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Effectiveness of Virtual Surgical Planning in Mandibular Reconstruction Using a Custom-Made Plate and Split Rib Bundle Bone Graft: A single arm prospective study

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Abstract

Background

Mandibular reconstruction requires precise restoration of continuity, contour, and occlusion to achieve acceptable functional and aesthetic outcomes. Virtual surgical planning (VSP) and patient-specific reconstruction plates may improve the accuracy and reproducibility of mandibular reconstruction. This study aimed to evaluate the effectiveness of VSP-guided mandibular reconstruction using a custom-made reconstruction plate and a split rib bundle bone graft in patients with benign mandibular lesions.

Methods

This prospective single-arm clinical study included 30 adult patients with benign mandibular lesions requiring segmental mandibulectomy and immediate reconstruction. All patients underwent preoperative thin-slice computed tomography, virtual surgical planning, and fabrication of a patient-specific custom-made mandibular reconstruction plate. Reconstruction was performed using a split rib bundle graft. Clinical and radiographic follow-up was conducted for 12 months. Outcomes included mandibular symmetry, radiographic accuracy, graft-volume change, postoperative pain, occlusion, graft success, patient satisfaction, and complications.

Results

The mean age was 37.23 ± 10.15 years, and 56.7% of patients were male. Significant postoperative improvement in mandibular symmetry was observed at all measured landmarks (all $p < 0.001$), with the overall mean asymmetry index decreasing from 41.91 ± 5.32 preoperatively to 6.48 ± 2.46 postoperatively. Radiographic discrepancy between the virtual plan and postoperative outcome was minimal, with menton deviation of 0.053 ± 0.266. Mean graft volume decreased significantly over time from 15.61 ± 2.22 cm^3 at baseline to 14.11 ± 2.13 cm^3 at 12 months ($p < 0.001$). Stable postoperative occlusion was achieved in 28 patients (93.3%). Overall graft success was 96.7%, and 76.7% of patients were very satisfied, while 13.3% were satisfied. Complications were uncommon; plate loosening or removal occurred in 1 patient (3.3%), and 1 late complication (3.3%) was recorded.

Conclusion

VSP-guided mandibular reconstruction using a custom-made plate and a split rib bundle bone graft appears to be an accurate and clinically effective reconstructive option in selected benign mandibular defects. The technique provided substantial improvement in symmetry, high graft success, favorable occlusal outcomes, and high patient satisfaction, with a low short-term complication rate.

Introduction

Segmental mandibular defects produce major aesthetic and functional consequences, including loss of facial symmetry, impaired mastication, speech disturbance, altered swallowing, and disruption of

occlusal relationships. Accordingly, mandibular reconstruction remains one of the most demanding procedures in maxillofacial surgery, because successful treatment requires not only restoration of continuity but also accurate recovery of contour, intermaxillary relationship, and the skeletal foundation needed for later oral rehabilitation. Historically, this process relied heavily on intraoperative freehand judgment, but the growing use of computer-assisted surgery has shifted much of the reconstructive decision-making from the operating room to the preoperative planning phase[1, 2].

Virtual surgical planning (VSP) and CAD/CAM technology have become increasingly integrated into mandibular reconstruction workflows because they allow three-dimensional analysis of the defect, simulation of osteotomies, predefinition of graft position, and fabrication of patient-specific guides and fixation hardware. This digital workflow is particularly attractive in complex mandibular defects, where even small errors in segment positioning may translate into malocclusion, asymmetry, condylar displacement, or difficulties with future prosthetic rehabilitation. Although microvascular bone flaps remain the standard reconstructive option for extensive composite, irradiated, or soft-tissue-deficient defects, VSP has been shown to improve operative efficiency and reproducibility, especially when combined with patient-specific plates[2–4].

Nonvascularized bone grafting maintains its utility in meticulously chosen mandibular defects. The technique of split rib bundle grafting is particularly noteworthy due to its capacity to provide a biologically viable corticocancellous graft that can be configured to restore mesiodistal span, vertical height, and buccolingual thickness. Furthermore, contemporary evidence supports the notion that nonvascularized grafts can yield significant success in segmental mandibular reconstruction, particularly in favorable recipient beds, especially among nonirradiated patients presenting with benign pathologies and sufficient soft-tissue coverage.[5–7].

However, a gap remains between the modern digital reconstruction literature and the classical split rib bundle graft literature. Most contemporary VSP studies focus on fibula or other vascularized flaps, whereas the use of VSP and a custom-made mandibular plate to guide split rib bundle graft reconstruction has been much less thoroughly described. This distinction matters, because combining a low-technology biologic grafting concept with a high-precision digital workflow may offer a pragmatic alternative in selected benign mandibular defects, especially where prolonged microvascular surgery is unnecessary or impractical. Therefore, the present study aimed to evaluate the effectiveness of VSP-guided mandibular reconstruction using a custom-made plate and split rib bundle bone graft, with particular emphasis on geometric accuracy, graft behavior, functional outcomes, complications, and patient satisfaction[2–4].

Patients and methods

Study design and setting

This prospective single-arm clinical study was conducted on 30 adult patients diagnosed with benign mandibular lesions requiring segmental mandibulectomy and immediate reconstruction. All patients were managed at the Department of Cranio-Maxillofacial and Plastic Surgery, Faculty of Dentistry, Alexandria University, Egypt. The study was designed to evaluate the effectiveness of virtual surgical planning (VSP) in mandibular reconstruction using a patient-specific custom-made reconstruction plate and a split rib bundle bone graft.

Sample size

The target sample size was 30 patients. This estimate was generated using G*Power software version 3.1.9.2 (Universität Kiel, Germany) based on complication rates reported previously for different mandibular defect patterns, using a two-sided α error of 0.05 and a study power of 80%. Two additional cases were included to compensate for possible dropout. Given the single-arm design of the present study, this sample size should be considered pragmatic.

Eligibility criteria

Patients were eligible if they were 18 years of age or older, of either sex, had a benign mandibular lesion planned for treatment by segmental mandibulectomy, and were expected to have adequate soft-tissue coverage after resection. Patients were excluded if they were medically unfit for general anesthesia, had soft-tissue deficiency better managed by free osseocutaneous flap reconstruction, had a history of head and neck radiotherapy or were scheduled to receive postoperative radiotherapy, had obvious preoperative infection at the resection site, or had recurrent lesions requiring wider composite resection and free flap reconstruction.

Preoperative assessment

All patients underwent detailed history taking and full clinical examination. Preoperative assessment included evaluation of lesion characteristics, previous surgical history, medical comorbidities, and intraoral status, particularly oral hygiene and dental condition as potential contributors to postoperative infection. Standardized preoperative photographs were obtained. Routine laboratory investigations included complete blood count, blood group, bleeding and clotting profile, fasting blood glucose, liver function tests, and renal function tests. Before surgery, the oral cavity was meticulously prepared by scaling, elimination of septic foci, restoration of carious teeth when indicated, treatment of gingival or periodontal infection, and removal of retained roots.

Virtual surgical planning

Preoperative thin-slice maxillofacial computed tomography was obtained for all patients and converted into a three-dimensional digital model. Virtual surgical planning was then performed to define the extent of resection, determine the osteotomy lines, and restore the native mandibular contour and occlusal alignment. Based on the finalized virtual plan, a patient-specific custom-made mandibular reconstruction plate was designed and manufactured using computer-aided techniques. The plate was sterilized before surgery and used intraoperatively to reproduce the planned mandibular alignment accurately while minimizing the need for manual plate bending. (Fig. 1)

Surgical technique

All procedures were performed under general anesthesia. Surgical access depended on defect location. Lateral mandibular defects were approached through a combined intraoral lower sulcus incision and extraoral extended submandibular incision, whereas midline defects were approached through a combined intraoral lower sulcus incision and transverse collar incision. When the lesion extended to the mandibular angle, coronoidectomy was performed to minimize displacement of the proximal segment caused by temporalis muscle traction. In cases where the lesion approximated or involved the condyle, disarticulation was performed with preservation of the articular disc whenever feasible.

After resection, the proximal and distal mandibular stumps were contoured and smoothed to facilitate tension-free watertight mucosal closure and to prevent mucosal perforation by sharp bony edges. The outer cortex at the recipient sites was decorticated using a rose-head bur to expose cancellous bone and improve graft incorporation. Rib grafts were harvested through a curved submammary incision, usually from two alternating ribs. When condylar reconstruction was required, a costochondral component was preserved. After confirmation of pleural integrity, the donor wound was closed in layers. The harvested ribs were then split longitudinally using a fine osteotome while preserving the medullary component. (Fig. 2)

The patient-specific reconstruction plate was first fixed to the residual mandibular stumps using at least three screws on each side of the defect. One split rib segment was then fixed proximally and another distally within the prepared recipient bed. The remaining rib segments were telescoped to bridge the defect and secured together as a bundle using screws, with or without transosseous circumferential wires, and then fixed to the reconstruction plate. Additional rib segments were added when necessary to restore buccolingual thickness and vertical height while preserving adequate interarch space for future dental rehabilitation. In cases of condylar resection, a split costochondral graft was used for condylar replacement. In central mandibular defects, the genial musculature was suspended to the reconstruction plate with Vicryl 0 sutures to maintain tongue support and reduce the need for tracheostomy. The oral mucosa was closed in two layers using Vicryl sutures, and the external wound was closed in three layers with suction drainage maintained for 2 to 3 days.

Outcome assessment and follow-up

Patients were followed clinically and radiographically for 12 months after surgery. Early postoperative assessment included wound healing, hematoma, and infection. Intermediate follow-up focused on graft exposure and infection. Late follow-up included assessment of facial contour, scar appearance, graft take, mandibular continuity, sinus formation, recurrence, and functional outcome. Graft volume was assessed serially at baseline, 6 months, and 12 months. Postoperative pain at the donor and recipient sites was also recorded over follow-up. Patient satisfaction was assessed using a 5-point Likert scale ranging from 1 (very dissatisfied) to 5 (very satisfied).

Radiographic evaluation included assessment of mandibular symmetry and geometric accuracy of reconstruction. Symmetry indices were measured preoperatively and postoperatively at the condylion (Co), lateral point (La), gonion (Go), and mental foramen (Mf), in addition to calculation of the overall mean asymmetry index. Radiographic discrepancy between the virtually planned and postoperative mandibular positions was measured at the same landmarks on both reconstructed and healthy sides, together with menton deviation. Functional outcomes included postoperative occlusion, graft integration, graft exposure, need for secondary graft removal, and postoperative complications. Outcomes were also analyzed according to defect-site category: body defect, body plus angle defect, and body plus angle plus ramus defect.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics. Continuous variables were summarized as mean ± standard deviation (SD), whereas categorical variables were presented as frequencies and percentages. Preoperative and postoperative asymmetry indices were compared using paired-samples t-tests. Serial graft-volume measurements at baseline, 6 months, and 12 months were analyzed using repeated-measures analysis of variance. Because Mauchly's test indicated violation of the sphericity assumption, Greenhouse-Geisser-corrected results were reported. Postoperative pain across follow-up time points was analyzed using Friedman's test followed by Bonferroni-adjusted pairwise comparisons. Comparisons according to defect site were performed using one-way analysis of variance for continuous variables and categorical testing as appropriate. A two-tailed p value < 0.05 was considered statistically significant.

Results

Patient characteristics

A total of 30 patients were included in the study. The mean age was 37.23 ± 10.15 years. Seventeen patients (56.7%) were male and 13 (43.3%) were female. The most common pathology was ameloblastoma, identified in 12 patients (40.0%), followed by odontogenic keratocyst in 8 (26.7%), odontogenic myxoma in 4 (13.3%), vascular malformation in 3 (10.0%), and ossifying fibroma in 3 (10.0%). Regarding defect location, 13 patients (43.3%) had body defects, 9 (30.0%) had body plus angle

defects, and 8 (26.7%) had body plus angle plus ramus defects. The mean reconstruction time for the entire cohort was 59.13 ± 12.25 min (Table 1).

Symmetry and radiographic accuracy

A significant postoperative improvement in mandibular symmetry was observed at all measured landmarks (Table 2, Fig. 1). The Co asymmetry index decreased from 37.99 ± 8.37 preoperatively to 4.60 ± 4.12 postoperatively, corresponding to a mean difference of 33.39 (95% CI 29.69 to 37.10; $p < 0.001$). Similarly, the La asymmetry index decreased from 38.90 ± 9.48 to 4.51 ± 4.36, with a mean difference of 34.39 (95% CI 31.70 to 37.10; $p < 0.001$). The Go asymmetry index decreased from 49.33 ± 14.32 to 8.38 ± 5.21, with a mean difference of 40.94 (95% CI 36.20 to 45.70; $p < 0.001$). The Mf asymmetry index decreased from 41.41 ± 18.05 to 8.42 ± 5.53, with a mean difference of 32.99 (95% CI 26.80 to 39.10; $p < 0.001$). The overall mean asymmetry index declined from 41.91 ± 5.32 preoperatively to 6.48 ± 2.46 postoperatively, corresponding to a mean difference of 35.43 (95% CI 33.63 to 37.23; $p < 0.001$) (Table 2, Fig. 1).

Table 2
Symmetry assessment outcomes before and after reconstruction

Variable	Preoperative mean ± SD	Postoperative mean ± SD	MD (95% CI)	p value
Co asymmetry index	37.99 ± 8.37	4.60 ± 4.12	33.39 (29.69 to 37.10)	**< 0.001**
La asymmetry index	38.90 ± 9.48	4.51 ± 4.36	34.39 (31.70 to 37.10)	**< 0.001**
Go asymmetry index	49.33 ± 14.32	8.38 ± 5.21	40.94 (36.20 to 45.70)	**< 0.001**
Mf asymmetry index	41.41 ± 18.05	8.42 ± 5.53	32.99 (26.80 to 39.10)	**< 0.001**
Overall mean asymmetry index	41.91 ± 5.32	6.48 ± 2.46	35.43 (33.63 to 37.23)	**< 0.001**

Radiographic discrepancy analysis demonstrated minimal deviation between the virtually planned and postoperative mandibular anatomy, supporting the geometric accuracy of the reconstructive protocol (Table 3). Mean discrepancy values ranged from − 0.003 ± 0.255 at the reconstructed-side Mf to 0.229 ± 0.383 at the healthy-side Go. Mean menton deviation was 0.053 ± 0.266.

Table 3
Radiographic accuracy outcomes

Radiographic discrepancy variable	Mean ± SD	Range
Co reconstructed side	0.171 ± 0.262	-0.30 to 0.70
Co healthy side	0.058 ± 0.158	-0.18 to 0.34
La reconstructed side	0.190 ± 0.359	-0.20 to 1.06
La healthy side	0.076 ± 0.268	-0.50 to 0.60
Go reconstructed side	0.004 ± 0.151	-0.30 to 0.30
Go healthy side	0.229 ± 0.383	-0.20 to 1.10
Mf reconstructed side	-0.003 ± 0.255	-0.60 to 0.30
Mf healthy side	0.123 ± 0.376	-0.50 to 0.90
Menton	0.053 ± 0.266	-0.60 to 0.40

Operative and clinical outcomes according to defect site

Reconstruction time differed numerically across defect-site groups, with the longest mean operative time observed in the body plus angle plus ramus group (64.88 ± 5.96 min), followed by the body plus angle group (62.33 ± 17.23 min) and the body group (53.38 ± 8.86 min); however, this difference did not reach statistical significance ($p = 0.068$) (Table 4). Patient satisfaction by defect site also did not differ significantly ($p = 0.383$) (Table 4). In the body plus angle plus ramus group, all patients were very satisfied (100.0%). In the body plus angle group, 7 patients (77.8%) were very satisfied, 1 (11.1%) was satisfied, and 1 (11.1%) was neutral. In the body group, 8 patients (61.5%) were very satisfied, 3 (23.1%) were satisfied, and 2 (15.4%) were neutral.

Graft-volume changes and postoperative pain

Graft volume progressively decreased during follow-up (Table 5, Fig. 2). For the whole cohort, the mean graft volume declined from 15.61 ± 2.22 cm^3 at baseline to 14.60 ± 2.10 cm^3 at 6 months and 14.11 ± 2.13 cm^3 at 12 months. Repeated-measures analysis of variance demonstrated a significant effect of time on graft volume, which remained statistically significant after Greenhouse-Geisser correction ($F = 100.304$, $p < 0.001$) (Table 5, Fig. 2).

Table 5
Graft volume according to defect site over time and postoperative pain outcomes

Time point	Body + Angle + Ramus (n = 8)	Body + Angle (n = 9)	Body (n = 13)	Total (n = 30)	p value
Baseline graft volume (cm³)	18.50 ± 0.69	16.04 ± 0.73	13.53 ± 0.96	15.61 ± 2.22	**< 0.001**
Postoperative 6-month graft volume (cm³)	17.29 ± 0.58	15.10 ± 0.71	12.60 ± 0.88	14.60 ± 2.10	**< 0.001**
Postoperative 12-month graft volume (cm³)	16.86 ± 0.55	14.47 ± 0.83	12.18 ± 1.09	14.11 ± 2.13	**< 0.001**
Repeated-measures ANOVA, Greenhouse-Geisser F	F = 100.304				**< 0.001**
Post operative pain at donor and recipient site					
Bonferroni-adjusted pairwise pain comparisons					
Comparison	**Adjusted p value**				
2 weeks vs 1 week	**0.008**				
2 weeks vs 24 h	**< 0.001**				
2 weeks vs preoperative	**< 0.001**				
1 week vs 24 h	0.056				
1 week vs preoperative	**< 0.001**				
24 h vs preoperative	**0.008**				
Friedman test for pain, χ^2	88.946				
Friedman test p value	**< 0.001**				

When analyzed according to defect site, graft volume differed significantly among groups at all follow-up time points (Table 5). At baseline, mean graft volumes were 18.50 ± 0.69 cm³ in the body plus angle plus ramus group, 16.04 ± 0.73 cm³ in the body plus angle group, and 13.53 ± 0.96 cm³ in the body group ($p < 0.001$). At 6 months, the corresponding values were 17.29 ± 0.58 cm³, 15.10 ± 0.71 cm³, and 12.60 ± 0.88 cm³, respectively ($p < 0.001$). At 12 months, mean graft volume remained highest in the body plus angle plus ramus group (16.86 ± 0.55 cm³), followed by the body plus angle group (14.47 ± 0.83 cm³) and the body group (12.18 ± 1.09 cm³) ($p < 0.001$). Bonferroni post hoc analysis showed significant pairwise differences between all defect-site groups at each time point.

Postoperative pain also changed significantly over time (Table 5). Friedman's test demonstrated a significant overall difference in pain scores across the assessed time points ($\chi^2 = 88.946$, $p < 0.001$). Bonferroni-adjusted pairwise comparisons showed significant differences between 2 weeks and 1 week

(adjusted p = 0.008), 2 weeks and 24 h (adjusted p < 0.001), 2 weeks and preoperative assessment (adjusted p < 0.001), 1 week and preoperative assessment (adjusted p < 0.001), and 24 h and preoperative assessment (adjusted p = 0.008). The comparison between 1 week and 24 h did not remain statistically significant after adjustment (adjusted p = 0.056).

Functional outcomes, graft success, and complications

Functional outcomes were favorable overall (Table 6, Fig. 3). Stable postoperative occlusion was achieved in 28 patients (93.3%), whereas 2 patients (6.7%) had a minor occlusal discrepancy. No cases of postoperative malocclusion were recorded. Overall patient satisfaction was high: 23 patients (76.7%) were very satisfied, 4 (13.3%) were satisfied, and 3 (10.0%) were neutral, with no patients reporting dissatisfaction or very poor satisfaction.

Graft success was achieved in 29 of 30 patients (96.7%) (Table 6). Successful graft integration and immobilization were documented in 29 patients (96.7%), and absence of graft exposure was likewise observed in 29 patients (96.7%). One patient (3.3%) required secondary surgery for graft removal, corresponding to an overall graft failure rate of 3.3%. Postoperative complications were uncommon. Plate loosening or removal occurred in 1 patient (3.3%), and 1 late complication (3.3%) was recorded during the second 6 months of follow-up. No recipient-site infection, recipient-site wound dehiscence, reoperation, malocclusion relapse, donor-site infection, donor-site wound dehiscence, pneumothorax, or early complication during the first 6 months was observed (Table 6).

Discussion

Principal interpretation of the present findings

The present study supports the feasibility and short-term effectiveness of mandibular reconstruction using virtual surgical planning (VSP), a patient-specific custom-made reconstruction plate, and a split rib bundle graft in selected patients with benign mandibular lesions. The most important finding was not simply that reconstruction was achievable, but that it was reproducible with a high degree of geometric fidelity. The marked postoperative reduction in asymmetry indices, together with the minimal discrepancy between the virtual plan and the final postoperative anatomy, suggests that the planned mandibular contour and alignment were transferred to the operative field with a high level of precision[8]. This was accompanied by favorable clinical outcomes, including stable occlusion in most patients, a high graft success rate, low complication frequency, and high patient satisfaction. Taken together, these data indicate that the combination of digital planning and biologically adaptable autogenous rib grafting can produce clinically meaningful restoration of form and function in carefully selected mandibular defects.

At the same time, the findings should be framed with precision. This study does not demonstrate that this method is superior to vascularized free-flap reconstruction, nor does it establish superiority over conventional freehand planning, because there was no comparison arm. What it does show is that, in a

favorable reconstructive setting defined by benign pathology, adequate soft-tissue coverage, absence of radiotherapy, and absence of active infection, VSP-assisted reconstruction with a custom plate and split rib bundle graft can achieve a level of accuracy and early stability that is difficult to dismiss as merely anecdotal. That distinction matters, because the discussion should emphasize appropriately selected indication rather than universal applicability.

Why the digital workflow likely mattered

The strongest explanatory framework for the present results is the digital workflow itself. Mandibular reconstruction is particularly sensitive to small errors in segment positioning because inaccuracies at the stump level can propagate into facial asymmetry, condylar malposition, occlusal disharmony, and impaired prosthetic rehabilitation. VSP shifts critical decisions from intraoperative estimation to a preoperative three-dimensional environment, where the surgeon can define resection margins, restore the native arch form, and anticipate fixation strategy before the first incision. This conceptual shift was one of the earliest promises of computer-assisted mandibular reconstruction and remains one of its most consistent advantages in the literature. Hirsch et al. described this transition as a genuine paradigm shift in head and neck reconstruction, and later reviews have reinforced that computer-assisted workflows are especially valuable when accurate contour restoration and occlusal preservation are priorities[4, 8].

The radiographic findings of the current study align well with this broader literature. Roser et al. showed early on that free fibula mandibular reconstruction planned virtually could closely reproduce the intended surgical result, while Barr et al., in their systematic review and meta-analysis, concluded that VSP improves operative efficiency and may improve accuracy and outcomes compared with traditional techniques. More recently, El-Mahallawy et al. reported a highly significant degree of agreement between preoperative virtual planning and postoperative outcomes and also emphasized the need for standardized evaluation methods when accuracy is assessed. The present study contributes to that same line of evidence, but does so in a different reconstructive context: not a fibula flap series, but a nonvascularized rib-graft construct stabilized with a patient-specific plate. That is an important distinction, because it suggests that the benefit of VSP is not confined to microsurgical flap transfer; rather, its central value may lie more broadly in improving geometric control of mandibular reconstruction regardless of the graft source[3, 4, 8].

The custom-made plate likely played a major role in enabling this translation from plan to execution. In conventional reconstruction, even an accurate virtual plan can be undermined by manual plate adaptation, intraoperative distortion, or segmental rotation during fixation. Patient-specific plates reduce this source of error by serving not only as a fixation device but also as a positioning template. Studies by Zeller et al. and Möllmann et al. suggest that patient-specific plates improve reconstruction accuracy and long-term stability compared with manually bent plates, while Tran et al. further argued that such plates provide a more accurate scaffold for assembling donor bone segments and may reduce operative inefficiency associated with repeated manual contouring. In your series, the low discrepancy values and

the favorable occlusal outcomes are entirely consistent with that mechanism. The plate was not simply a hardware choice; it was part of the reconstructive logic[9–11].

Biological plausibility and performance of the split rib bundle graft

The present study is also important because it revisits a classical biologic reconstructive concept through a modern digital framework. The split rib bundle graft has deep roots in the Alexandria school of mandibular reconstruction. El-Sheikh et al.[6] described the bundle technique as a way to achieve not only mesiodistal spanning of the defect but also restoration of vertical height and buccolingual thickness by telescoping and augmenting split rib segments. Their rationale was biologically intuitive: the split rib exposes cancellous and marrow-containing surfaces, improves revascularization relative to intact cortical rib grafts, and allows a compact, customizable graft architecture. In the original series, complete graft take was reported in the majority of patients, and complete graft loss was not encountered. The technical details in your current protocol and manuscript clearly derive from that same reconstructive philosophy, but with the crucial addition of preoperative digital planning and patient-specific fixation[2, 6].

That historical continuity strengthens the biologic plausibility of your findings. In your cohort, graft volume decreased significantly over time, yet this occurred alongside a 96.7% graft success rate, stable postoperative occlusion in 93.3% of patients, and only one case requiring secondary graft removal. That pattern is better interpreted as postoperative remodeling than as simple graft failure[12]. Nonvascularized grafts are expected to undergo a phase of adaptation and partial resorption; the clinically relevant question is whether this remodeling compromises mandibular continuity, contour, fixation stability, or function. In your series, the answer appears to be largely negative over the first postoperative year. This is consistent with earlier work on rib grafting, including Habib and Hassan's long-term follow-up of rib grafts in long-span mandibular defects and Bachelet et al.'s report that costal grafting can provide good reconstructive and rehabilitative results in selected indications[13].

A skeptic might argue that these favorable results reflect selection rather than technique. That criticism is partly correct, and it should be acknowledged rather than avoided. Your inclusion criteria deliberately excluded patients with soft-tissue deficiency, infection, previous radiotherapy, planned postoperative radiotherapy, and recurrent lesions requiring composite free-flap reconstruction. Those exclusions are not weaknesses of the surgical judgment; they are part of what made this reconstructive strategy reasonable. The literature on nonvascularized mandibular grafting repeatedly shows that success is highly dependent on local biologic conditions, soft-tissue quality, stabilization, and case selection. Moura et al., in a systematic review, and Dastgir et al., more recently, both support the idea that nonvascularized grafting remains viable in segmental mandibular defects when used under favorable conditions. Therefore, the success of your series should be presented as evidence of appropriately indicated success, not as evidence that graft vascularization is unnecessary[5, 14].

Functional recovery, esthetics, and the patient perspective

From a clinical perspective, the value of mandibular reconstruction is ultimately judged less by millimetric discrepancy than by what the patient experiences: facial symmetry, oral competence, comfort, the ability to maintain occlusion, and the absence of major complications requiring reintervention. In this regard, your findings are particularly encouraging. Stable occlusion was achieved in nearly all patients, frank postoperative malocclusion was not observed, patient satisfaction was high across all defect categories, and dissatisfaction was absent. This suggests that the reconstructed mandible was not merely radiographically acceptable but functionally and aesthetically acceptable to patients as well. That is an important distinction, because in mandibular reconstruction the success of a technically elegant procedure is diminished if it does not translate into meaningful restoration of appearance and oral function.

These patient-centered outcomes are also conceptually aligned with contemporary reconstructive priorities. Reviews of digital mandibular reconstruction have increasingly emphasized prosthetically driven planning, restoration of the mandibular arch, and preservation of intermaxillary relationships as central goals of reconstruction rather than secondary refinements. Probst et al. emphasized that VSP facilitates integration of later dental rehabilitation into the original reconstructive design, and that accurate placement of bone elements and fixation hardware is critical for this downstream rehabilitative pathway. Your technique appears to support that philosophy. Although the study did not evaluate implant placement or final dental rehabilitation, the use of a custom plate, restoration of symmetry, and preservation of interarch space all suggest that the reconstruction was performed with future rehabilitation in mind rather than simply to bridge a bony defect. That point is worth making in the manuscript, but carefully, because actual implant-based outcomes were not measured[2, 4, 15].

The postoperative pain profile and donor-site data add another layer to this interpretation. Pain declined significantly over follow-up, and no donor-site infection, dehiscence, or pneumothorax was reported. Rib grafting is often viewed with caution because of concerns about donor morbidity, but these results suggest that, with careful technique and case selection, donor-site complications can remain low. That observation is consistent with the traditional appeal of costal grafting as a less resource-intensive option with acceptable morbidity in selected patients. Still, because uncommon donor-site complications may be underdetected in small series, the text should avoid language such as “minimal donor morbidity was proven” and instead state that donor-site morbidity was low in this cohort[13].

Where this technique fits within current reconstructive practice

A more rigorous discussion should explicitly position this method within the present reconstructive hierarchy. Microvascular osseous free flaps remain the standard of care for extensive segmental defects, composite defects, irradiated beds, and cases requiring large-volume soft-tissue replacement. That position is not challenged by the current study. Rather, your data suggest that in a narrower but clinically relevant subgroup, namely benign mandibular lesions in nonirradiated patients with preserved or reconstructable soft tissue, a nonvascularized split rib bundle graft can be enhanced substantially by

the addition of VSP and a patient-specific plate. In other words, the study supports a selective reconstructive algorithm, not a reconstructive revolution [4, 16].

That selective role may be especially relevant in environments where the cost, duration, or logistical demands of microsurgical reconstruction are limiting[17]. This is one of the more compelling practical implications of the work, but it should still be stated with restraint. VSP itself introduces additional planning cost and may not always be readily available. Economic analyses remain mixed, although a recent systematic review suggested that VSP is often cost-saving or cost-neutral when reductions in operating room time and hospitalization are considered. Even so, cost-effectiveness depends heavily on workflow structure, institutional volume, and whether planning is outsourced or performed in-house. Therefore, the present study supports technical feasibility and clinical promise, but it does not establish economic superiority. That remains an important topic for future research, especially if this method is to be advocated as a pragmatic alternative in resource-conscious settings [18].

Limitations and future directions

The limitations of this study should be discussed candidly. First, the absence of a control group prevents direct comparison with conventional planning, stock reconstruction plates, or vascularized bone flaps. Second, the sample size was modest and the study was conducted at a single center, which may limit external generalizability. Third, the follow-up period, while sufficient to evaluate early integration, remodeling, and complications, is still too short to assess long-term skeletal stability, plate fatigue, late contour changes, or the full pathway to prosthetic rehabilitation. Fourth, patient satisfaction was assessed with a simple Likert scale rather than a validated quality-of-life instrument. Finally, the cohort was intentionally restricted to favorable cases; therefore, the results should not be extrapolated to malignant, irradiated, infected, or composite defects. These limitations do not negate the findings, but they do define their correct level of inference.

Future work should move in two directions. The first is comparative: prospective studies comparing VSP-assisted split rib bundle reconstruction with conventional freehand rib-graft reconstruction would help isolate the true incremental value of the digital workflow. The second is longitudinal: longer follow-up is needed to determine whether the favorable early graft integration and symmetry seen here translate into durable contour stability, reliable function, and successful implant-supported rehabilitation. A cost analysis would also be valuable, because the clinical attractiveness of this technique will depend not only on what it achieves, but on what it requires[15, 18].

Conclusion

In conclusion, within the limits of this prospective single-arm study, virtual surgical planning–guided mandibular reconstruction using a custom-made reconstruction plate and split rib bundle graft appears to be an accurate and clinically effective option for selected benign mandibular defects. The technique was associated with marked improvement in mandibular symmetry, minimal deviation between the virtual plan and the postoperative result, high graft success, favorable occlusal outcomes, and high

patient satisfaction, while complications were uncommon. The progressive reduction in graft volume over time appeared to reflect postoperative remodeling rather than clinical failure, as structural continuity and functional stability were maintained in the vast majority of patients. These findings support the value of combining digital planning with a biologically adaptable nonvascularized grafting strategy in carefully selected cases. However, because the study was non-comparative and limited to benign, nonirradiated defects with adequate soft-tissue coverage, the results should be interpreted as evidence of feasibility and short-term effectiveness rather than superiority over vascularized or conventionally planned reconstruction. Further comparative studies with longer follow-up are needed to clarify long-term skeletal stability, cost-effectiveness, and the role of this approach in broader reconstructive indications.

Abbreviations

ANOVA
Analysis of variance
CAD/CAM
Computer-aided design/computer-aided manufacturing
CI
Confidence interval
Co
Condylion
CT
Computed tomography
Go
Gonion
La
Lateral point
Mf
Mental foramen
PSI
Patient-specific implant
SD
Standard deviation
SRBG
Split rib bundle graft
VSP
Virtual surgical planning

Declarations

Ethics approval and consent to participate:

Ethical approval was obtained from the Institutional Review Board of Alexandria University . Written informed consent was obtained from all participants.

Consent for publication:

Not applicable.

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References

1. Hirsch DL, Garfein ES, Christensen AM, Weimer KA, Saddeh PB, Levine JP (2009) Use of Computer-Aided Design and Computer-Aided Manufacturing to Produce Orthognathically Ideal Surgical Outcomes: A Paradigm Shift in Head and Neck Reconstruction. J Oral Maxillofac Surg 67(10):2115–2122
2. Probst FA, Liokatis P, Mast G, Ehrenfeld M (2023) Virtual planning for mandible resection and reconstruction. Innovative Surg Sci 8(3):137–148
3. Barr ML, Haveles CS, Rezzadeh KS, Nolan IT, Castro R, Lee JC, Steinbacher D, Pfaff MJ (2019) Virtual Surgical Planning for Mandibular Reconstruction With the Fibula Free Flap. Ann Plast Surg 84(1):117–122
4. El-Mahallawy Y, Abdelrahman HH, Al-Mahalawy H (2023) Accuracy of virtual surgical planning in mandibular reconstruction: application of a standard and reliable postoperative evaluation methodology. BMC Oral Health 23(1)
5. Dastgir R, Coffey J, Quereshy H, Baur DA, Quereshy FA (2024) Nonvascularized bone grafts: how successful are they in reconstruction of segmental mandibular defects? *Oral Surgery, Oral Medicine*. Oral Pathol Oral Radiol 137(5):e63–e72
6. El-Sheikh MM, Zeitoun IM, Medra AM (1992) The split rib bundle graft in mandibular reconstruction. J Cranio-Maxillofacial Surg 20(8):326–332
7. Habib AMA, Hassan SA (2019) The feasibility of rib grafts in long span mandibular defects reconstruction: A long term follow up. J Cranio-Maxillofacial Surg 47(1):15–22
8. Roser SM, Ramachandra S, Blair H, Grist W, Carlson GW, Christensen AM, Weimer KA, Steed MB (2010) The Accuracy of Virtual Surgical Planning in Free Fibula Mandibular Reconstruction: Comparison of Planned and Final Results. J Oral Maxillofac Surg 68(11):2824–2832
9. Möllmann HL, Apeltrath L, Karnatz N, Wilkat M, Riedel E, Singh DD, Rana M (2021) Comparison of the Accuracy and Clinical Parameters of Patient-Specific and Conventionally Bended Plates for Mandibular Reconstruction. Front Oncol 11
10. Tran KL, Mong ML, Durham JS, Prisman E (2022) Benefits of Patient-Specific Reconstruction Plates in Mandibular Reconstruction Surgical Simulation and Resident Education. J Clin Med 11(18):5306

11. Zeller AN, Neuhaus MT, Weissbach LVM, Rana M, Dhawan A, Eckstein FM, Gellrich NC, Zimmerer RM (2020) Patient-Specific Mandibular Reconstruction Plates Increase Accuracy and Long-Term Stability in Immediate Alloplastic Reconstruction of Segmental Mandibular Defects. J Oral Maxillofac Surg 19(4):609–615
12. Habib AMA, Hassan SA (2019) The feasibility of rib grafts in long span mandibular defects reconstruction: A long term follow up. J Craniomaxillofac Surg 47(1):15–22
13. Bachelet JT, Bourlet J, Château J, Jacquemart M, Dufour C, Mojallal A, Gleizal A (2015) Costal Grafting in Mandibular Reconstruction. Plast Reconstr Surg Glob Open 3(11):e565
14. Moura LB, Carvalho PHA, Xavier CB, Post LK, Torriani MA, Santagata M, Chagas Júnior OL (2016) Autogenous non-vascularized bone graft in segmental mandibular reconstruction: a systematic review. Int J Oral Maxillofac Surg 45(11):1388–1394
15. Li Y, Shao Z, Zhu Y, Liu B, Wu T (2019) Virtual Surgical Planning for Successful Second-Stage Mandibular Defect Reconstruction Using Vascularized Iliac Crest Bone Flap. Ann Plast Surg 84(2):183–187
16. Kumar BP, Venkatesh V, Kumar KAJ, Yadav BY, Mohan SR (2015) Mandibular Reconstruction: Overview. J Oral Maxillofac Surg 15(4):425–441
17. Obimakinde OS, Popoola SO, Ojo KO, Yusuf MB, Omotayo JA, Akinbade AO (2025) Mandibular reconstruction with non-vascularized bone graft in a double bridging technique. Niger Med J 66(1):91–98
18. Xiao JB, Banyi N, Tran KL, Prisman E (2024) Cost Outcomes of Virtual Surgical Planning in Head and Neck Reconstruction: A Systematic Review. Head Neck 47(3):1037–1057

Table 1 and 4,6

Table 1 and 4,6 are available in the Supplementary Files section.

Figures

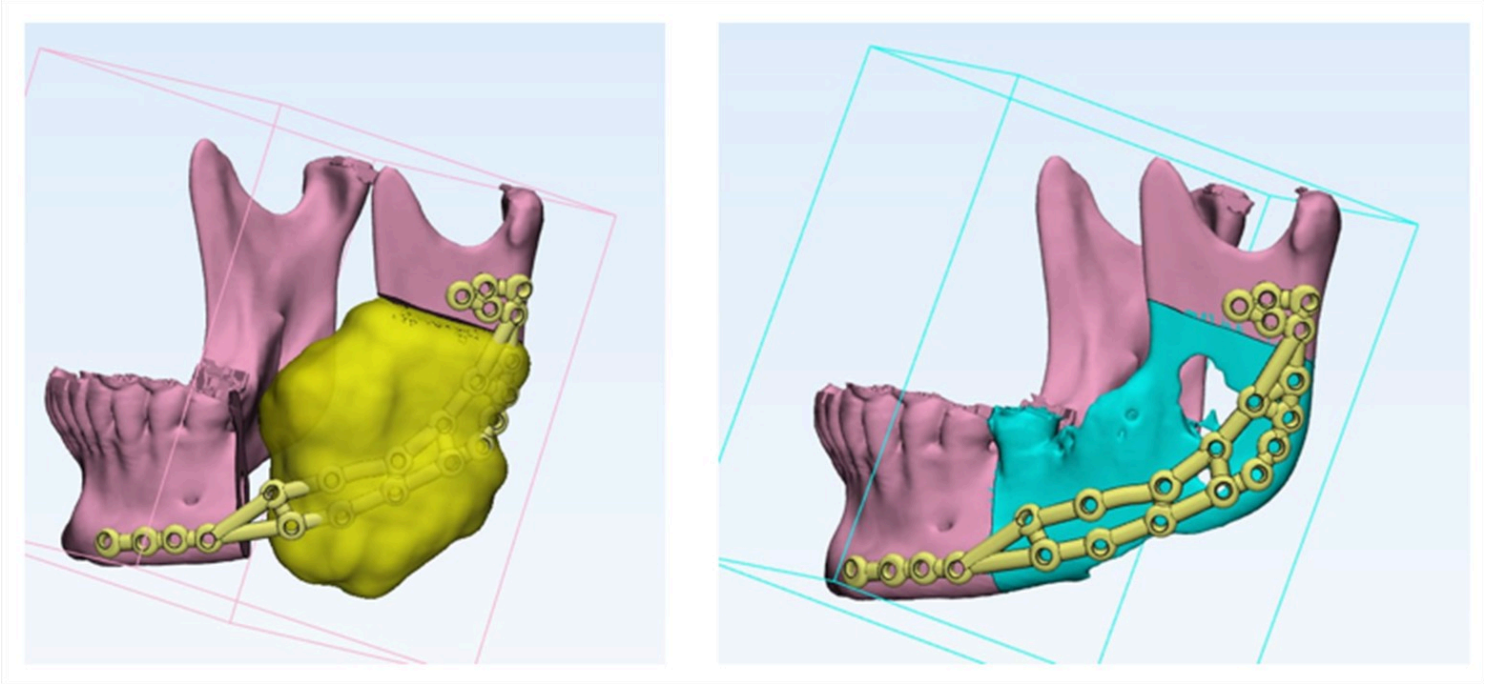


Figure 1

Computer assisted 3D reconstruction of mandible and custom designed plate

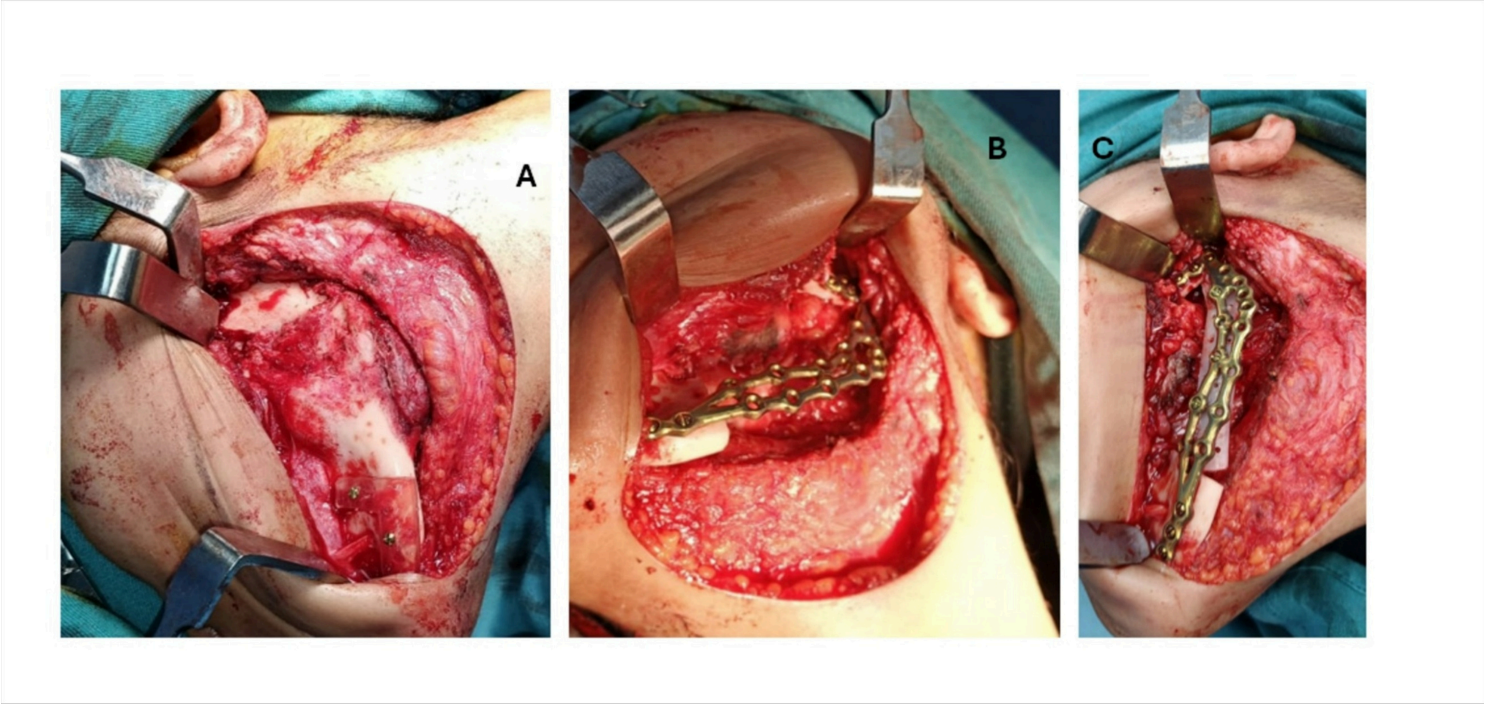


Figure 2

(A)Surgical incision of mandible showing tumour , (B) Surgical site after excision of tumor and making sure custom plate is aligned , (C) Final alignment of custom plate and Rib graft

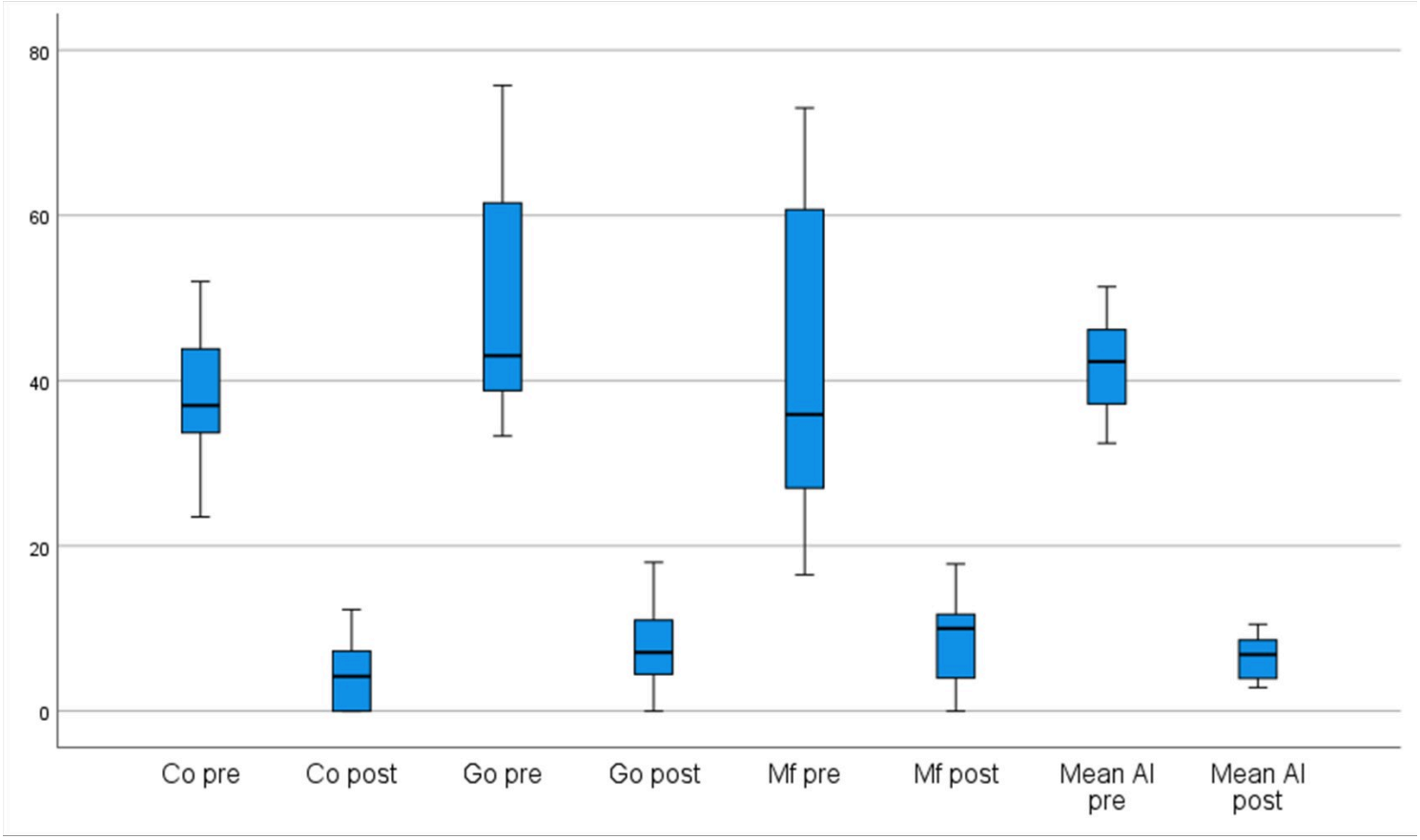


Figure 3

Preoperative and postoperative symmetry indices

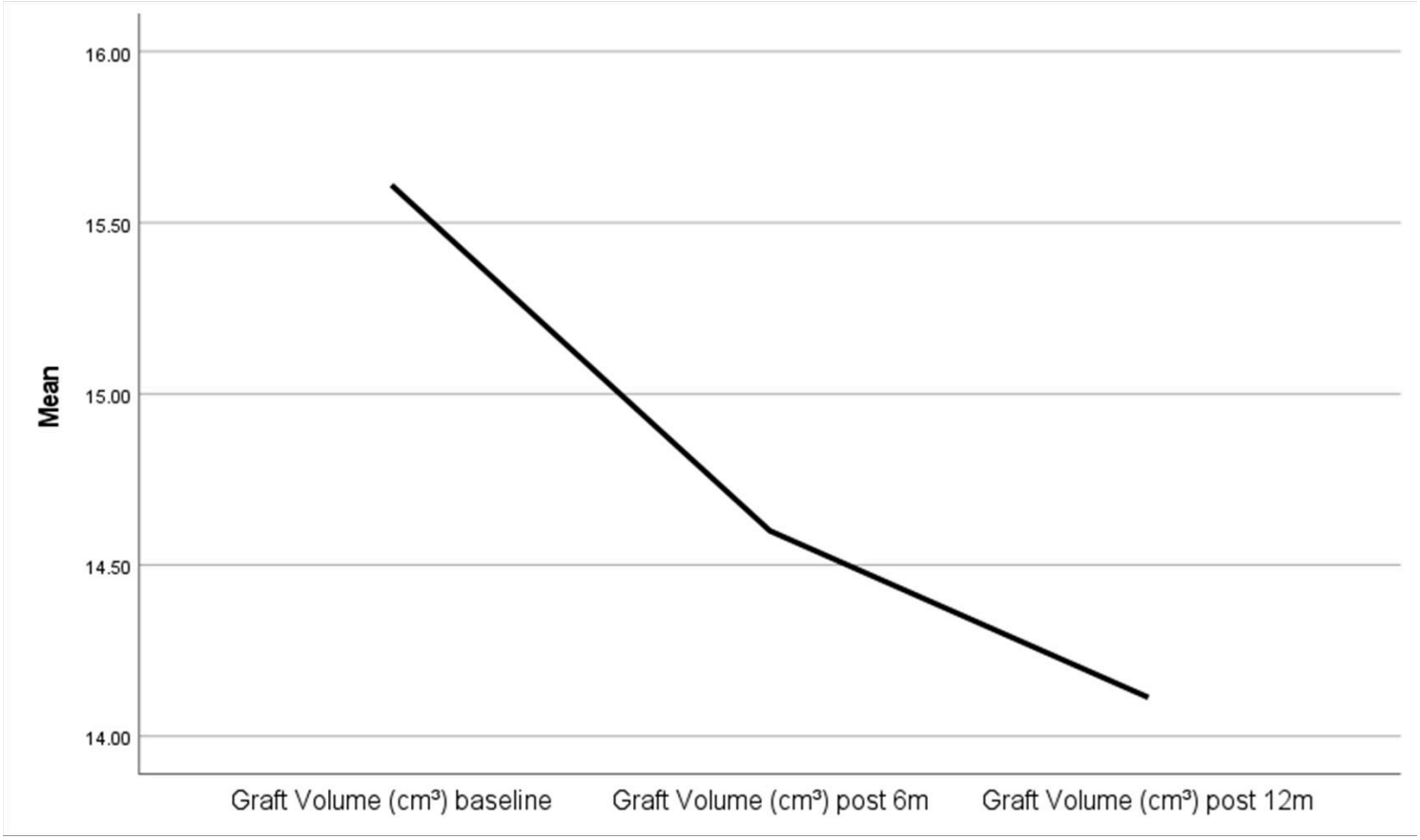


Figure 4

Graft-volume change over time

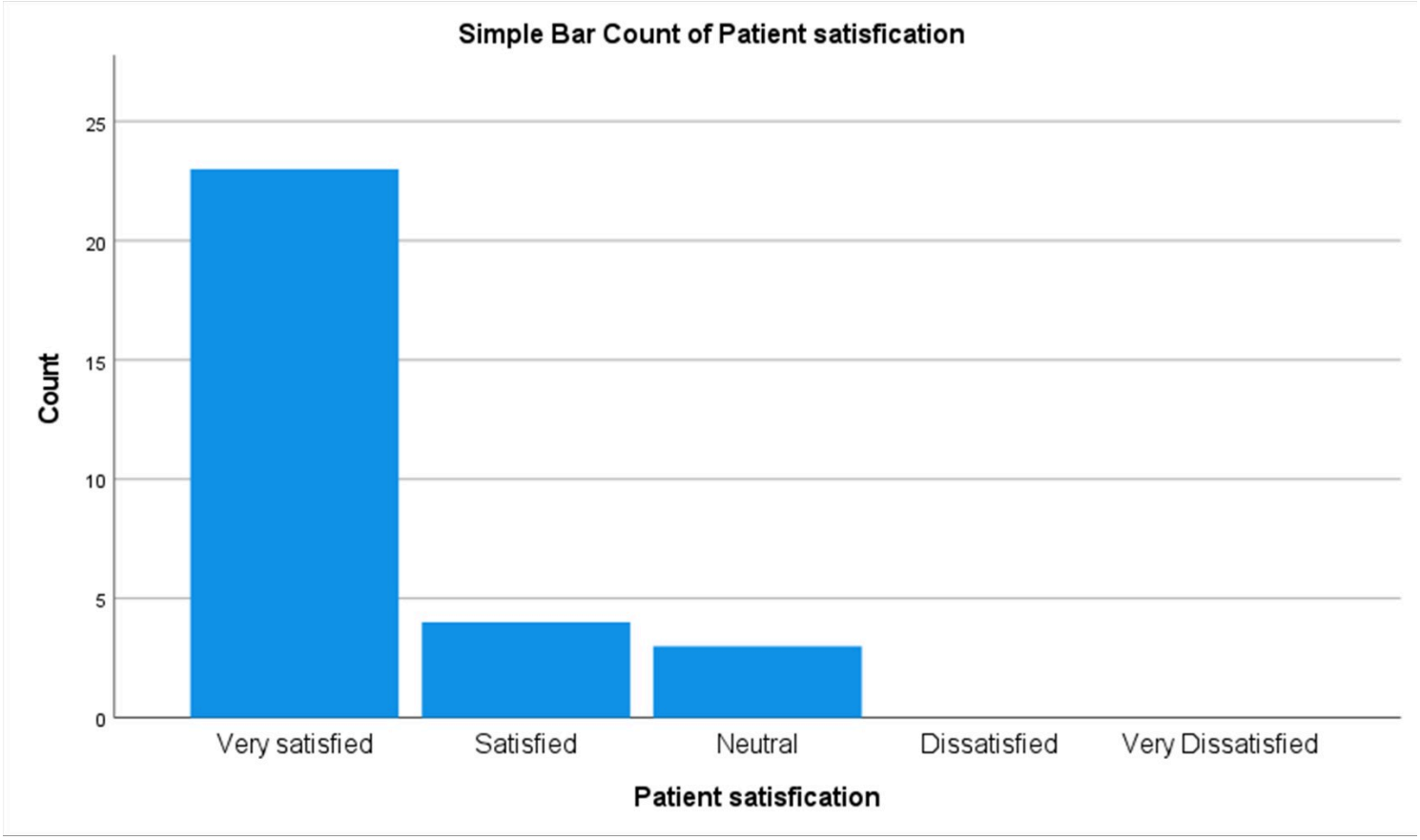


Figure 5

Patient satisfaction

Supplementary Files

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- Table146.docx