Gait Analysis Evaluation of Early Weight-Bearing After Surgical Fixation of Ankle Fractures: A Prospective Observational Study

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AIM: Post-operative weight-bearing strategies after surgical fixation of ankle fractures remain controversial. This prospective observational pilot study aimed to evaluate whether an early weight-bearing (EWB) protocol influences weight-bearing symmetry during static stance and clinical and functional recovery compared with a restricted weight-bearing protocol.
METHODS: Thirty-three patients undergoing surgical fixation for ankle fractures were allocated to either EWB (n = 17) or restricted weight-bearing (RWB) (n = 16) according to surgeon preference and fracture characteristics. Clinical, radiographic, and gait analysis outcomes were assessed at 6 weeks, 3 months, and 6 months postoperatively. The primary outcome was weight-bearing symmetry during bipodalic static stance. Secondary outcomes included subjective return to balance, independence in activities of daily living (ADL), and return to work. Data were analyzed using nonparametric tests.
RESULTS: At 6 weeks, the EWB group demonstrated significantly greater weight-bearing symmetry during static stance compared to the RWB group (eyes open, $p = 0.048$; eyes closed, $p = 0.044$). Patients in the EWB group also showed higher rates of subjective return to balance (76% vs 31%, $p = 0.009$) and ADL independence (82% vs 50%, $p = 0.049$). No significant differences were observed in return to work ($p = 0.805$). No complications were observed in either group.
CONCLUSIONS: In this small observational cohort, early weight-bearing was associated with improved early weight-bearing symmetry and functional recovery without observed complications. These findings should be interpreted cautiously, due to the study design and sample size and require confirmation in larger controlled studies.

Keywords: ankle fracture; gait analysis; early weight-bearing; rehabilitation; post-operative management

Introduction

Ankle fractures are among the most common fractures in adults. The incidence is approximately 137 cases/100,000 people, with a higher frequency in athletes and elderly patients, affecting both men and women equally [1].

As for many other lower limb fractures, when surgery is indicated, the orthopedic surgeon must choose between early weight-bearing and a more restrictive approach for post-operative management. Post-operative management after lower limb fracture fixation should consider the consequences of both weight-bearing excess and absence [2]. Excessive load on a non-ready bone structure can lead to loss of fracture reduction, migration of fracture fragments, malunion, and nonunion. On the contrary, immobilization and unloading prevent micro-movements of the bone structure, reduce mobility, muscle strength, and joint function, and lead to an increase in edema [2]. Despite the clear potential advantages and disadvantages of the two different approaches, there is no consensus in the literature about postoperative management [3].

According to the Arbeitsgemeinschaft für Osteosynthesefragen (AO) principles of fracture management, no weight-bearing or toe touch weight-bearing for 6–12 weeks, followed by progressive weight-bearing (25% increase per week), should be chosen in the initial management of peri- and intra-articular fractures of the lower extremities. However, in properly fixed malleolar fractures, partial weight-bearing could be allowed from the first day [3].

In addition to traditional clinical and radiographic outcomes, gait analysis provides objective and quantitative information on lower limb biomechanics and load distribution. While clinical measures such as return to function and patients' reported outcomes reflect overall recovery, they

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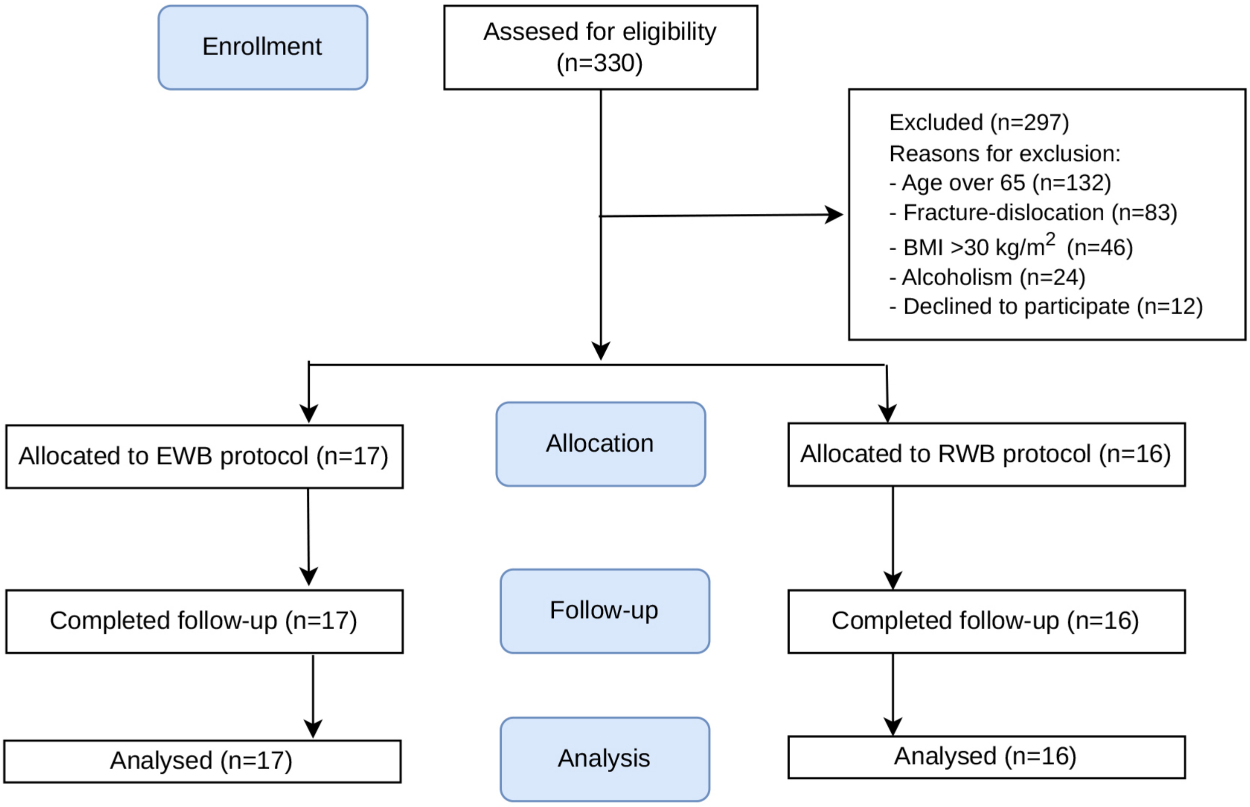

Fig. 1. Flow diagram of patient selection. BMI, body mass index; EWB, early weight-bearing; RWB, restricted weight-bearing.

may not fully capture subtle alterations in weight-bearing patterns and neuromuscular control. Gait analysis allows assessment of weight-bearing symmetry, postural stability, and dynamic loading strategies, providing a more detailed understanding of functional recovery after ankle fracture fixation. This objective approach may help identify early differences between rehabilitation protocols that are not detectable through conventional clinical evaluation alone.

In this context, the use of gait analysis in the present study aims to provide objective insight into the effects of early weight-bearing protocols on load symmetry and functional recovery.

The primary outcome of this study was to evaluate weight-bearing symmetry during bipodalic static stance in patients undergoing early versus restricted weight-bearing protocols after ankle fracture fixation. We hypothesized that early weight-bearing could promote a more rapid restoration of symmetrical load distribution between limbs. Secondary outcomes included subjective perception of balance, independence in activities of daily living (ADL), return to work, and selected gait parameters. The inclusion of gait analysis provides objective biomechanical data that complement traditional clinical outcomes.

Methods

This prospective observational monocentric pilot study was approved by the local Ethics Committee (Comitato Etico Unico Regionale-CEUR, protocol 047_2020) and conducted in accordance with the Declaration of Helsinki. Adult patients (18–65 years) who underwent surgical fixation for ankle fractures at Cattinara Hospital from March 2021 to March 2024 were considered eligible.

Inclusion criteria were isolated ankle fractures (AO-OTA 43-A and B, Weber B) treated with internal fixation, the ability to comply with post-operative rehabilitation, and availability for follow-up and gait analysis assessments (Fig. 1). Intraoperatively, the stability of the ankle was evaluated.

Exclusion criteria included:

- Fracture-dislocations,
- AO/OTA 43-C3 fractures,
- Weber C fractures treated with a syndesmotic screw,
- Open fractures,
- Neurodegenerative or psychiatric disorders, substance abuse,
- Body mass index (BMI) >30 kg/m^2,
- Associated fractures,
- Alcohol abuse,
- Refusal to participate.

All enrolled patients provided informed consent.

The post-operative rehabilitation protocol (early weight-bearing [EWB] vs restricted weight-bearing [RWB]) was determined by the treating surgeon in accordance with routine clinical practice. Allocation was based on fracture

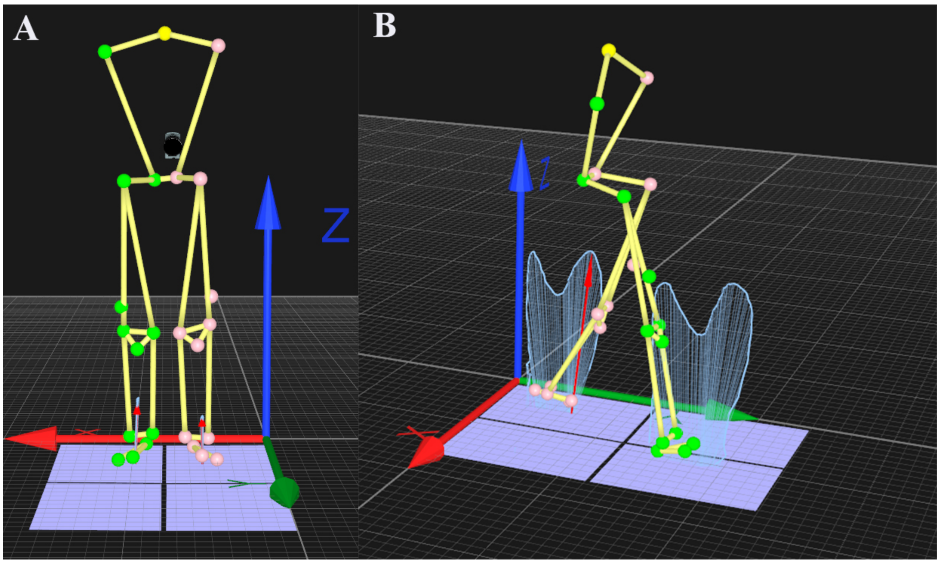

Fig. 2. Gait analysis results under two conditions: (A) static stance with eyes open and (B) walking. This picture was created with the Qualisys Track Manager software (version 2.7, Qualisys AB, Göteborg, Sweden).

characteristics, fixation stability, and patient-related factors. In general, early weight-bearing was prescribed for fractures deemed stable after fixation, whereas more complex or less stable patterns were managed with restricted weight-bearing.

The EWB protocol consisted of early mobilization without cast immobilization and partial weight-bearing (20 kg) for 1 week, followed by progressive permissive loading as tolerated. The RWB protocol included cast immobilization and non-weight-bearing for 4 weeks, followed by gradual loading and physiotherapy.

Outcome Measures

Patients were evaluated at 6 weeks, 3 months, and 6 months postoperatively through clinical, radiographic, and gait analysis assessments.

The primary outcome was weight-bearing symmetry during bipodal static stance, assessed through gait analysis.

Secondary outcomes included subjective return to static balance, independence in activities of daily living (ADL), return to work, and selected gait parameters.

Independence was assessed as a dichotomous variable (yes/no), based on patient self-perception. Radiographic healing was evaluated using the Radiographic Union Scale in Tibial Fractures (RUST) criteria. Although this score was originally developed for tibial fractures, it was used as a standardized method to assess cortical bridging and fracture healing in the present study [4]. However, its use in ankle fractures is not validated and results should be interpreted with caution. Moreover, loss of reduction, implant failure, and nonunion were eventually recorded.

Gait analysis was performed on a computerized platform equipped with 8 optoelectronic cameras (5, 4 MP, 180 fps, Qualisys Oqus) that track 25 markers on the patient's body using the Helen Hayes model (2008, Ariel Dynamics). Collected data were analyzed with the Qualisys Track Manager software (version 2.7, Qualisys AB, Göteborg, Sweden).

The tasks the patients were asked to accomplish differed across the three endpoints. At 6 weeks, patients were asked to perform a bipodal stabilometry test with both eyes open and closed to assess variations in their stability with and without visual input. They performed the stabilometry first with both arms along the body and then with the arm on the same side of the injured ankle abducted by 90°. Then, they were asked to perform the 'Sit-to-Stand' test. In the Sit-to-Stand test, we evaluated the initial peak weight load and then the symmetry of weight loading after a few seconds, when the load distribution was more homogeneous (Fig. 2).

At 12 and 24 weeks postoperatively, they were asked to repeat the same exercises and, in addition, to perform the Sit-to-Walk test, Gait Initiation test, and Walk test. During evaluation of the Walk test, we observed the percentage of time spent weight-bearing on the injured side compared to the healthy side, step length, and step velocity. Step length was expressed in meters (m) as the anterior–posterior distance between consecutive heel strikes. In contrast, walking velocity was expressed in meters per second (m/s), calculated as the ratio between distance covered and time.

The gait parameters included in the final analysis were predefined based on clinical relevance and feasibility in a small sample. These included weight-bearing symmetry during static stance and loading characteristics during the Sit-to-Stand (STS) test.

Statistical Analysis

Normality was assessed using the Shapiro–Wilk test. Continuous variables are presented as median and IQR (Q1, Q3); however, gait analysis parameters are reported as me-

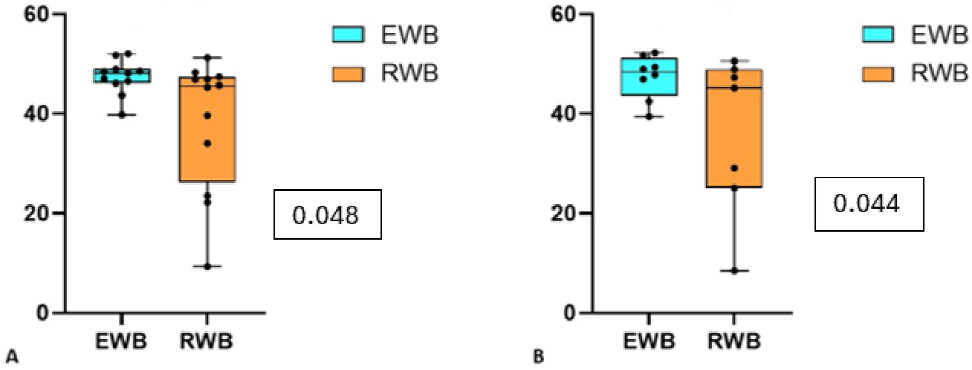

Fig. 3. Weight-bearing on the injured limb at 6 weeks from surgery during bipodalic stance. Percentage of weight-bearing on the injured limb during bipodalic stance with open (A) and closed (B) eyes, in both groups: restricted weight-bearing (RWB, orange, n = 16) and early weight-bearing (EWB, blue, n = 17) groups. Significance for the Mann-Whitney test. Data are presented as box plots showing the median (central line), IQR (box), and minimum and maximum values (whiskers) with individual data points displayed.

Table 1. Demographics and fracture patterns of the included sample.

Variable	RWB	EWB	*p*-value
Participants (N, %)	16 (48%)	17 (52%)	
Female, N (%)	9 (56%)	10 (59%)	0.881
Age	42 (35–55)	40 (27–57)	0.899
Fracture type			0.387
Bimalleolar fracture	9 (56%)	7 (41%)	
Trimalleolar fracture	7 (44%)	10 (59%)	

Data are presented as counts and percentages, and median (IQR) values as appropriate. Percentages are calculated within each group. RWB, restricted weight-bearing; EWB, early weight-bearing.

dian and range (minimum–maximum) to better describe data dispersion in this small sample, while categorical variables are reported as counts and percentages. Nonparametric tests were used due to the non-normal distribution of variables. Between-group comparisons were performed using the Mann–Whitney U test for continuous variables and Fisher's exact test for categorical variables. Within-group comparisons across conditions were analyzed using the Wilcoxon signed-rank test or Friedman test as appropriate. A *p*-value < 0.05 was considered statistically significant. Statistical analysis was performed using SPSS software (version 22.0, IBM Corp., Armonk, NY, USA).

Results

A total of 33 patients met the inclusion criteria and were enrolled in the study between March 2021 and March 2024. Seventeen patients were assigned to the early weight-bearing (EWB) group and sixteen to the restricted weight-bearing (RWB) group.

Baseline characteristics were comparable between groups, with no significant differences in age, sex distribution, or fracture type (Table 1).

Safety Outcomes

No complications related to surgery, such as infections, deep venous thromboembolism (DVT), loss of reduction, malunion, or nonunion, were noted in the EWB or the RWB group.

Clinical and Functional Outcomes

At 6 weeks postoperatively, patients in the EWB group showed significantly higher rates of subjective return to static balance compared to the RWB group (76% vs 31%, $p = 0.009$). Similarly, independence in activities of daily living (ADL) was higher in the EWB group (82% vs 50%, $p = 0.049$). No significant difference was observed in return to work at 6 weeks (35% vs 31%, $p = 0.805$). No significant between-group differences were observed in ADL independence at 3 months. Return-to-work rates were comparable between groups at both 6 weeks and 3 months (Table 2).

Gait Analysis

At 6 weeks postoperatively, the EWB group demonstrated significantly greater weight-bearing symmetry during bipodalic static stance compared with the RWB group, both with eyes open ($p = 0.048$) and closed ($p = 0.044$) (Fig. 3). No significant differences were observed between groups in most step velocity, including step length and gait parameters. However, a significantly higher initial loading peak during the Sit-to-Stand (STS) test was observed in the EWB group ($p = 0.044$). At the same time, no difference was found in final loading values ($p = 0.147$) (Table 3). No significant differences were observed between the two groups in the Sit-to-Walk test and Gait Initiation test at the corresponding follow-up time point (all $p > 0.05$). The same gait analysis protocol was applied at all follow-up time points; however, only the 6-week data are graphically presented to highlight early differences, as at later follow-up evaluations, no significant differences in gait parameters or weight distribution were observed between groups.

Table 2. EWB vs RWB group clinical and functional outcomes.

Variable	RWB (N = 16)	EWB (N = 17)	*p*-value
Subjective return to static balance (N, %)			
6 weeks	5 (31%)	13 (76%)	0.009
Independence in the ADL (N, %)			
6 weeks	8 (50%)	14 (82%)	0.049
Return to work (N, %)			
6 weeks	5 (31%)	6 (35%)	0.805
3 months	16 (100%)	16 (94%)	1.000

Data are presented as counts and percentages (%). ADL, activities of daily living. *p*-values were calculated using Fisher's exact test.

Table 3. Weight-bearing percentages on the injured limb at different endpoints from surgery during dynamic and functional gait analysis tasks in the RWB and EWB groups.

Variable	RWB (N = 16)	EWB (N = 17)	*p*-value
STS test (% of the weight loading on the injured ankle) at			
Initial peak	44.9 (33.0–47.8)	47.1 (46.4–48.9)	0.044
Final weight loading	46.1 (32.1–48.4)	50.4 (46.5–50.7)	0.147
At 3 months			
Static OA	48.6 (48.2–49.8)	48.3 (47.6–52.4)	0.353
Step length	0.65 (0.60–0.68)	0.62 (0.57–0.63)	0.382
Step velocity	1.02 (0.97–1.03)	0.82 (0.76–0.99)	0.178
At 6 months			
Static OA	50.7 (50.2–52.0)	47.8 (45.9–50.9)	0.226
Step length	0.6 (0.56–0.64)	0.64 (0.58–0.67)	0.115
Step velocity	1.07 (0.93–1.14)	1.07 (1.04–1.11)	0.374

Data are presented as medians and ranges. STS, Sit-to-Stand; Static OA, Static with eyes open. *p*-values were calculated using the Mann-Whitney U test.

Discussion

Historically, postoperative management of ankle fractures has favored weight-bearing restrictions, based on the concern that early weight-bearing could increase the risk of nonunion, loss of reduction, and implant failure. However, more recent evidence has challenged this paradigm, suggesting that early weight-bearing does not increase radiographic failure rates when stable fixation is achieved [5]. In addition, mechanical loading and early mobilization are known to exert beneficial effects on bone remodelling, cartilage health, and muscle function [6–11]. EWB may also promote functional independence, particularly in more active or elderly populations. Although several meta-analyses support clinical safety and effectiveness of early weight-bearing protocol, objective data on gait mechanics in this setting remain limited [12–16].

The main finding of this pilot observational study is that early weight-bearing was associated with improved weight-bearing symmetry during static stance at 6 weeks postoperatively compared with a restricted protocol. This finding is clinically relevant, as symmetrical load distribution represents a key component of postural control, reflecting neuromuscular coordination, confidence in limb loading, and readiness for functional activities. The observed differences between groups diminished at later follow-ups, suggesting that early weight-bearing may primarily influence the rate of recovery rather than long-term outcomes.

Functional outcomes in the present study were consistent with this interpretation. Patients who were managed with early weight-bearing demonstrated higher rates of independence in activities of daily living and earlier recovery of subjective balance during the early postoperative phase. However, these differences were no longer evident at 3 and 6 months, indicating convergence of outcomes over time. This pattern supports the hypothesis that early loading may accelerate early functional recovery without necessarily altering long-term results.

In line with previous studies and meta-analyses, early weight-bearing in the present cohort was not associated with an increased rate of complications [5,17,18]. No cases of loss of reduction, implant failure, nonunion, or malunion were observed in either group. These findings, given the limited sample size, are insufficient to draw a firm conclusion regarding the safety of the EWB protocol; they support existing literature indicating that, in adequately stabilized ankle fractures, early loading does not negatively affect radiographic outcomes [19–21].

The gait analysis findings provide objective support for the clinical observations. At 6 weeks, patients in the early weight-bearing group exhibited a more symmetrical load distribution between limbs during bipodalic static stance. This may reflect a reduced tendency toward protective unloading of the operated limb and a more rapid restoration of physiological loading patterns. In contrast, no significant differences were observed in most dynamic gait parameters, including step length and walking speed, although the early weight-bearing group showed a higher initial loading peak during the Sit-to-Stand task. These findings suggest that the primary impact of early loading may be more evident in controlled or static conditions, rather than in complex dynamic tasks. Previous studies have shown that patients recovering from ankle fractures may present persistent alterations in gait parameters, including reduced step length, cadence, and loading symmetry [22–24]. Although such abnormalities often improve over time, deficits in postural control and load distribution may persist, particularly in certain patient populations [25–27]. In this context, the earlier restoration of symmetrical loading observed in the present study may represent a relevant intermediate outcome, potentially associated with improved neuromuscular adaptation during rehabilitation.

Interestingly, both groups demonstrated improved load symmetry in conditions without visual input, suggesting a progressive reliance on proprioceptive mechanisms during recovery. Additionally, tasks requiring increased attentional demand, such as stance with ipsilateral arm abduction, were associated with increased loading on the operated limb in both groups. These findings may reflect adaptive motor strategies aimed at prioritizing task performance over protective unloading.

At later follow-ups, gait parameters and loading symmetry became comparable between groups, although variability appeared to increase at 6 months. This variability may reflect individual differences in rehabilitation strategies and motor adaptation. In some cases, patients may develop compensatory patterns or even preferential loading of the operated limb, possibly related to overtraining or altered perception of limb function. These aspects highlight the importance of targeted rehabilitation strategies aimed at restoring symmetrical load distribution and balanced neuromuscular control.

Several limitations of this study must be acknowledged. First, the small sample size significantly limits statistical power and precludes definitive conclusions. Second, the non-randomized design and allocation based on surgeon preference and fracture stability introduce a relevant risk of selection bias. Patients in the early weight-bearing group were more likely to have more stable fracture patterns, which may have contributed to the observed differences. Although inclusion and exclusion criteria were applied to reduce heterogeneity, residual confounding cannot be excluded. In addition, variability in rehabilitation protocols and timing may have influenced recovery trajectories. No formal correction for multiple comparisons was applied due to the exploratory nature of the study. Finally, gait analysis was limited to selected parameters and follow-up time points, and longer-term biomechanical adaptations were not assessed.

Despite these limitations, this study provides novel objective data on gait symmetry following ankle fracture fixation and suggests that early weight-bearing may facilitate earlier restoration of physiological load distribution. These results should be considered hypothesis-generating and require confirmation in larger, controlled studies with standardized rehabilitation protocols and longer follow-up.

Conclusions

In this small prospective observational study, early weight-bearing was associated with improved early weight-bearing symmetry and faster functional recovery. No complications were observed; however, given the limited sample size and non-randomized design, these findings should be interpreted with caution. Further, larger controlled studies are required to confirm these preliminary results.

Availability of Data and Materials

The data used and analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

GC, BT, and SS were responsible for patient recruitment and data collection. BT, GS, and SS have performed the evaluations at three endpoints and were responsible for data curation and formal analysis. BT, SS, AM, and ABS have performed the statistical analysis and written the original draft. LM, GC and MD have designed and supervised the study. All authors contributed to the critical revision of the manuscript for important intellectual content. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki. The local Ethics committee (Comitato Etico Unico Regionale-CEUR) approved the prospective observational monocentric study protocol, protocol code 047_2020. Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patients to publish this paper.

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Conflict of Interest

The authors declare no conflict of interest.

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