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*Article*

# Impact of Early Enteral Nutrition on Postoperative Recovery in Cardiac Surgery Patients: A Cross-sectional Observational Study

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## Abstract

**Background**: The impact of early enteral nutrition (EEN) on postoperative outcomes in cardiac surgery patients remains underexplored despite its potential benefits. This study investigated the effects of EEN on recovery markers and complications in this patient population. **Methods**: For this purpose, a cross sectional-observational study was carried out on 180 patients who underwent heart surgery. The patients were randomly assigned to receive either EEN within 6–12 hours after the surgery or usual postoperative care. The main outcomes assessed were infection rates, duration of hospitalization and total morbidity. The secondary outcomes assessed included the duration until the first bowel movement, gastrointestinal problems, wound healing and patient satisfaction. Albumin and pre-albumin levels were used to evaluate the nutritional status. **Results**: The use of EEN resulted in a substantial decrease in infection rates (13 *vs.* 24%, $p > 0.05$) and a shorter duration of hospital stay (7.5 *vs.* 8.8 days, $p < 0.05$). The overall morbidity rate was slightly lower, however the difference was only marginally significant (17 *vs.* 28%). Patients with EEN also exhibited a reduced duration until the first bowel movement (48 *vs.* 72 hours, $p < 0.05$), a lower incidence of gastrointestinal problems (10 *vs.* 22%, $p < 0.05$), and enhanced wound healing. The EEN group had a superior nutritional state at discharge, characterized by elevated levels of albumin and pre-albumin. The EEN group exhibited a higher level of patient satisfaction compared to the group didn't receive EEN (90 *vs.* 75%, $p < 0.05$). **Conclusion**: EEN had a considerable positive impact on the postoperative outcomes of patients undergoing cardiac surgery. It effectively reduced the infection rates, hospital stay duration and gastrointestinal issues. Additionally, EEN improved nutritional markers and enhanced patient satisfaction. These findings endorsed the integration of EEN into conventional postoperative therapy to enhance recovery.

## Keywords

cardiac surgery; enteral nutrition; nutritional strategies; surgical outcomes

## Introduction

The effectiveness of providing early enteral nutrition (EEN) to heart surgery patients to improve their recovery after the operation is an important aspect of clinical research. This is because cardiac procedures present complex metabolic requirements and recovery difficulties [1]. And cardiac procedures, such as coronary artery bypass grafting and valve replacements, trigger a significant stress reaction in patients [2]. This response is marked by an increased metabolic rate, leading to higher energy consumption and breakdown of proteins. This metabolic disturbance can worsen the challenges of recovery, prolong the length of hospital stay and heighten the vulnerability to complications [3,4]. Historically, there has been a practice of postponing the reintroduction of food through the digestive system after heart surgery, mostly due to concerns about the functioning of the gastrointestinal system and the surgical connections [5]. Nevertheless, recent changes in clinical practice indicate that EEN may not only be possible but also advantageous in this group of patients [6].

Cardiac surgery, which includes a range of treatments from coronary artery bypass grafting to heart transplantation, frequently leads to considerable physiological stress and metabolic changes [7]. The stress reaction can result in a hypermetabolic condition marked by heightened energy usage and breakdown of proteins. If not addressed, this can lengthen hospital stays and raise the likelihood of problems like infections and impaired wound healing. Historically, conventional methods have generally preferred to postpone the start of enteral nourishment because of concerns regarding the functioning of the gastrointestinal system and integrity of surgical connections [8].

Early enteral nutrition enhances the protective function of the gut and may decrease the occurrence of hospital-acquired infections by reducing the movement of bacteria and preserving the integrity of gut lining [9]. Furthermore, it has a vital function in regulating the immunological response, so directly affecting inflammation and patient's capacity to fight postoperative infections. EEN, or exclusive enteral nutrition, counteracts catabolism and promotes the production of proteins essential for tissue regeneration and development by directly supplying the required nutrients [10].

**Table 1. Composition of enteral nutrition formula in EEN group.**

| Nutrient category | Description | Amount per kg body weight | Total daily amount (average adult) |
|---|---|---|---|
| Proteins | High-quality proteins from casein or whey | 1.2 to 1.5 g | 84 to 105 g |
| Carbohydrates | Easily digestible forms | Variable, adjusted to meet energy needs | 200 to 300 g |
| Fats | Medium-chain triglycerides | Variable, adjusted to meet energy needs | 70 to 100 g |
| Vitamins and Minerals | To support immune function, wound healing and electrolyte balance | Standard daily values | Standard daily values |
| Fiber | To promote gastrointestinal health and prevent constipation | 10 to 20 g | 10 to 20 g |

EEN, early enteral nutrition.

**Table 2. The demographic features of the participants.**

| Variable | Received EEN (n = 90) | Did not receive EEN (n = 90) | $\chi^2$ | $p$-value |
|---|---|---|---|---|
| Age (years), Mean ± SD | 62.3 ± 8.5 | 63.1 ± 8.3 | –1.520 | 0.130 |
| Gender (male), n (%) | 55 (61) | 53 (59) | 0.023 | 0.879 |
| Type of surgery, n (%) | | | | |
| Coronary bypass | 46 (51) | 42 (47) | 0.440 | 0.803 |
| Valve replacement | 29 (32) | 33 (37) | | |
| Other | 15 (17) | 15 (17) | | |
| BMI (kg/m²), Mean ± SD | 27.4 ± 4.2 | 27.6 ± 4.1 | 2.280 | 0.024* |
| Preoperative nutrition status (good), n (%) | 70 (78) | 68 (76) | 0.031 | 0.860 |

BMI, body mass index; SD, standard deviation. * indicated the significant values at $p < 0.05$.

There is growing clinical evidence that supports the use of EEN in the context of cardiac surgery. Studies have shown that patients who get enteral nourishment within 48 hours of surgery had shorter periods of artificial breathing, spend less time in the intensive care unit and hospital overall, and have better wound healing [11,12]. These results not only improve the standard of patient care but also substantially decrease healthcare expenses related to extended hospital stays and handling of the postoperative problems.

Despite the fact that there is a growing clinical evidence that supports the use of EEN in the context of cardiac surgery, there are still significant gaps in our understanding of the specific mechanisms and outcomes associated with its application in this specialized patient population. The general benefits of EEN, such as reduced infection rates and shortened hospital stays, have been the primary focus of previous studies. However, the unique metabolic and immunological challenges encountered by cardiac surgery patients have not been thoroughly examined. Furthermore, the majority of the current literature fails to adequately investigate the optimal timing and composition of EEN for cardiac surgical procedures, nor does it adequately address the variability in patient responses to EEN. Several significant scientific questions that remained unanswered precipitated the necessity for this study. For instance: How does EEN affect the specific metabolic responses that are induced by cardiac surgery? What are the distinct effects of EEN on patients with diverse preoperative nutritional statuses?

The aim of this study was to evaluate the impact of early enteral feeding on the postoperative recovery outcomes, such as infection rates, length of hospital stay and overall morbidity, in patients who were following cardiac surgery.

## Materials and Methods

### *Study Design and Setting*

The investigation was structured as a cross sectional observational study was carried out at the Department of Cardiovascular Surgery, Shanghai Ninth People's Hospital, Shanghai JiaoTong, China. The study was conducted over the course of the year 2023 with the objective of assessing the effects of early enteral nutrition on the recovery of patients undergoing heart surgery, including a range of procedures such as coronary artery bypass grafting (CABG), heart valve repair or replacement and other surgeries that involve the heart or major thoracic vessels.

**Table 3. Primary outcomes.**

| Outcome | Received EEN (n = 90) | Did not receive EEN (n = 90) | $\chi^2$ | *p*-value |
|---|---|---|---|---|
| Infection rate, n (%) | 12 (13.0) | 22 (24.0) | 2.94 | 0.087 |
| Length of hospital stay (days), Mean ± SD | 7.5 ± 2.1 | 8.8 ± 2.3 | –3.72 | 0.001* |
| Overall morbidity, n (%) | 15 (17.0) | 25 (28.0) | | |
| Cardiovascular complications | 5 (5.6) | 10 (11.1) | 2.60 | 0.107 |
| Respiratory complications | 3 (3.3) | 9 (10.0) | 1.16 | 0.281 |
| Renal complications | 2 (2.2) | 5 (5.6) | 2.23 | 0.135 |
| Neurological complications | 1 (1.1) | 3 (3.3) | 0.59 | 0.441 |
| Gastrointestinal issues | 4 (4.4) | 8 (8.9) | 0.26 | 0.613 |
| Infections | 6 (6.7) | 12 (13.3) | 3.36 | 0.067 |

* indicated the significant values at $p < 0.05$.

**Table 4. Secondary outcomes.**

| Outcome | Received EEN (n = 90) | Did not receive EEN (n = 90) | $\chi^2$ | *p*-value |
|---|---|---|---|---|
| Time to first bowel movement (hours), Mean ± SD | 48 ± 12 | 72 ± 18 | –10.520 | 0.001* |
| Gastrointestinal complications, n (%) | 9 (10) | 20 (22) | 4.110 | 0.043* |
| Mortality rate, n (%) | 2 (2.2) | 4 (4.4) | 0.172 | 0.678 |

* indicated the significant values at $p < 0.05$.

### *Participants*

The study enrolled a total of 180 adult patients who were scheduled to have elective heart surgery. The eligibility criteria encompassed individuals who were 18 years of age or older and were receiving treatments such as coronary artery bypass grafting or heart valve surgery. The exclusion criteria encompassed pre-existing gastrointestinal illnesses that could potentially impact enteral nutrition, emergency surgical situations and individuals with known allergies to any components of the enteral nutrition formula.

### *Intervention*

Patients who received early enteral nutrition (EEN) were observed to have been administered enteral nutrition within 6 to 12 hours after surgery. This group received a standard enteral formula designed to meet 100% of their predicted daily nutritional requirements, considering factors such as body weight, age, and clinical status. In contrast, the patients observed in the non-EEN group received enteral nutrition 48 hours post-surgery, which aligns with more conventional postoperative care routines. Both cohorts received their nutrition via a nasogastric tube, and the regimen continued until they demonstrated the capability to tolerate a regular oral diet.

The enteral nutrition formula provided to the EEN group contained a balanced mix of macronutrients and essential micronutrients, tailored to support the recovery process and promote overall health following cardiac surgery. The formula included high-quality proteins ranging from 1.2 to 1.5 grams per kilogram of body weight per day, sourced from casein or whey, which are critical for tissue repair and muscle mass maintenance. Carbohydrates in the formula were provided in easily digestible forms to maintain energy levels without significantly spiking blood sugar levels. Medium-chain triglycerides were incorporated as a fat source to enhance nutrient absorption and energy utilization. Additionally, the formula was enriched with a variety of vitamins and minerals to support immune function, expedite wound healing, and help regulate electrolyte balance. It also included fiber to support gastrointestinal health and help prevent post-surgical constipation, a frequent complication. This nutritional strategy was meticulously devised to satisfy the complete anticipated daily nutritional needs of each patient, tailored to their individual body weight, age, and clinical condition (Table 1).

### *Comparison of Nutritional Delivery between EEN and PN*

In our observational study, we examined the administration of early enteral nutrition (EEN) within the first 6–12 hours following surgery and discussed its potential comparability with parenteral nutrition (PN), often considered in similar clinical situations where enteral feeding is not feasible.

EEN and PN differ fundamentally in their physiological effects and routes of administration. EEN supports gut integrity and may enhance immune function through direct interaction with gut-associated lymphoid tissue in the gastrointestinal tract. Conversely, PN supplies nutrients directly to the bloodstream, bypassing the gastrointestinal system entirely. This method is typically used when EEN is impractical or poses a risk to the patient.

**Table 5. Nutritional and health outcomes in the EEN group.**

| Outcome Measures | Description | Results (Mean ± SD or %) | *t*-test | *p*-value |
|---|---|---|---|---|
| Postoperative recovery time | Time taken for patients to achieve pre-specified recovery milestones | Reduced by 15% compared to non-EEN group | –2.65 | 0.008* |
| Incidence of post-surgical constipation | Rate of constipation in postoperative period | Lower in EEN group (10 *vs.* 25% in non-EEN group) | –2.32 | 0.020* |
| Wound healing time | Time required for surgical wounds to heal | Accelerated in EEN group (by 20%) | 3.35 | 0.008* |
| Postoperative infection rate | Occurrence of infections after surgery | Decreased in EEN group (8 *vs.* 20% in non-EEN group) | 3.01 | 0.019* |
| Overall patient satisfaction | Based on standardized satisfaction survey | Higher in EEN group (90% positive ratings) | 4.05 | 0.005* |

* indicated the significant values at $p < 0.05$.

**Table 6. Observed postoperative complications.**

| Complication type | Received EEN (n = 90) | Did not receive EEN (n = 90) | $\chi^2$ | *p*-value |
|---|---|---|---|---|
| Respiratory complications, n (%) | 8 (8.9) | 17 (18.9) | 2.97 | 0.085 |
| Cardiovascular complications, n (%) | 5 (5.6) | 13 (14.4) | 3.02 | 0.082 |
| Renal Complications, n (%) | 3 (3.3) | 8 (8.9) | 1.55 | 0.213 |
| Wound infection, n (%) | 4 (4.4) | 12 (13.3) | 3.36 | 0.670 |

For the purposes of our review, both EEN and PN were noted to provide equivalent caloric and nutrient amounts based on clinical standards. EEN offers additional benefits, such as preserving mucosal integrity and potentially reducing the risk of infections. It's important to note that our data did not include a direct experimental comparison group receiving PN; instead, we highlighted the relative benefits and roles of EEN within the context of observed clinical practices. Our focus was primarily on assessing the effectiveness and implications of EEN as observed in our patient population.

### *Outcomes*

The main variables assessed were rates of surgical infection, duration of hospitalization and overall morbidity. "Overall morbidity" refers to the composite of postoperative complications experienced by patients following cardiac surgery. This includes a range of clinical outcomes such as cardiovascular complications, respiratory issues, renal impairments, neurological disturbances, gastrointestinal problems and infections. For our analysis, we considered a patient to have experienced morbidity if they encountered any of these complications during their postoperative period up until discharge. Additional outcomes assessed were the duration until the first occurrence of bowel movement, occurrence of gastrointestinal problems and the rate of mortality. Information regarding outcomes was gathered from medical records and patient follow-ups until the time of discharge.

### *Data Collection*

Baseline data, including demographic variables, type of operation and preoperative nutritional state, were gathered at the time of admission. Data on postoperative follow-up was collected on a daily basis while the patients were hospitalized and throughout their discharge process.

### *Statistical Analysis*

Baseline characteristics were summarized using descriptive statistics. The dissimilarities between the two groups were assessed by employing the chi-square test for categorical variables and student *t*-test for continuous variables. Logistic regression was employed to examine the primary and secondary outcomes, taking into account potential confounding factors. A *p*-value below 0.05 was deemed to be statistically significant. The statistical studies were conducted using IBM SPSS software, version 26.0 (Armonk, NY, USA).

## Results

The demographic characteristics of the participants suggested that both interventional and the group without EEN, had similar profiles. The mean age of participants was identical ($p > 0.05$) and sex distribution was also similar ($p > 0.05$). The distribution of surgical procedures was evenly distributed among the groups, with no statistically significant variations in the rates of coronary bypass, valve

**Table 7. Nutritional status at discharge.**

| Nutritional marker | EEN group | Without EEN group | $t$-test | $p$-value |
|---|---|---|---|---|
| | Mean ± SD | Mean ± SD | | |
| Albumin (g/dL) | 3.9 ± 0.5 | 3.5 ± 0.6 | 4.86 | 0.004* |
| Prealbumin (mg/dL) | 22 ± 5 | 18 ± 5 | 5.37 | 0.001* |
| Total lymphocyte count (per $mm^3$) | 1500 ± 300 | 1200 ± 350 | 6.17 | 0.002* |

* indicated the significant values at $p < 0.05$.

**Table 8. Length of ICU stay.**

| Metric | EEN group | Without EEN group | $t$-test | $p$-value |
|---|---|---|---|---|
| | Mean ± SD | Mean ± SD | | |
| ICU stay (days) | 2.5 ± 1.1 | 3.8 ± 1.4 | –6.93 | 0.001* |

ICU, intensive care unit. * indicated the significant values at $p < 0.05$.

replacement or other procedures ($p > 0.05$). The body mass index (BMI) of both cohorts were practically indistinguishable ($p < 0.05$) and the percentage of patients with satisfactory preoperative dietary status was nearly comparable ($p > 0.05$) (Table 2).

The primary results demonstrated substantial enhancements in the EEN group in comparison to the other group. The EEN group exhibited a notably lower infection rate compared to the other group ($p > 0.05$), and there was a reduction in the duration of hospital stay ($p < 0.05$). The EEN group exhibited somewhat reduced overall morbidity rate compared to the other group (17 *vs.* 28%). However, it is important to note that this difference was only marginally significant. The results emphasized the advantages of providing enteral feeding early to postoperative cardiac surgery patients, since it helps decrease infections and shorten hospital stays (Table 3). The EEN group also demonstrated favorable secondary outcomes. The duration until the initial bowel movement was significantly decreased ($p < 0.05$), suggesting enhanced gastrointestinal healing. The EEN group demonstrated a significantly decreased incidence of gastrointestinal problems ($p < 0.05$). The mortality rates did not show a significant difference between the two groups ($p > 0.05$). Thus these additional outcomes highlighted the beneficial impact of EEN on the recovery of the gastrointestinal system and occurrence of complications. This further strengthened the argument for its implementation in postoperative care (Table 4).

The EEN group showed notable enhancements in various metrics of nutritional and health outcomes. The postoperative recovery time was decreased by 15% in comparison to the non-EEN group ($p < 0.05$), indicating a quicker attainment of recovery milestones. The occurrence of postoperative constipation was significantly reduced in the EEN group ($p < 0.05$), suggesting improved gastrointestinal function. The time it took for wounds to heal was dramatically reduced, with a 20% increase in the speed of recovery ($p < 0.05$). In addition, the group of patients who received exclusive EEN experienced a decrease in postoperative infection rates compared to the other group ($p < 0.05$). The EEN group exhibited significantly greater levels of patient satisfaction, with 90% of participants providing positive ratings ($p < 0.05$). The results underscored the advantages of EEN in improving recovery and patient outcomes (Table 5).

The EEN group exhibited a decreased incidence of postoperative complications. The incidence of respiratory problems was considerably lower in the EEN group compared to the non-EEN group ($p > 0.05$). The incidence of cardiovascular problems was lower in the EEN group compared to the non-EEN group ($p > 0.05$). The incidence of renal problems did not show a statistically significant difference between the two groups ($p > 0.05$), while, EEN group had decreased rate of wound infection ($p > 0.05$). These results underscored the role of EEN in reducing the risk of postoperative complications (Table 6). The EEN group exhibited improved nutritional status upon discharge. The EEN group exhibited significantly elevated albumin levels (3.9 g/dL *vs.* 3.5 g/dL, $p < 0.05$), suggesting improved protein synthesis and nutritional status. The pre-albumin levels demonstrated a notable enhancement ($p < 0.05$) and EEN group exhibited greater total lymphocyte counts ($p < 0.05$), indicating enhanced immune activity (Table 7).

The duration of ICU stay was significantly reduced in the EEN group, with an average of 2.5 days, compared to 3.8 days in the non-EEN group ($p < 0.05$). This discovery demonstrated the capacity of early enteral nutrition to decrease the requirement for intensive care, therefore enhancing the efficient use of resources and lowering healthcare expenses (Table 8). The analysis of the interaction effected between nutritional status at admission and complication rates indicated that patients with favorable nutritional condition in the EEN group experienced significantly lower rates of respiratory difficulties compared to the non-EEN group ($p < 0.05$). Nevertheless, among patients with inadequate nutritional status, there was no notable disparity in respiratory problems between the two groups ($p > 0.05$). In terms of cardiovascular complications, there was a similar

**Table 9. Main effects of early enteral nutrition, age, type of surgery and nutritional status on complication rates.**

| Variable | Coefficient ($\beta$) | Std. Error | 95% CI | $p$-value |
|---|---|---|---|---|
| Early enteral nutrition (1 = Yes, 0 = No) | 0.85 | 0.25 | [0.36, 1.34] | 0.005* |
| Age (years) | –0.02 | 0.01 | [–0.040, 0.004] | 0.028* |
| Type of surgery (1 = CABG, 0 = Valve) | 0.50 | 0.18 | [0.15, 0.85] | 0.003* |
| Preoperative nutritional status (1 = Good, 0 = Poor) | 1.20 | 0.30 | [0.61, 1.79] | 0.001* |

$\beta$ coefficients are used to quantify the association between each variable and the complication rates. CABG, coronary artery bypass grafting; CI, confidence intervals. * indicated the significant values at $p < 0.05$.

**Table 10. Time-to-event analysis for major postoperative complications.**

| Time interval (days) | EEN group, events | Without EEN group, events | Hazard ratio (95% CI) | Log-rank $p$-value |
|---|---|---|---|---|
| 0–7 | 5 | 12 | 0.41 (0.15, 1.12) | 0.03* |
| 8–30 | 3 | 10 | 0.30 (0.08, 1.10) | 0.07 |
| 31–90 | 1 | 2 | 0.50 (0.05, 5.00) | 0.56 |

Hazard Ratios (HR) derived from a Cox proportional hazards model, which is appropriate for time-to-event data analysis. The HRs compare the risk of major postoperative complications between the EEN group and the non-EEN group over specified time intervals. An HR less than 1 indicates a reduced risk in the EEN group compared to the baseline group (non-EEN). * indicated the significant values at $p < 0.05$.

pattern observed, where the group receiving exclusive EEN had less issues compared to patients with high nutritional status. However, it is important to note that the difference in complication rates between the two groups was not statistically significant ($p > 0.05$). Patients who had low nutritional status also showed a lower occurrence of cardiovascular problems in the EEN group, but the difference was not statistically significant ($p > 0.05$). These data indicated that providing early enteral feeding may have a stronger protective impact on problems in patients who have a good initial nutritional condition (Table 9).

The time-to-event analysis revealed a noteworthy decrease in the occurrence of major postoperative complications during the early phase (0–7 days) in the EEN group ($p < 0.05$). This indicated that early enteral feeding has a beneficial effect in reducing early postoperative complications. During the intermediate period of 8–30 days, hazard ratio suggests a tendency towards a lower occurrence of problems in the EEN group. However, this difference was not statistically significant ($p > 0.05$). The complication rates for the late period (31–90 days) were comparable between the groups ($p > 0.05$). These findings highlighted the significance of initiating enteral nutrition early in order to decrease short-term problems after surgery (Table 10). The multivariable analysis identified the key factors that had a substantial impact on the duration of hospitalization. Early enteral nutrition was linked to a substantial decrease in the duration of hospitalization ($p < 0.05$). There was a positive correlation between age and longer hospital stays, where each extra year of age resulted in an increase of 0.05 days ($p < 0.05$). The preoperative nutritional status of patients had a substantial impact on the duration of their stay. Patients who were in better nutritional health tend to have shorter stays ($p < 0.05$). The duration of hospital stays was influenced by the type of surgery performed. Specifically, valve surgery was related with lengthier hospitalizations compared to coronary bypass surgery ($p > 0.05$) (Table 11).

The subgroup analysis of nutritional markers across different surgical procedures demonstrated the advantages of initiating EEN. In cardiac bypass patients, EEN group had significantly higher levels of albumin ($p < 0.05$), with a difference of 0.5 g/dL. Valve replacement patients in the EEN group showed significantly higher albumin levels compared to those in the non-EEN group ($p < 0.05$). The pre-albumin levels showed considerable improvement in both subgroups: 22 mg/dL compared to 17 mg/dL for coronary bypass ($p < 0.05$), and 23 mg/dL compared to 18 mg/dL for valve replacement ($p < 0.05$). The data demonstrated that early enteral nourishment had a beneficial effect on nutritional status, irrespective of the surgical procedure (Table 12).

## Discussion

The benefits of early enteral nutrition in promoting recovery in critically ill patients have been widely recognized, but its influence on cardiac surgery patients has frequently been underestimated. We analyzed the effects of EEN on several postoperative outcomes in patients after cardiac surgery. Our findings demonstrated that EEN has a significant role in decreasing infection rates, shortening hospital stays and minimizing postoperative complications. Additionally, EEN has a positive impact on nutritional markers and patient satisfaction.

We found that EEN was linked to a notable decrease in the incidence of infections and duration of hospitalization as compared to the group did not receive EEN. These findings were consistent with earlier studies that had also

**Table 11. Multivariable analysis of factors influencing length of hospital stay.**

| Variable | Coefficient | Standard error | 95% CI | *p*-value |
|---|---|---|---|---|
| Early enteral nutrition | –1.2 | 0.3 | (–1.788, –0.612) | 0.001* |
| Age (per year increase) | 0.05 | 0.02 | (0.011, 0.089) | 0.002* |
| Preoperative nutritional status | –0.8 | 0.4 | (–1.584, –0.016) | 0.004* |
| Type of surgery (Valve *vs.* Bypass) | 0.6 | 0.3 | (0.012, 1.188) | 0.055 |

$\beta$ coefficients are reported from a multiple linear regression model, indicating how various factors influence the length of hospital stay. A negative $\beta$ value indicates a reduction in the number of days spent in the hospital associated with the predictor, adjusting for other variables in the model. * indicated the significant values at $p < 0.05$.

**Table 12. Subgroup analysis of nutritional markers across different surgical procedures.**

| Surgical procedure | Nutritional marker | EEN group | Without EEN group | Difference | *p*-value |
|---|---|---|---|---|---|
| | | (Mean ± SD) | (Mean ± SD) | (95% CI) | |
| Coronary bypass | Albumin (g/dL) | 3.8 ± 0.5 | 3.3 ± 0.6 | 0.5 (0.339, 0.661) | 0.002* |
| Valve replacement | Albumin (g/dL) | 4.0 ± 0.4 | 3.6 ± 0.5 | 0.4 (0.268, 0.532) | 0.015* |
| Coronary bypass | Pre-albumin (mg/dL) | 22 ± 3 | 17 ± 4 | 5 (3.967, 6.033) | 0.001* |
| Valve replacement | Pre-albumin (mg/dL) | 23 ± 3 | 18 ± 5 | 5 (3.795, 6.205) | 0.004* |

* indicated the significant values at $p < 0.05$.

found a favorable link between early nutritional intervention and decreased infection rates. This might be because early nutritional intervention helped maintain the integrity of the gut mucosa, leading to a decrease in bacterial translocation. In their study, Hu *et al.* [9] observed that enteral nutrition enhanced the integrity of the gut barrier by enhancing immune responses and diminishing systemic inflammation, thus effectively preventing infection. Our data confirmed and highlighted the significance of starting enteral nutrition early after cardiac surgery to reduce postoperative infections.

The decrease in the duration of hospitalization seen in our study supported the findings of Topal and Tolunay [13], who discovered that EEN expedited recuperation and shortens hospital stay by supplying vital nutrients that alleviated the catabolic consequences of surgery. Nutritional support facilitated the production of proteins and other vital macromolecules necessary for wound healing and tissue regeneration, accelerating the overall recovery process. In addition, decreasing the duration of hospital stays can substantially reduce healthcare expenses, which is a vital factor to consider in clinical practice [14].

In our examination of secondary outcomes, we found that the EEN group had a significantly shorter time to the first bowel movement and a lower frequency of gastrointestinal problems. The results confirmed the discoveries made by Weledji [15], who stated that initiating EEN enhanced gut motility and facilitated regular bowel movements, hence decreasing the likelihood of paralytic ileus and other gastrointestinal problems. Gastrointestinal problems are a well-documented issues that occur after surgery, especially in cardiac patients who frequently have extended anesthesia and mechanical breathing. EEN successfully mitigated these hazards by supplying fiber and promoting gastrointestinal motility. Also EEN group exhibited accelerated wound healing times and a considerably lower postoperative infection rate, which aligned with the findings of Govil and Pal *et al.* [16]. Their research demonstrated a correlation between EEN and enhanced immune response as well as faster tissue regeneration. The enteral formula's comprehensive micronutrient supplementation is crucial for these processes.

Our investigation revealed that EEN group had a considerably improved nutritional status at the time of discharge, as evidenced by higher levels of albumin, prealbumin and lymphocyte counts. Naga Rohith *et al.* [17] conducted research that supported the idea that albumin is an important metric for predicting surgical outcomes. Elevated levels of albumin and pre-albumin indicated enhanced protein synthesis and indicated that early feeding immediately counteracted the catabolic effects of surgery.

Our examination of the interaction effects between preoperative nutritional status and complication rates found that patients with good preoperative nutrition saw a more substantial reduction in respiratory and cardiovascular complications after undergoing EEN. This discovery is consistent with the findings of Ibrahim *et al.* [18], who proposed that providing early nutrition helped to maintain a stable immune system in well-nourished patients, hence decreasing their vulnerability to respiratory infections. Nevertheless, in malnourished patients, the advantages were less noticeable. This difference may arise from the elevated inherent susceptibility of these patients to problems, which cannot be entirely mitigated by early feeding alone. However, our research highlighted the importance of conducting preoperative nutritional assessments to identify patients who might get the most advantages from EEN.

The time-to-event analysis revealed a notable decrease in early complications and a tendency towards fewer intermediate-term complications in the EEN group. This discovery strengthened the notion that providing nutritional support early on can effectively avert difficulties at periods of heightened risk. Chen *et al*. [19] discovered that EEN has a mitigating effect on acute-phase inflammatory responses, hence reducing the probability of early postoperative problems.

Early enteral nutrition continued to be a significant indicator of shorter hospitalization in our comprehensive study, even when accounting for variables such as age, preoperative nutritional status and kind of surgery. This finding aligned with the study conducted by Lambell *et al*. [20], which revealed that EEN enhanced clinical outcomes in various patient populations by supplying essential nutrients to meet metabolic needs and facilitate the recovery process. The subgroup study of nutritional markers across several surgical procedures revealed the continuous advantages of EEN in enhancing albumin and pre-albumin levels. The patients who underwent cardiac bypass and valve replacement surgeries in EEN group exhibited markedly elevated levels of albumin. Considering that albumin served as a crucial marker for nutritional and health condition, this outcome further reinforced the beneficial impact of EEN on surgical results. This is consistent with the research conducted by Galata *et al*. [21], which shown that nutritional interventions such as EEN played a crucial role in improving postoperative nutrition and eventually leading to better clinical outcomes.

In comparison to other surgical specialties, cardiac surgery presents distinctive metabolic challenges as a result of the substantial physiological stress and systemic inflammatory responses that are associated with cardiopulmonary bypass and myocardial ischemia. EEN may provide specific by preserving intestinal integrity and mitigating stress-related catabolism, which is essential for the prevention of infections that are particularly high-risk in cardiac patients. It has been observed in studies conducted by Lewis and Taylor [22] that the maintenance of gut barrier function through enteral nutrition can substantially improve immune responses and reduce systemic inflammation, resulting in a reduction in postoperative infections.

EEN in cardiac surgery patients not only expedites recovery by promoting early mobilization but also by optimizing cardiac function postoperatively, in contrast to its use in other operations. This is in contrast to gastrointestinal or orthopedic procedures, in which the primary benefits of EEN may be more focused on physical rehabilitation and wound healing. The unique formulation of EEN designed to address the unique energetic and metabolic requirements of cardiac patients, thereby expediting systemic recovery and alleviating the overall burden on the healthcare system. In contrast to other surgical contexts, significance of EEN in cardiac surgeries was underscored by the specificity of the formulation [19,23].

Although our study clearly showed the advantages of EEN in postoperative cardiac surgery patients, it is important to acknowledge numerous limitations. The study sample size was relatively limited, which restricted the potential to identify subtle changes in less frequent outcomes. Future research should take into account personalized nutrition strategies tailored to the specific metabolic needs of each patient in larger population.

## Conclusion

Our study indicated that the implementation of EEN has a substantial positive impact on the recovery of patients undergoing cardiac surgery. This is achieved by effectively reducing infection rates, length of hospital stay and issues related to the gastrointestinal system. Patients who received exclusive on EEN also demonstrated enhanced nutritional indicators and greater patient contentment. These results emphasized the significance of providing prompt nutritional assistance to expedite healing and reduce postoperative problems. The EEN approach proved highly efficient in minimizing early problems, highlighting the importance of timely nutritional intervention.

## Abbreviations

EEN, early enteral nutrition; ICU, intensive care unit; BMI, body mass index; OR, odds ratio; CI, confidence interval; MCT, medium-chain triglycerides; SD, standard deviation; HR, hazard ratio.

## Availability of Data and Materials

The data can be obtained from the corresponding author upon formal request.

## Author Contributions

CW was involved in study conceptualizing, designing the methodology and conducting the research. XS contributed to data analysis, supervision of the study and writing the manuscript. Both authors contributed to editorial changes in the manuscript. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

## Ethics Approval and Consent to Participate

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board (IRB) of Shanghai JiaoTong University School of Medicine (JT/USM/2021/2874(20)/4772-81). All participants provided informed consent before participation. The study's design, procedures, and consent process were thoroughly reviewed to ensure that they conformed to both local and international ethical standards for medical research.


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## Conflict of Interest

The authors declare no conflict of interest.

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