2A—Cortex Invasion

Correct	5
Cortical encroachment	4
Minor frank penetration (<2.0 mm)	2
Moderate frank penetration (2.1—4.0 mm)	1
Severe frank penetration (>4.1 mm)	0

Table 4. C2B—Length

Anterior cortex penetration <2 mm	5
Anterior cortex reached or not reached <4 mm	4
Anterior cortex not reached >4 mm	3
Anterior cortex penetration >2 mm	2

Table 5. C2C—Transverse Foramen

Not violated	0
Violated	−3

Table 6. Cervical Screw Placement Accuracy Score

Cervical Screw Placement Accuracy Score	Placement
≥8	Optimal
6 or 7	Suboptimal
≤5	Misplacement

Table 7. Cervical Screw Placement Accuracy Score Overview

	Number
C1A—cortex invasion	
Correct	5
Cortical encroachment	4
Minor frank penetration (<2.0 mm)	2
Moderate frank penetration (2.1—4.0 mm)	1
Severe frank penetration (>4.1 mm)	0
C1B—length	
Anterior cortex penetration <2 mm	5
Anterior cortex reached	4
Anterior cortex not reached <2 mm	3
Anterior cortex not reached >2 mm	2
anterior cortex penetration >2 mm	2
C1 CSPAs	x
C2A—cortex invasion	
Correct	5
Cortical encroachment	4
Minor frank penetration (<2.0 mm)	2
Moderate frank penetration (2.1—4.0 mm)	1
Severe frank penetration (>4.1 mm)	0
C2B—length	
Anterior cortex penetration <2 mm	5
Anterior cortex reached or not reached <4 mm	4
Anterior cortex not reached >4 mm	3
Anterior cortex penetration >2 mm	2
C2C—transverse foramen	
Not violated	0
Violated	−3
C2 CSPAs	x

CSPAs, Cervical Screw Placement Accuracy score.

Table 8. Comparison Between the Results Found and the Literature According to a Monoparametric Evaluation: Cortex Invasion (Criteria A of Cervical Screw Placement Accuracy Score)

Criterion A	C1—Right, n (%)	C1—Left, n (%)	C2—Right, n (%)	C2—Left, n (%)	Total, n (%)
Correct	15 (71.4)	15 (75)	12 (57.1)	16 (80)	58 (70.7)
Cortical encroachment	6 (28.6)	5 (25)	8 (38.9)	4 (20)	23 (28.1)
Minor frank penetration	—	—	—	—	
Moderate frank penetration	—	—	—	—	
Severe frank penetration	—	—	1 (4)	—	1 (1.2)
Total	21	20	21	20	82

Based on the results obtained, compared with the existing literature, it is conceivable that the recent introduction of iCT could be associated with a consistent improvement in the accuracy of positioning of the screws.

The use of a multiparametric score (CSPAs) could improve the evaluation of screw placement, allowing better analytic accuracy and pushing the reference scale to a higher and more precise level.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Vittorio Sancipriano: Formal analysis, Investigation, Writing – original draft. **Federica Penner:** Formal analysis, Investigation, Writing – original draft. **Fabio Cofano:** Formal analysis, Investigation, Writing – original draft. **Marco Ajello:** Resources. **Nicola Marengo:** Resources. **Salvatore Petrone:** Writing – review & editing. **Francesco Zenga:** Writing – review & editing. **Manuela Crobeddu:** Resources. **Andrea Bianco:** Resources. **Christian Cossandi:** Project administration. **Diego Garbossa:** Project administration.

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