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Virtual surgical planning in tripod zygomatico-maxillary complex fractures: A prospective comparison between two different strategies

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ABSTRACT

Multifragmentary and displaced zygomaticomaxillary complex (ZMC) fractures are often a challenge for the maxillofacial surgeon. The aim of this study was to evaluate the improved performance in the management of patients with tripod fracture of the orbito-zygomaticomaxillary complex, using two different methods of virtual surgical planning — virtual reduction and mirroring — compared with traditional management. A cohort of 60 patients was selected and divided into three groups, each consisting of 20 individuals. Patients in the first group were managed using the virtual reduction method, those in the second group using the mirroring method, and those in the third group using a traditional surgical approach. Having achieved virtual fracture reduction, a stereolithographic model was printed, on which preplating of the plates was performed. The results showed that virtual reduction was the most accurate in absolute terms, with a mean discrepancy in juxtaposition of the preoperative and postoperative CT images of 0.175 mm (SD ± 0.147), compared with 0.403 (SD ± 0.166) for the mirror method (and traditional method (0.875, SD ± 0.112; $p > 0.0001$). The average surgical time for virtual reduction (89.5 min) was faster than for mirroring (94.25 min) and for the traditional approach (96.75 min). In conclusion, the use of virtual surgical planning allows greater intraoperative accuracy, reduced surgical time, and reduced postoperative complications compared with traditional surgery. Of the two methods, virtual reduction performed best for the outcomes decribed.

1. Introduction

Facial fractures represent the most frequent cause of hospitalization in maxillofacial and head and neck surgery operating units (Rootman et al., 1995; Kunz et al., 2014). Specifically, traumatic events relating to the head–neck region, while involving almost all the bones that constitute the facial skeleton, usually affect the most exposed anatomical regions (Kunz et al., 2014; Ungari et al., 2012). The zygomatic bone, with its articular processes, accounting for 30–50% of all fractures of the facial massif (Committeri et al., 2023). This type of injury involves the bones that make-up the cheek and upper jaw, and can cause significant facial asymmetry and functional impairment if not treated properly (Bergeron and Raggio, 2022; Snider et al., 2017).

Fractures affecting the zygomatic bone can be distinguished into isolated fractures of the zygomatic arch or fractures of the zygomaticomaxillary complex (ZMC). In general, the latter, given their relative complexity and the varying extent of the clinical-instrumental picture, can often represent a significant challenge for the surgeon, whether experienced or novice (Hollier et al., 2003; Gruss et al., 1990; Ellis et al., 1985).

Virtual surgical planning (VSP) is a rapidly advancing technology that has revolutionized the field of craniofacial surgery. This technique allows surgeons to use advanced computer software to simulate surgical procedures and plan the optimal approach for treating complex facial

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fractures, such as those of the zygomaticomaxillary complex (Follmar et al., 2007; Louis et al., 2017, Kellman and Bersani, 2002). VSP enables surgeons to precisely analyze the extent of the fracture and develop a customized treatment plan, including preoperative visualization and virtual modeling of the affected area (Stanley, 1989; Kochhar and Byrne, 2013). This results in more accurate surgical outcomes, reduced surgical time and complications, and improved patient satisfaction (Strong and Gary, 2017).

In the field of virtual surgical planning of these fractures there are two distinct methods — mirroring and virtual reduction. There is little description in the literature of the existing differences between these two methods. The aim of this study was to evaluate the improved performance in the management of patients with tripod fracture of the orbito-zygomaticomaxillary complex using these two methods of VSP, and to compare them with the traditional management of fractures of the same nature.

2. Materials and methods

2.1. Data collection

This prospective, nonprofit, observational study evaluated a cohort of 60 patients with dislocated tripod fracture of the zygomaticomaxillary complex, enrolled between May 5, 2022 and September 1, 2023 and assessed in the Maxillofacial/Head and Neck Surgery Operative Unit of 'Federico II' University Hospital in Naples, a regional referral center for craniomaxillofacial trauma (Article 1, paragraph 203, L.F. Campania Region, 2011). All clinical investigations and procedures were conducted according to the principles expressed in the Declaration of Helsinki. Ethical approval, to access and use the data, was obtained from the Federico II/Cardarelli Research Ethic Committee (270/2023).

Patients were selected and included according to the following criteria: 18 years of age or older; fractures requiring fixation using no. 3 plates (open reduction-internal fixation-ORIF-3); patients who signed written informed consent. The exclusion criteria were patients with: psychiatric problems; fractures that did not require fracture fixation with no. 3 plates; comminuted fractures and/or those without fragment detachability; osteoporosis/osteomalacia; craniofacial malformations; or previous traumatic event in the orbito-zygomatic region.

2.2. Cohort recruitment

Patients were randomly allocated to one of three cohorts. 20 patients underwent ORIF-3 fixation of zygomaticomaxillary complex fractures after preoperative virtual surgical planning using a virtual reduction technique. This approach involved computer-aided design (CAD) manual repositioning of the fragments of the fractured bony structure using the Meshmixer 3.5 Installer Application (Autodesk, Inc., San Rafael, CA, USA), to obtain the contention of the fractures.

20 patients underwent ORIF-3 fixation of the zygomaticomaxillary complex fracture through preoperative virtual surgical planning using the mirroring technique. This approach involves the mirrored duplication of the unfractured side of the face, to evaluate the displacement of the fractures, using the Meshmixer 3.5 software (Maglitto et al., 2021; Ostaş et al., 2022).

The virtual surgical planning in both techniques led to the preoperative bending and adaptation of the surgical titanium plates (preplating), benefiting from the stereolithographical models obtained from the computer-aided design/computer-aided manufacturing (CAD/CAM) processing (Rootman et al., 1995).

The 20 patients in the final group were managed using a traditional surgical approach, without any preoperative virtual surgical planning.

2.3. Digital workflow

All patients underwent computed tomography (CT) examination of the facial massif on admittance to the Department, using the same machine. These CT examinations were first downloaded in DICOM (digital imaging and communications in medicine), viewed using RadiAnt DICOM Viewer (64-bit) software (Medixant, Poznań, Poland) (Fig. 1).

Next, to obtain a 3D model of the image, rapid segmentation software (InVesalius 3.1; Centro de Tecnologia da Informação Renato Archer (CTI), Brazil) was applied, through which the files could be converted to STL (standard triangulation language) format (Fig. 2).

Finally, to perform the virtual reduction and mirroring techniques, the STL format files were processed using the open-source software Meshmixer 3.5 (Fig. 3).

After reducing each fracture on the virtual model, the STL-format file was processed using Preform 3D printing software (Formlabs, Somerville, Massachusetts, USA) in order to set the model for 3D printing. A resin stereolithography 3D printer (Formlabs Form 3B+) was then used, with Formlabs Model V2 resin (ISO 10993-5: 2009) chosen for its mechanical characteristics, including a tensile strength of 27 MPa and modulus of elasticity of 1.1 GPa. Once printing was completed, the model was immersed for 20 min in isopropyl alcohol, using a Form Wash device (Formlabs). The final light-curing step employed the Form Cure device (Formlabs), which uses UV to increase tensile strength up to 48 MPa and modulus of elasticity up to 2.3 GPa.

Finally, it was possible to model the surgical plates on the 3D object obtained, preoperatively (pre-plating), by modifying three 1.6 mm thick titanium plates (KLS Martin GmbH + Co., Freiburg im Breisgau, Germany) to be applied during surgery. Each plate was modeled to obtain a patient-specific osteosynthesis medium, and was autoclaved at a temperature of 160 °C for 60 min, 24 h before surgery (Fig. 4).

To identify the presurgical planning technique that gave better results in terms of fracture reduction, the three different approaches were compared using the 'automatic scan alignment' function offered by Geomagic software. Using this, the overlap between postoperative CT (postsurgical reduction) and preoperative CT scans, for both the virtual reduction and mirroring techniques, was obtained. The discrepancy between the bone surfaces was then calculated, to obtain the following data: minimum and maximum value, mean, standard deviation and root mean square (RMS).

In the cohort managed using virtual reduction, the comparison was carried out between the fractured representation (virtually reduced) from the preoperative CT scan and the reduced and fixated construct from the postoperative CT scan.

In the cohort managed using the mirroring technique, the STL file for the reduced side from the postoperative CT scan was compared with the duplicate mirrored (unfractured) side from the preoperative CT scan (Fig. 5).

Finally, in the cohort managed using a traditional approach, with no VSP, STL files from postoperative CT scans were compared with the duplicate mirrored (unfractured) side from the preoperative CT scan, as with the mirroring technique. To evaluate the discrepancies for the traditional surgical technique, the mirror of the healthy side was

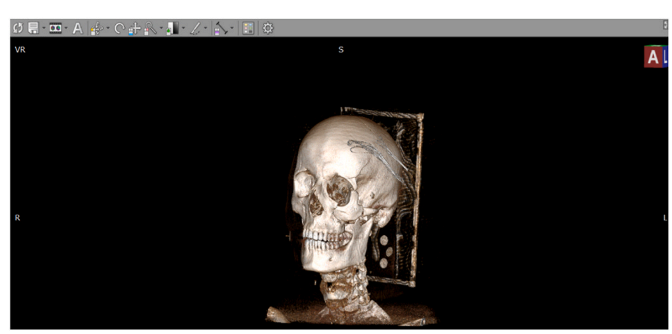

Fig. 1. Preoperative CT scans in DICOM (digital imaging and communications in medicine) format displayed via RadiAnt DICOM Viewer software (64-bit).

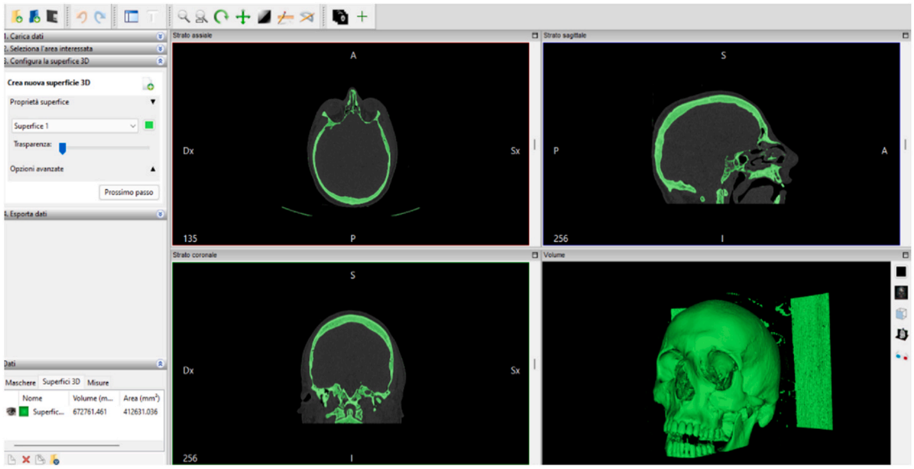

Fig. 2. Creation of the 3D model of the image using the rapid segmentation software InVesalius 3.1, through which it was possible to convert the file into STL (standard triangulation language) format.

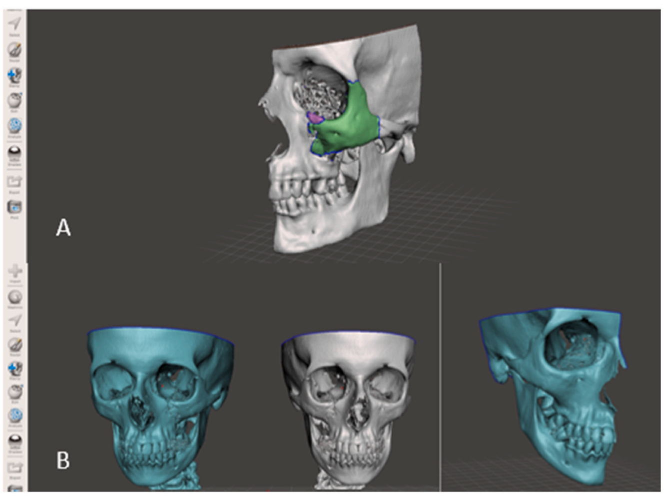

Fig. 3. (A) Virtual reduction of the displaced zygomatic bone using Meshmixer 3.5 Installer Application software. (B) Mirroring technique (mirror duplication of the healthy side), realised through the Meshmixer 3.5 Installer Application software.

generated solely to assess the postoperative outcome and not for preplating.

3. Results

Of the cohort of 60 patients used for this study, 42 were male and 18 were female. The most represented age group (20–40 years) comprised 30 patients, followed by 40–80 years (20 patients), 0–20 years (six patients), and ≥80 (four patients).

With regard to the study sample, events that led to fractures of the orbito-zygomaticomaxillary region were recorded. In order of frequency, traffic accidents were the most common cause (29 patients), followed by domestic accidents (13 patients) and syncopal episodes (11 patients). Incidents of interpersonal violence (four cases) and accidents at work (three cases) represented lower, but not negligible, frequencies.

Fractures of the left side of the face occurred in 34 patients, with the remaining 26 patients presenting fractures on the right. In some cases, fractures in sites outside the zygomatic region were involved.

For each method, mean values for overlaps between the pre- and postoperative CT images (in STL format) were averaged for each group (Fig. 6). Analysis of the mean values for patients treated with the mirroring and virtual reduction methods suggested that the latter was the most precise in absolute terms. The mean discrepancy value for the VSP group was 0.175 (SD ± 0.147), compared with 0.403 (SD ± 0.166) for the mirroring method and 0.875 (SD ± 0.112) for the traditional method.

In all three cases, the average variables between the means obtained from the overlaps between pre- and postoperative CT images followed a

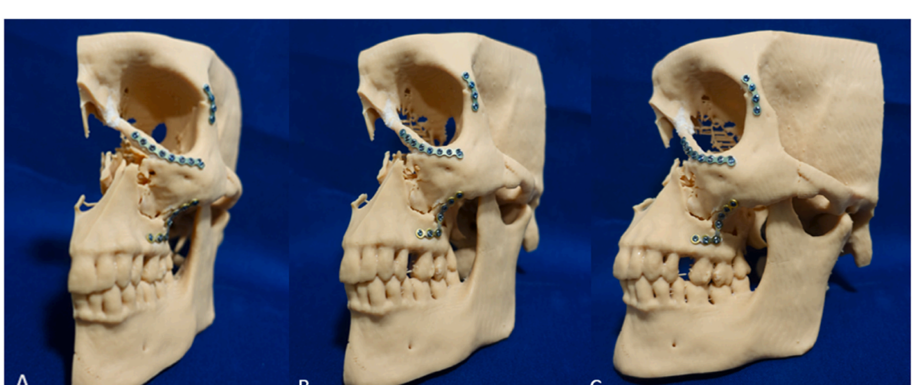

Fig. 4. 3D resin model on which preplating and osteosynthesis of the plates was performed: (A) frontal view; (B) three-quarter view; (C) profile view.

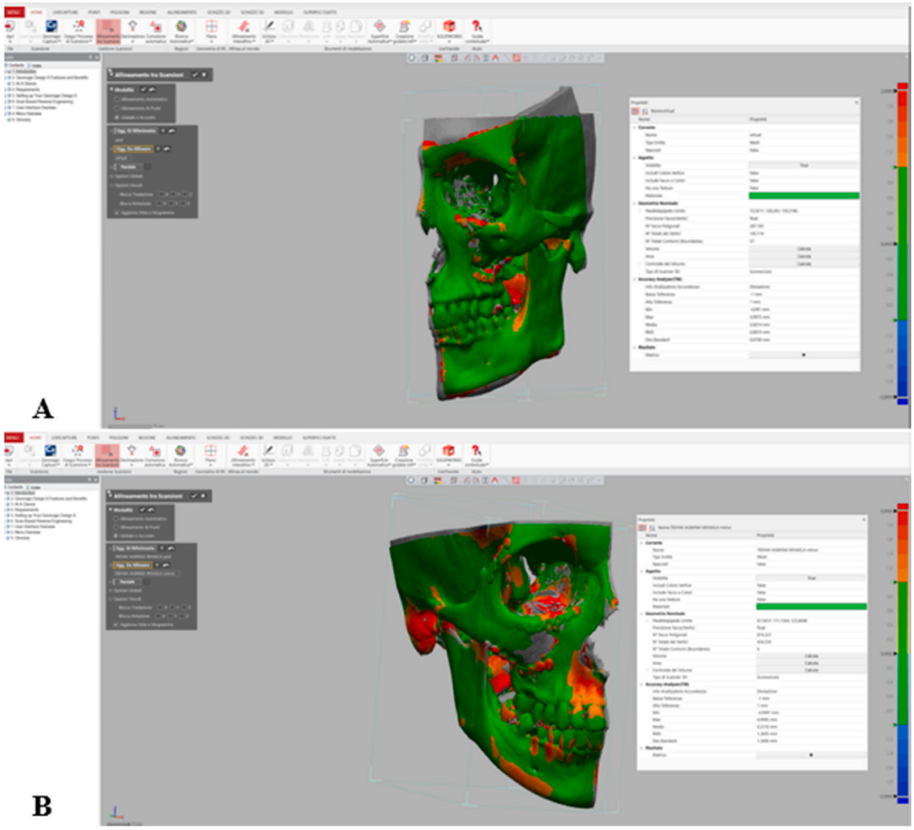

Fig. 5. Superimposition and comparison between the preoperative 3D virtual model with (A) virtual reduction and (B) mirroring technique and the postoperative 3D models obtained from CT scans after surgery. The statistical data obtained are shown in the white panel. An optimal range of discrepancy of -1 mm $< x < +1$ mm (low and high tolerance, respectively) was set, while gap values of -2 mm $< x < -1$ mm and $+1$ mm $< x < +2$ mm were also considered acceptable. All values outside the above ranges were excluded. The colorimetric maps (Geomagic Design X by 3D Systems) were produced in such a way as to visually highlight the different areas of discrepancy: green areas correspond to the optimal range; orange areas show discrepancy values greater than $+1$ mm; light blue indicates areas with discrepancy values greater than -1 mm; red areas show areas with discrepancy values greater than $+2$ mm; blue areas indicate discrepancy values greater than -2 mm.

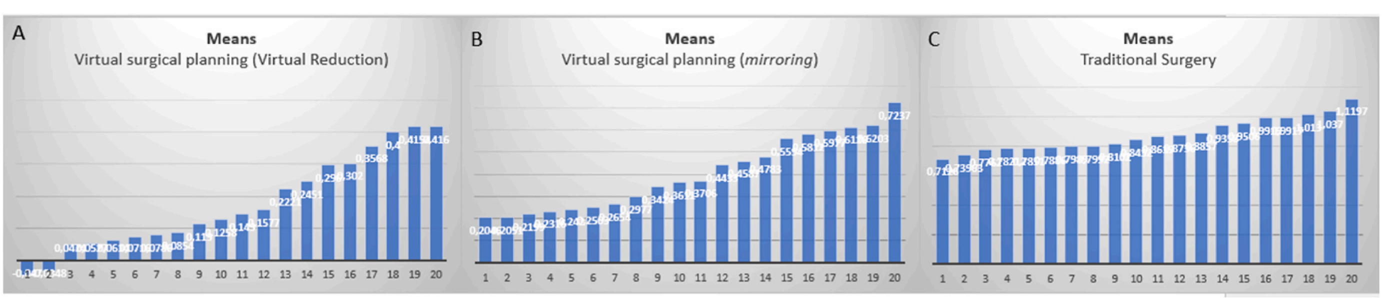

Fig. 6. Trends in mean overlaps for patients treated with (A) virtual surgical planning-reduction; (B) mirroring; and (C) traditional surgery.

normal distribution.

The classical normality tests (Shapiro–Wilk, Anderson–Darling, Lilliefors, Jarque–Bera) showed a calculated p-value greater than 0.05, which is considered to be the minimum limit of significance, below which the hypothesis of normal distribution of values would be null.

The difference between the mean values for the discrepancies obtained in the patients treated with the aid of virtual reduction and those treated with mirroring methods was 0.228 in favor of the former. The bilateral Z-test for two independent samples and the bilateral t-test for two independent samples produced a p-value > 0.0001 in both cases, less than the alpha significance value of 0.05, and thus indicating a significant difference.

The difference between the mean values for the discrepancies obtained in the patients treated with the mirroring method and those treated using the traditional surgical technique was 0.472 in favor of the former. The two-sided Z-test for two independent samples and the bilateral t-test for two independent samples produced a p-value $>$ 0.0001 in both cases, less than the alpha significance value of 0.05, and thus indicating a significant difference.

The difference between the mean values for the discrepancies obtained in patients treated with the virtual reduction method and those treated using the traditional surgical technique was 0.472 in favor of the former. The two-sided Z-test for two independent samples and the bilateral t-test for two independent samples produced a p-value $>$ 0.0001 in both cases, less than the alpha significance value of 0.05, and thus indicating a significant difference (Table 1).

Table 1
Mean discrepancies for the three approaches.

Variable	No. of patients	Min value	Max value	Mean	St. deviation
VR	20	−0.047	0.416	0.175	0.147
MR	20	0.205	0.724	0.403	0.166
TST	20	0.713	1.120	0.875	0.112

Clinical assessment of the patients following surgery identified postoperative complications in two patients treated by virtual surgical planning with virtual fracture reduction, three patients treated by virtual surgical planning using the mirroring technique, and in seven patients treated by the traditional surgical technique. These are detailed in Table 2. Importantly, these postoperative complications were recorded only in patients whose surgical treatment was managed by assistant surgeons in training, attending the fifth year of their residency programme in the Maxillofacial Surgery Department of Federico II University Hospital (junior surgeons).

The average surgical times (obtained from the clinical records) for all three surgical preparation modalities (Fig. 7) were 78.57143 min for senior surgeons, 97.61905 min for intermediate surgeons, and 105.5556 min for junior surgeons. Table 3 shows that surgical times were longer for novice surgeons and shorter for senior surgeons, regardless of the surgical approach used.

Mean surgical times for the three groups were as follows: virtual reduction, 89.5 min; mirroring, 94.25 min; and traditional surgery; 96.75 min (Fig. 8).

The statistical analysis showed that the mean dependence between time and surgical experience was 38% (mean correlation), with the *p*-value calculated by Fisher's test indicating that the correlation between time and surgical experience was statistically significant.

The mean dependence between time and type of preoperative planning (virtual reduction, mirroring, traditional surgery) was 2% (almost null), with the *p*-value calculated by Fisher's test indicating that the correlation between time and type of preoperative planning was not statistically significant.

An evaluation of the costs relating to the printing process was conducted. The printer model used (Formlabs Form 3B+) cost approximately EUR 5130. The total amount of resin used was 1000 ml, at a cost of EUR 135. Approximately 143 ml of material was required to make each 3D model, costing approximately EUR 20.00 per unit.

4. Discussion

Fractures of the zygomaticomaxillary complex, as well as other types of fracture and, in general, surgical treatments of similar magnitude, are increasingly benefiting from an approach that includes in-depth preoperative planning, which can guide the operator through all phases of surgery (Rootman et al., 1995; Kunz et al., 2014; Ungari et al., 2012; Committeri et al., 2023).

Virtual surgical planning (VSP) is used to plan the surgical treatment of this type of fracture with the aid of 3D software, allowing the postoperative outcome to be visualized.

Mirroring is a well-established technique, often used in reconstructive procedures, particularly in cases of unilateral fractures involving multiple bone fragments, and in the absence of a known previous facial asymmetry. It is quick and easy to perform, since the mirroring tool is a function offered by the software (Longeac et al., 2021; Abdul Lateef Hassan and Abbood, 2022).

In cases with known or suspected bone asymmetry, virtual reduction allows a better preoperative fit of the surgical plates; in patients with a bilateral fracture it is the only option. In addition, this method allows greater confidence in dealing with complex fracture cases, and makes it possible to avoid differences in plate profile caused by facial asymmetry, which are more prevalent when using the mirroring technique (Maglitto et al., 2021).

With the aid of CAD/CAM technology, it is possible to print stereolithographic models of the anatomical structures affected by the fracture, in order to study and define the extent of the surgical reduction, before approaching the patient on the operating table (Ostaş et al., 2022; Zoabi et al., 2022; Ghai et al., 2018).

There is great interest in this type of planning, especially with a view to improving surgical times and postoperative outcomes, while reducing the risk of complications. To these undoubted benefits must be added the important didactic role of this approach, which is helpful for the less experienced surgeon when treating complex fractures (Balakrishnan et al., 2015).

The aim of our study was to evaluate the improvement in performance in the management of patients with tripod fracture of the orbitozygomaticomaxillary complex using CAD/CAM methods. Specifically, the validity of the reduction and surgical fixation, and the improvement in operative time, using two different methods of VSP — virtual reduction and mirroring —when compared with the traditional management of fractures of the same nature, were analyzed. In addition, the occurrence of possible postoperative complications, according to the surgeons' degree of experience, was taken in account.

In order to obtain a comparison between VSP (virtual reduction or mirroring) and the traditional surgical technique, a cohort of 60 patients was selected and divided into three groups, each consisting of 20 patients enrolled in the Maxillofacial Surgery Unit of the Federico II University Hospital in Naples.

In the first group, the virtual reduction of the fracture was performed with Meshmixer 3.5 software, after obtaining the file in STL format by processing the preoperative CT scan using InVesalius 3.1 software.

In the second group, the mirroring technique was applied, which involves mirroring the unfractured side of the face to guide reduction of the fractured side. The STL-format file, generated from the preoperative CT scan, was obtained using the same procedure as described for virtual reduction, with the mirrored data generated using Meshmixer 3.5 software. In this case, however, the process was undoubtedly quicker, since an automatic function was available to generate the mirror. Subsequently, a plain cut was made along the interincisive line of the 3D surface obtained, in this case excluding the fractured representation and retaining the healthy one.

In the third group, reduction and fixation of the fracture were performed using the traditional surgical technique, without virtual planning and therefore without presurgical shaping of the plates. In this case, however, the preoperative CT scan was also used to generate a 3D surface using InVesalius 3.1 software; subsequently, the mirroring technique was applied using the Meshmixer 3.5 software. This last procedure was carried out to allow the superimposition of the postoperative CT scan with the 3D surface of the unfractured side obtained by mirroring, in order to allow evaluation of the postoperative outcome and comparison with the two VSP study groups.

For the two VSP groups the 3D surfaces were printed in the

Table 2
Postoperative complications in patients treated with virtual surgical planning (virtual reduction and mirroring) and with the standard surgical approach (junior surgeons).

Complication	Virtual surgical planning (virtual reduction)		Virtual surgical planning (mirroring)		Traditional surgical technique	
	Patients	Rate (n_{tot} = 20)	Patients	Rate (n_{tot} = 20)	Patients	Rate (n_{tot} = 20)
Oedema	1	5%	2	10%	3	15%
Postoperative bleeding	0	0%	0	0%	1	5%
Hematoma	1	5%	1	5%	2	10%
Hematoma + oedema	0	0%	0	0%	1	5%
None	18	90%	17	85%	13	65%

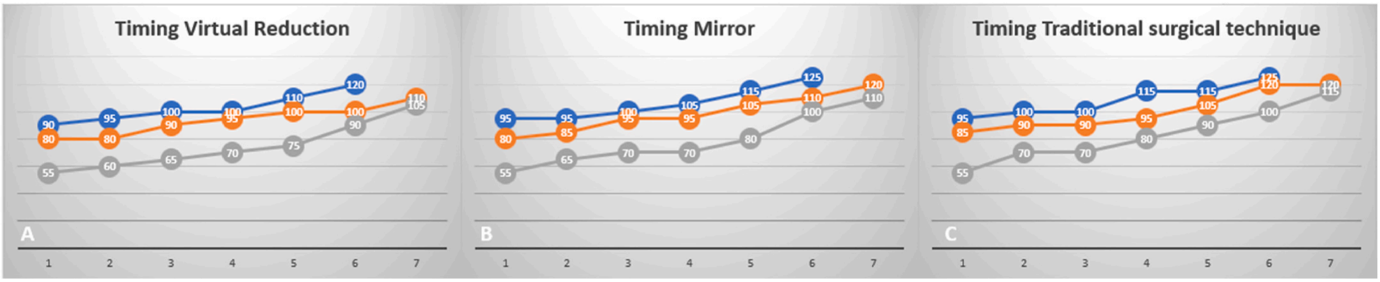

Fig. 7. A comparison of mean surgical times: (A) virtual reduction; (B) mirroring; (C) traditional surgry

Table 3
Surgical times (in minutes) for surgeons with different levels of experience for patients treated with the aid of virtual reduction, mirroring, and the traditional surgical technique.

Senior surgeons							
VR	55	60	65	70	75	90	105
MR	55	65	70	70	90	100	110
TST	55	70	70	80	90	100	115
Patient	1	2	3	4	5	6	7
Intermediate surgeons							
VR	80	80	90	95	100	100	110
MR	80	85	95	95	105	110	120
TST	85	90	90	95	105	120	120
Patient	1	2	3	4	5	6	7
Junior surgeons							
VR	90	95	100	100	110	120	
MR	95	95	100	105	115	125	
TST	95	100	100	115	115	125	
Patient	1	2	3	4	5	6	

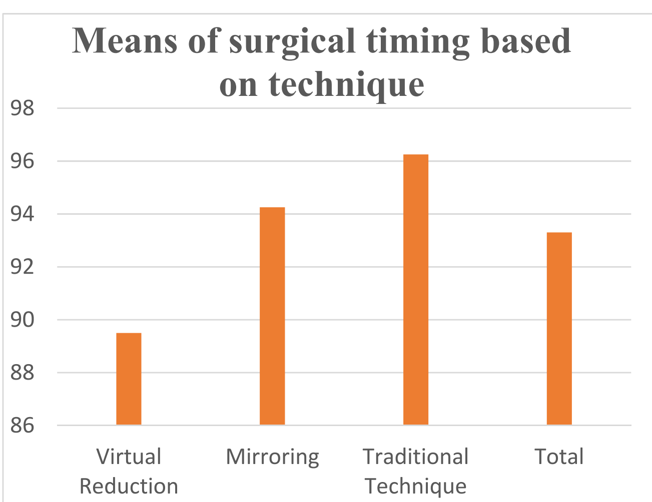

Fig. 8. Mean surgical durations according to technique.

Maxillofacial Surgery Unit of the Federico II University Hospital, with the use of the Formlabs Form 3B + printer using Formlabs Model V2 resin. On the 3D model obtained, preoperative shaping of the plates (preplating) was carried out, thus avoiding this step during surgery.

Alignment and comparison of the two bone surfaces were performed using Geomagic software. The software made it possible to automatically align the two 3D models and then to obtain statistical data, which were useful for comparing the outcomes of the three different techniques, in terms of mean discrepancy values.

Analysis of the results, in particular of the values of mean, standard deviation, and mean square deviation, suggested that the virtual reduction planning method was the most accurate in absolute terms.

Analysis of the means indicated that the overlaps between the pre- and postoperative CT images (in STL format) for the patients operated with the aid of VSP were more homogeneous compared with those for traditional surgery. The mean values of discrepancies for the mirroring and virtual reduction methods showed that virtual planning was more precise (0.175 $\pm$ 0.147 vs 0.403 $\pm$ 0.166). The value recorded for the traditional method was 0.875 $\pm$ 0.112.

The results were in line with the international scientific literature. For example, Hassan et al. (2022) showed that when using VSP and a three-dimensional model for precurvature of the titanium miniplates and orbital mesh relating to zygomaticomaxillary complex, orbital, and combined fractures, no significant differences were was found between the intact side measurements and those at 4 months after surgery with regard to orbital volume, enophthalmos, and zygomatic bone position. In our study, the virtual reduction method proved to be, albeit slightly, more accurate in virtual planning than the mirroring method. The literature offers no studies comparing the mirroring and virtual reduction methods in the field of virtual surgical planning.

Postoperative complications were analyzed according to the technique used and the experience of the surgeon (senior, intermediate, junior). According to Cuddy et al. (2021) and Xue et al. (2019) the most frequent complications are oedema, facial asymmetry, diplopia, hematoma, and postoperative hemorrhage (Cuddy et al., 2021; Xue et al., 2019).

For the selected cohort of patients, the following clinical signs were noted in the postoperative phase: oedema, postoperative hemorrhage, and hematoma, which were sometimes present concomitantly. In addition, it was noted that, for all three methods, these events occurred exclusively following surgery performed by residents (juniors) attending the last year of the residency programme in maxillofacial surgery at Federico II University Hospital.

In particular, oedema and hematoma affected, respectively, 1 and 1 patients treated by virtual surgical planning with virtual fracture reduction; 2 and 1 patients treated by virtual surgical planning with the mirroring technique; and 3 and 2 patients treated by the traditional surgical technique. In the latter cases, postoperative hemorrhage was also found in one patient and coexistence of hematoma and oedema again in another. These data show that the incidence of complications is lower when surgery is planned preoperatively using the method that has been tested, and is also negatively correlated with the experience of the surgeon.

The comparison of average surgical duration for the virtual planning methods showed that the surgery performed by the experienced surgeon (>9 years) was faster in all three groups: the average surgical duration for senior surgeons was 78.57143 min, compared with 97.61905 min for intermediate surgeons and 105.5556 min for junior surgeons. The overall average duration was is 93.33333 min. The statistical analysis showed an average correlation of 38% between surgical duration and surgeon experience, demonstrating that the presence of an experienced surgeon significantly reduced surgical time.

Fisher's test was performed to assess the correlations between surgical time and experience and between surgical time and technique used. This showed a statistically significant association between time and experience, but not between surgical time and surgical approach.

With regard to costs, a number of studies in the literature have examined cost–benefit ratios relating to virtual surgical programming and 3D printing. According to Bergeron et al., when costs are too high, such as those derived from delivery requirements for acute trauma, the only economical alternative is to print in-house (Bergeron et al., 2021).

Valding et al. and Wilde et al. detailed how costs vary considerably depending on the programs used, the printer model available, and the type and quality of material used (Valding et al., 2018; Wilde et al., 2015).

Some software offers a free license (such as Meshmixer Installer 3.5), while others can reach substantial figures of between $2000 and $6000 (MIMICS; Materialize N.V., Louven, Belgium).

For the 3D printing process, there are dozens of technologies and hundreds of printers available. Some are designed for recreational use (starting at €300), while others are designed for professional use (from several thousand euros). The model of the printer will affect the accuracy and fidelity of the final part. The materials available also vary, with a wide price range (from €15 to €550 depending on the dealer).

Within the scope of this study, the software used for virtual surgical planning (RadiAnt DICOM Viewer; InVesalius 3.1; Meshmixer 3.5; Geomagic) all offered a free license. The Formlabs Form 3B + printer model, used for making the 3D models, belongs to the category of devices for professional use, with costs comparable to those reported in the literature. Each printed model, made with Formlabs Model V2 resin, cost about €20.

The costs were considered acceptable after consulting the literature in relation to the wide variety of modes and materials available for the printing process. Considering how the virtual planning and the related preprinting lowered the surgical times on average compared with the traditional surgical technique, an overall reduction in the costs of operating and maintaining the operating room, as well as the use of equipment and instruments, can also be expected, as highlighted by von Schudnat et al. (von Schudnat et al., 2023).

5. Conclusion

This comparative analysis of virtual reduction and mirroring techniques within the context of open reduction and internal fixation (ORIF)-3 for zygomaticomaxillary complex (ZMC) fractures demonstrated that virtual surgical planning (VSP) significantly enhanced intraoperative precision and accuracy. Additionally, VSP facilitated a reduction in surgical duration and reduced the likelihood of postoperative complications when compared with conventional surgical approaches. Of the two VSP methods analyzed, virtual reduction stood out as the superior technique, consistently yielding better outcomes across all evaluated parameters. This study aimed to equip surgeons with a comprehensive comparison between two distinct VSP methodologies, thereby enabling the selection of the most effective, efficient, and rapid treatment strategy for patients.

Author contributions

Umberto Committeri: conceptualization, software. Roberta Magliulo: visualization, investigation. Emanuele Carraturo: writing — review and editing, data curation. Antonio Arena: formal analysis, software. Vincenzo Abbate: software, methodology. Giovanni Salzano: writing — review and editing, software: Stefania Troise: software, supervision. Simona Barone: investigation, data resources. Cristiana Germano: data resources. Luigi Angelo Vaira: conceptualization, methodology. Francesco Giovacchini: writing — original draft, conceptualization. Rosanna Cataldo: resources, formal analysis. Maria Gabriella Grassia: data curation, software. Luigi Califano: project administration, supervision. Pasquale Piombino: project administration, supervision.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to improve readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

None.

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