Advanced International Journal for Research (AIJFR)
E-ISSN: 3048-7641 ● Website: www.aijfr.com ● Email: editor@aijfr.com

Study of The Effect Of High Fresh Gas Flows And Pattern Of Breathing On Rapid Preoxygenation

Dr. Sasmita Sidu[1], Dr. Manali Mohan[2]

Anaesthesiology
Maharashtra University of Health Sciences Nashik

1. Introduction

Pre-oxygenation is a critical procedure performed before the induction of anaesthesia to increase the body's oxygen reserves, thereby extending the duration of safe apnoea and reducing the risk of hypoxemia during the induction process[1]. Traditionally, pre-oxygenation involves the administration of 100% oxygen through a tightly fitted mask, usually for a duration of 3 to 5 minutes, or eight vital capacity breaths[2]. However, rapid sequence induction (RSI) necessitates more efficient and faster methods of pre-oxygenation to minimize the risk of aspiration while still achieving adequate oxygenation. Studies have explored various methods to optimize pre-oxygenation. For instance, pre-oxygenation with a facemask combined with nasal prongs has been shown to achieve a faster rise in end-tidal oxygen concentration compared to a facemask alone, although the time to oxygen desaturation remains comparable between the two methods.

Preoxygenation also washes nitrogen out of the lungs, saturates haemoglobin and allows oxygen to dissolve the plasma. Total oxygen stores build-up and delay the rest of arterial desaturation and hypoxia during apnoeic period.[8] Desaturation can lead to dysrhythmias, haemodynamic decompensation, hypoxic brain injury and ultimately death. Therefore, maintenance of arterial oxyhaemoglobin saturation level is critical in an apnoeic patient until airway control has been achieved.[2] End tidal concentration of oxygen > 90% is considered to maximum apnoea time. [3,10] This maximal preoxygenation prior to induction of GA in a routine procedure end more essential in anticipated difficult mask ventilation, different intubation or in emergency cases rapid sequence induction. [4,11,12]

The efficacy of pre-oxygenation is influenced by several factors, including the fresh gas flow (FGF) rates and the breathing patterns used[3]. Fresh gas flow rates determine how quickly and efficiently alveolar nitrogen can be replaced with oxygen. Higher flow rates have been shown to expedite this process, reducing the time needed to achieve optimal oxygenation levels. However, the optimal FGF rate for different patient populations and clinical scenarios remains a topic of ongoing research and debate [4].

Breathing patterns also play a critical role in the effectiveness of pre-oxygenation. Common techniques include tidal volume breathing (TVB), deep breathing (DB), and vital capacity breathing (VCB)[4]. TVB involves normal, relaxed breaths over a period of 3 to 5 minutes, ensuring gradual nitrogen washout. DB, on the other hand, consists of taking deep breaths over a shorter period, aiming for rapid

oxygenation. VCB involves taking a series of deep breaths to maximum lung capacity, which can quickly elevate alveolar oxygen levels. Each method has its advantages and limitations, and the choice of technique may depend on the clinical context and patient-specific factors [5].

This study aims to investigate the effects of different fresh gas flow rates (10 L/min and 15 L/min) and breathing patterns (TVB and DB) on the efficiency of rapid pre-oxygenation. By comparing the time taken to achieve an end-tidal oxygen concentration (EtO2) of 0.9 and the number of breaths required, this research seeks to identify the most effective combination of FGF rates and breathing patterns. The findings will contribute to the optimization of pre-oxygenation practices, enhancing patient safety and outcomes during anaesthesia induction.

AIMS and Objective

AIM OF STUDY- To see the effect of fresh gas flow and compare the pattern of breathing – 10L/min and 15L/min on rapid preoxygenation.

Primary Objective

1. To estimate the time taken to achieve an end-tidal oxygen concentration (EtO2) of 0.9 at given fresh gas flow rates of 10 L/min and 15 L/min using two patterns of breathing: Tidal Volume Breathing (TVB) and Deep Breathing (DB).
2. To compare the efficiency of TVB and DB in achieving rapid pre-oxygenation at fresh gas flow rates of 10 L/min and 15 L/min.

Secondary Objective

3. To estimate the average number of breaths required to achieve an EtO2 of 0.9 for each fresh gas flow rate (10 L/min and 15 L/min) using TVB and DB.
4. To assess patient comfort and tolerance for each breathing pattern and fresh gas flow rate combination during the pre-oxygenation process.

2. Review of Literature

Overview of Pre-oxygenation:

Preoxygenation is the administration of oxygen to a patient prior to intubation to extend ‘the safe apnoea time’ . It is a critical procedure in the field of anaesthesia aimed at increasing the body's oxygen reserves before the induction of general anaesthesia [6]. This procedure increases a patient's oxygen reserves before airway management or the onset of apnoea, hence essential to prevent hypoxemia, a condition characterized by low oxygen levels in the blood, during the apnoeic phase that occurs immediately following the administration of anaesthetic agents.

Hypoxemia can lead to severe complications, including brain damage and cardiac arrest, making effective pre-oxygenation a vital component of anaesthetic practice [7]. The primary purpose of pre-

oxygenation is to maximize the oxygen content in the lungs, blood, and tissues to extend the duration of safe apnoea. Safe apnoea refers to the period during which a patient can tolerate the absence of breathing without a significant drop in arterial oxygen saturation (SpO2) [8][9]. By filling the lungs with 100% oxygen, pre-oxygenation replaces the nitrogen present in the functional residual capacity (FRC) of the lungs with oxygen, thereby increasing the oxygen reserves available during apnoea.

The primary goal of pre-oxygenation is to extend the "safe apnoea time," which is the duration a patient can tolerate apnoea without significant desaturation of arterial oxygen. Achieving this goal relies on meeting several physiological objectives. The key objective is to achieve near 100% arterial oxygen saturation (SaO2) [10]. This maximizes the oxygen content of the blood by ensuring that haemoglobin is fully saturated with oxygen. Although oxygenating the plasma is also a goal, it is of lesser importance due to the low solubility of oxygen in blood.

Mechanism of oxygen transport and utilization:

Understanding the mechanisms of oxygen transport and utilization is fundamental to optimizing pre-oxygenation. Oxygen transport involves its movement from the alveoli to the bloodstream and ultimately to tissues where it is utilized for cellular respiration. This section provides a comprehensive explanation of these processes, emphasizing their importance in the context of pre-oxygenation.

Oxygen Transport from Alveoli to Bloodstream

The process of oxygen transport begins in the lungs, specifically in the alveoli, which are tiny air sacs where gas exchange occurs. When a person inhales, oxygen from the air fills the alveoli. The oxygen must then diffuse across the alveolar membrane into the pulmonary capillaries, where it enters the bloodstream.

Partial Pressure Gradient: The primary driver of oxygen diffusion is the partial pressure gradient between the alveoli and the blood. The partial pressure of oxygen (PaO2) in the alveoli is higher than in the deoxygenated blood returning from the tissues[11]. This difference in partial pressure causes oxygen to move from the alveoli into the blood until equilibrium is reached.

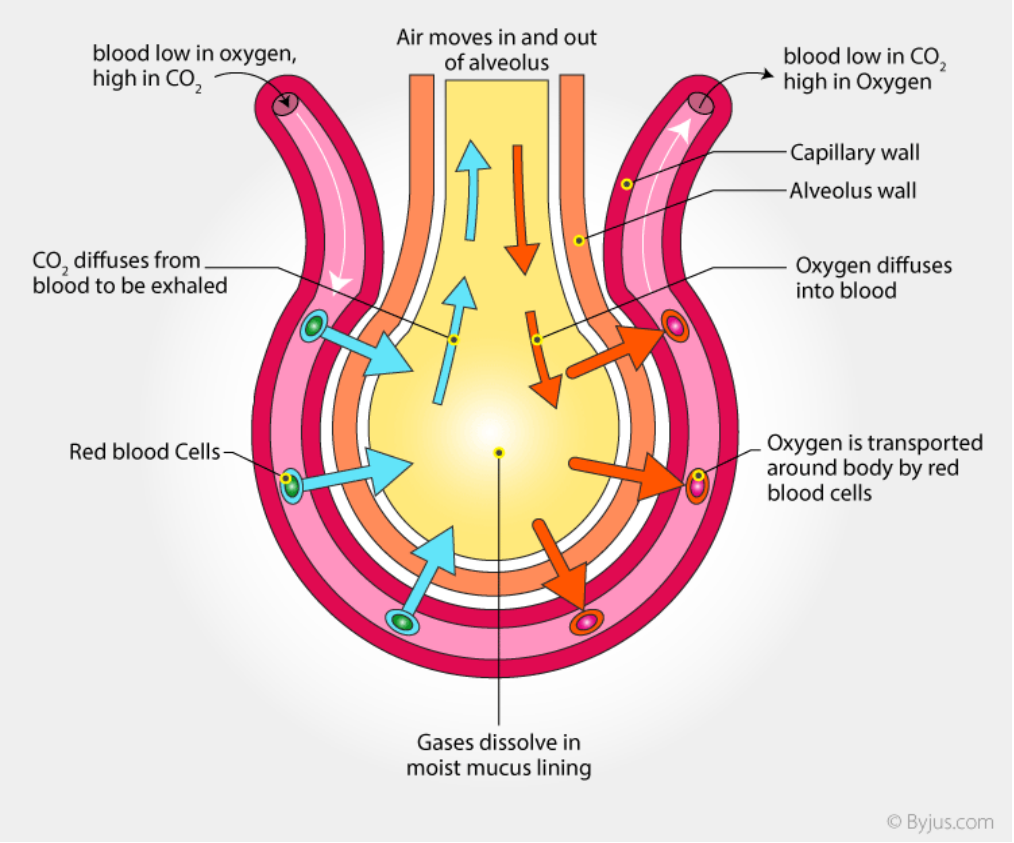


Figure 1: Oxygen transport from alveoli to bloodstream.

Role of Haemoglobin in Oxygen Transport

Once oxygen diffuses into the blood, it binds to haemoglobin molecules in red blood cells. Haemoglobin is a protein with four binding sites for oxygen, allowing it to carry up to four oxygen molecules at a time.

Oxygen-Haemoglobin Dissociation Curve: The relationship between the partial pressure of oxygen and haemoglobin saturation is depicted by the oxygen-haemoglobin dissociation curve [12]. This curve illustrates how haemoglobin's affinity for oxygen changes with varying levels of PaO2. At higher PaO2 (such as in the lungs), haemoglobin is almost fully saturated with oxygen. As blood travels to tissues where PaO2 is lower, haemoglobin releases oxygen to meet cellular demands [13].

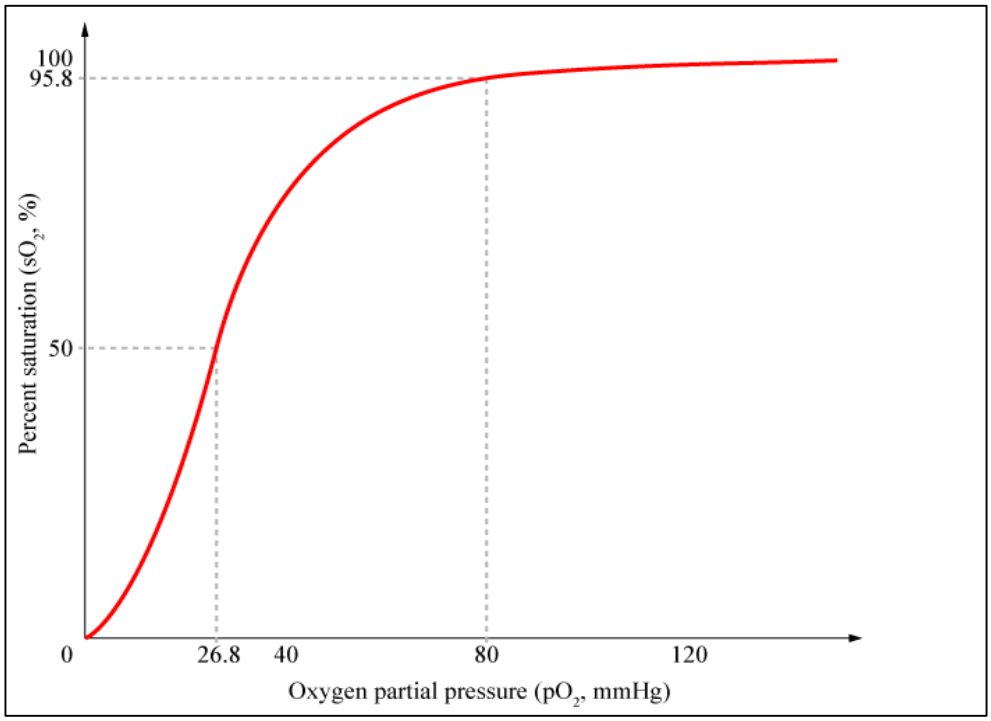


Figure 2: Oxygen Dissociation Curve (ODC)

Impact of Pre-Oxygenation on Oxygen Transport

Pre-oxygenation aims to maximize alveolar and arterial oxygen levels to enhance the efficiency of oxygen transport and utilization. By increasing the concentration of inhaled oxygen to 100%, pre-oxygenation significantly raises the PaO2 in the alveoli, leading to a higher diffusion gradient and more effective oxygen loading onto haemoglobin [14].

Extending Safe Apnoea Time: The primary benefit of pre-oxygenation is the extension of safe apnoea time. By saturating haemoglobin and increasing dissolved oxygen in plasma, pre-oxygenation provides a larger reservoir of oxygen that can sustain the patient during periods of apnoea, such as during intubation [15].

Achieving Optimal Haemoglobin Saturation: Ensuring that haemoglobin is fully saturated with oxygen (approaching 100% SaO2) is critical for maximizing the oxygen-carrying capacity of the blood. This is particularly important in patients with limited respiratory reserve or those undergoing procedures that require prolonged apnoea [16].

Enhanced Oxygen Reserves: By washing out nitrogen and replacing it with oxygen, pre-oxygenation increases the volume of oxygen stored in the lungs. This enhanced oxygen reserve serves as a buffer during the apnoeic period, providing continuous oxygen delivery to tissues even when breathing is temporarily halted [17].

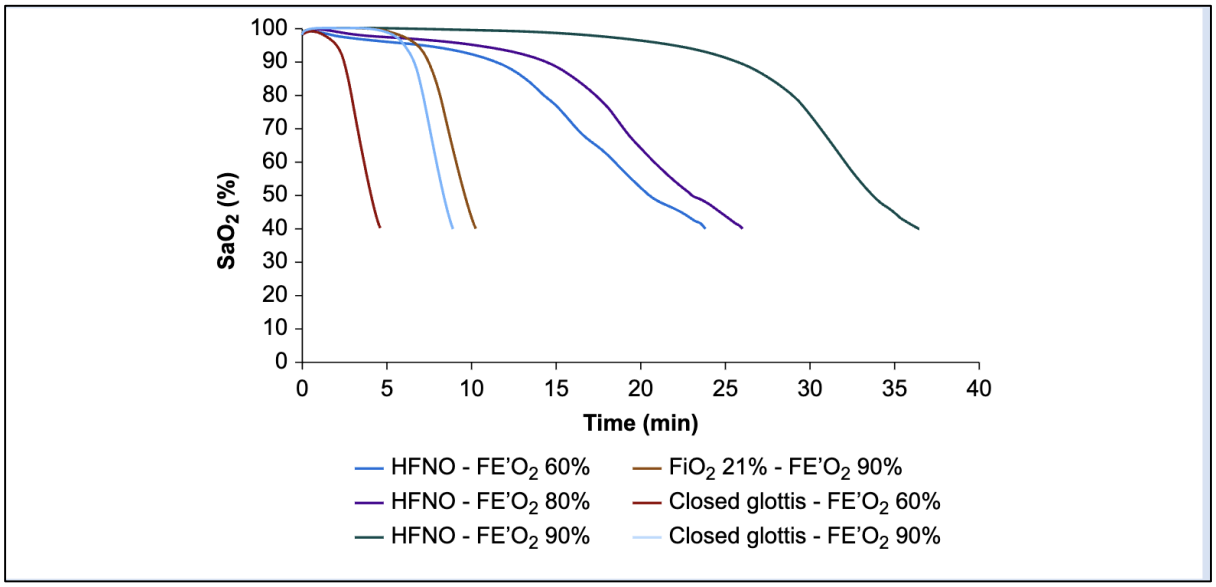
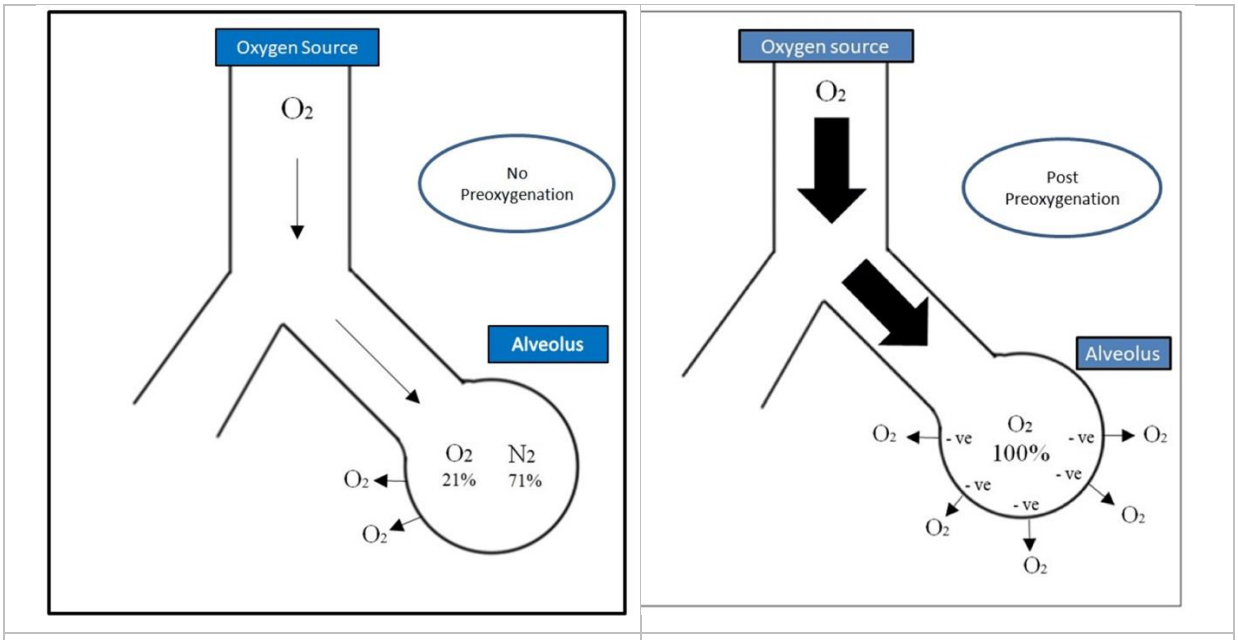


Figure 3: Oxygen saturation during apnoea (SaO2) in the virtual subject BMI35 kg m2 in labour, during HFNO

Mechanism of action of Pre-oxygenation:

The primary mechanism of Pre-oxygenation is 'denitrogenation' of the lungs, however maximal preoxygenation is achieved when the alveolar, arterial, tissue, and venous compartments are all filled with oxygen. It works by utilizing the oxygen-carrying capacity of the lungs and blood. When a patient breathes room air, which is approximately 79% nitrogen, the lungs contain about 450 mL of oxygen in an average healthy adult [18]. By breathing 100% oxygen, nitrogen in the lungs is washed out, increasing the oxygen content to approximately 3,000 ml. This significant increase in oxygen allows the lungs to serve as a substantial oxygen reservoir during apnoea [19]. The process involves the patient breathing in 100% oxygen through a tight-fitting mask or other delivery systems. As the patient inhales pure oxygen, the nitrogen in the alveoli is gradually replaced with oxygen. This increases the partial pressure of oxygen (PaO2) in the alveoli and subsequently in the blood, ensuring that there is a higher amount of dissolved oxygen available in the bloodstream [20].

The Functional Residual Capacity (FRC), which is the volume of air remaining in the lungs after a normal exhalation, plays a crucial role in this process [21]. By increasing the oxygen content in the FRC, pre-oxygenation ensures that there is a sufficient oxygen reserve to maintain adequate arterial oxygen saturation during the induction of anaesthesia and the subsequent apnoeic phase [22].



a b

Figure 4: Level of oxygenation without(a) and with(b) pre-oxygenation

Techniques of Pre-Oxygenation:

Preoxygenation is noted to be complete when all compartments, namely, alveoli, arteries, veins and tissues are fully saturated with oxygen. Achieving effective pre-oxygenation is essential for ensuring patient safety during the induction of anaesthesia. Several techniques are employed to maximize oxygen reserves in the lungs and blood, each with its own method and duration of oxygen delivery. The most common techniques include Tidal Volume Breathing (TVB), Deep Breathing (DB), Vital Capacity Breathing (VCB), and High-Flow Nasal Oxygen (HFNO) [23-25].

A. **Tidal Volume Breathing (TVB)**

Tidal Volume Breathing involves the patient breathing normally (tidal breaths) of 100% oxygen for a duration of 3 to 5 minutes [26]. This method is the most commonly used technique in clinical practice due to its simplicity and effectiveness. By allowing the patient to breathe at their natural rate and depth, TVB ensures a gradual and steady replacement of alveolar nitrogen with oxygen. Over the course of 3 to 5 minutes, the lungs become saturated with oxygen, significantly increasing the oxygen reserves available during apnoea[27]. This technique is particularly advantageous for patients who may not tolerate forced breathing techniques, providing a comfortable and effective means of pre-oxygenation.

B. Deep Breathing (DB)

Deep Breathing involves the patient taking deep, controlled breaths of 100% oxygen, typically for a shorter duration of 1 to 2 minutes. This technique aims to rapidly replace alveolar nitrogen with

oxygen. By taking deeper breaths, a larger volume of oxygen is inhaled with each breath, quickly increasing the alveolar oxygen concentration. However, while DB can rapidly elevate oxygen levels, it may not sustain them as effectively as the more prolonged TVB[28]. Deep breathing may be particularly useful in emergency situations where time is limited, or when rapid oxygenation is required before the induction of anaesthesia.

C. Vital Capacity Breathing (VCB)

Vital Capacity Breathing involves the patient taking a series of deep breaths to their maximum lung capacity (vital capacity) over a short period. This technique can quickly elevate alveolar oxygen levels by maximizing the volume of each breath. The patient is instructed to take deep, full breaths, filling their lungs completely with 100% oxygen. While VCB can achieve high levels of alveolar oxygenation rapidly, it may not maintain these levels as effectively over time compared to prolonged TVB. This technique is often used when there is a need for rapid oxygenation, such as in rapid sequence induction (RSI) of anaesthesia, where maintaining a high oxygen level during a short apnoeic period is crucial [29-31].

D. High-Flow Nasal Oxygen (HFNO)

High-Flow Nasal Oxygen involves the use of nasal cannulas to deliver high-flow oxygen (up to 60 litters per minute) to the patient. HFNO has gained popularity in recent years due to its effectiveness in both pre-oxygenation and maintaining oxygenation during the apnoeic phase. The high flow rate ensures a continuous delivery of oxygen, which helps to wash out alveolar nitrogen and maintain high oxygen levels. HFNO is particularly advantageous for patients who may have difficulty using a mask or in situations where mask fit and seal cannot be ensured. Additionally, HFNO can provide a level of positive end-expiratory pressure (PEEP), which can help keep the alveoli open and further enhance oxygenation [32]. This technique is especially useful in patients with respiratory conditions or those at risk of hypoxemia during the apnoeic phase of anaesthesia induction.

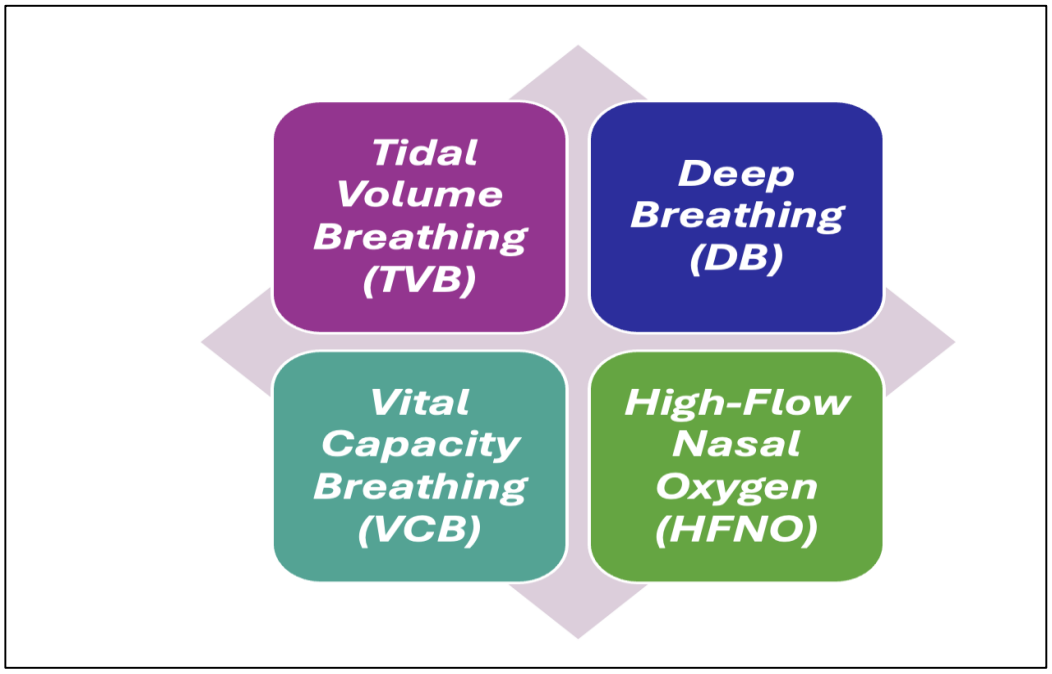


Figure 5: Techniques of Pre-Oxygenation

Fresh gas flow rate in pre-oxygenation:

Fresh gas flow (FGF) rates are a critical factor in pre-oxygenation, influencing the efficiency with which alveolar nitrogen is replaced by oxygen. The choice of FGF rate can significantly affect the time required to achieve adequate pre-oxygenation, the level of oxygen saturation achieved, and the overall safety of the induction process [33].

Importance of Fresh Gas Flow Rates

Fresh gas flow rates determine the speed and efficiency of oxygen delivery to the patient's lungs. Higher FGF rates accelerate the replacement of alveolar nitrogen with oxygen, thereby increasing the oxygen content in the lungs more rapidly. This is especially important during the pre-oxygenation phase, where the goal is to maximize the oxygen reserves before the onset of apnoea [33].

Recommended Fresh Gas Flow Rates

Research and clinical guidelines suggest varying FGF rates for optimal pre-oxygenation. Generally, flow rates between 6 to 15 litters per minute (L/min) are recommended, depending on the specific needs of the patient and the clinical context[34]. Below are the common FGF rates used in pre-oxygenation and their respective impacts:

Low Flow Rates (1-5 L/min)

- **Advantages:**
  - May be more comfortable for patients, especially those with anxiety or claustrophobia.

- Lower risk of causing mucosal drying and discomfort.

- **Disadvantages:**
  - Slower replacement of alveolar nitrogen, leading to prolonged time to achieve optimal pre-oxygenation.
  - Less effective in critically ill patients or those with high oxygen consumption.

Moderate Flow Rates (6-10 L/min)

- **Advantages:**
  - Provide a balance between comfort and efficiency.
  - More effective than low flow rates in achieving faster nitrogen washout.
- **Disadvantages:**
  - May still require longer duration to achieve full pre-oxygenation compared to high flow rates.

High Flow Rates (10-15 L/min)

- **Advantages:**
  - Rapid replacement of alveolar nitrogen with oxygen.
  - Shorter time to achieve optimal pre-oxygenation, which is crucial in emergency situations.
  - Effective in patients with high oxygen demand, such as those with obesity, pregnancy, or respiratory distress.
- **Disadvantages:**
  - Higher flow rates can cause discomfort due to dry and cold air, although this can be mitigated with heated and humidified oxygen.
  - Increased noise levels, which may cause anxiety in some patients.

Several clinical studies have investigated the impact of various fresh gas flow (FGF) rates on pre-oxygenation, revealing significant insights into optimizing oxygen delivery. For instance, Mushambi et al. found that FGFs of 10 L/min and 15 L/min were significantly more effective in achieving optimal pre-oxygenation compared to 5 L/min, but increasing the flow rate from 10 L/min to 15 L/min did not yield additional benefits, indicating a plateau effect at higher flow rates [35] [36].

Similarly, Chaudhari et al. concluded that higher FGFs decreased the time required to achieve 90% end-tidal oxygen (ETO2), with FGFs of 10 L/min or higher associated with a rapid rise in ETO2, reaching 90% more quickly than lower flow rates[37].

Bentsen et al. compared tidal volume breathing and deep breathing techniques with various FGF rates, finding that tidal volume breathing at a moderate flow rate (8 L/min) was effective in achieving high ETO2 levels within 3 to 5 minutes, highlighting the importance of combining appropriate breathing techniques with optimal FGF rates for efficient pre-oxygenation [38][39].

High-Flow Nasal Oxygen (HFNO) therapy, delivering up to 60 L/min, has gained popularity for its effectiveness in both pre-oxygenation and maintaining oxygenation during apnoea. Studies have shown

that HFNO provides continuous oxygen delivery and positive end-expiratory pressure (PEEP), enhancing alveolar oxygenation and maintaining high oxygen levels during the apnoeic phase [40]. HFNO is particularly useful in patients with mask intolerance or those at risk of hypoxemia. For example, a study by Lyons et al. demonstrated that high-flow nasal oxygen at 50 L/min during induction of anesthesia significantly prolonged the time to desaturation compared to no oxygen flow, although it did not significantly affect the rate of carbon dioxide accumulation during apnoea [41].

Additionally, Fadila et al. found that combining facemask with nasal prong pre-oxygenation resulted in a shorter time to reach an expired end-tidal oxygen (FEO2) of 0.8 compared to facemask alone, although the time to desaturation was comparable between the groups [42].

Jaber et al. reported that combining facemask with HFNO for pre-oxygenation and apnoeic oxygenation was associated with higher levels of lowest end-tidal oxygen within 2 minutes after intubation and less desaturation compared to facemask alone[43].

Furthermore, Tunnell's bench study indicated that high flow rates up to 80 L/min did not elevate airway pressures to a level that would result in gastric distention and potential aspiration, suggesting that higher flow rates may reduce the risk of HFNC failure by matching the patient's inspiratory peak flow demand.

However, a study by Ajeetha et al. found that HFNO did not achieve an acceptable level of pre-oxygenation (ETO2 ≥90% in 95% of individuals) in term pregnant women, indicating that it may be inadequate for pre-oxygenation in this specific population [44].

Overall, these findings underscore the importance of selecting appropriate FGF rates and techniques for effective pre-oxygenation, with HFNO offering significant advantages in certain clinical scenarios, particularly for patients with mask intolerance or at risk of hypoxemia [45].

Factors affecting the pre-oxygenation:

Pre-oxygenation is a critical step in anaesthesia that ensures the patient maintains adequate oxygen levels during the induction and apnoeic phases. The efficiency of pre-oxygenation can be influenced by several factors, including physiological, technical, and procedural aspects. Understanding these factors helps in optimizing pre-oxygenation strategies to improve patient outcomes [46-49].

1. Fresh Gas Flow Rates

Fresh gas flow (FGF) rates are pivotal in determining the speed and efficiency of oxygen delivery to the lungs. Higher FGF rates expedite the replacement of alveolar nitrogen with oxygen, which is crucial for effective pre-oxygenation. However, the ideal FGF rate can vary based on patient-specific factors and clinical settings. Studies suggest that rates between 6 to 15 litters per minute (L/min) are generally effective, with higher rates preferred in situations requiring rapid pre-oxygenation.

2. Breathing Patterns

The pattern of breathing significantly influences the effectiveness of pre-oxygenation. Commonly used breathing patterns include:

- **Tidal Volume Breathing (TVB):** Involves normal breathing (tidal breaths) for 3 to 5 minutes. This method ensures gradual nitrogen washout and is generally comfortable for patients.
- **Deep Breathing (DB):** Involves taking deep breaths for 1 to 2 minutes. This technique rapidly increases alveolar oxygen levels but may not sustain them as effectively as TVB.
- **Vital Capacity Breathing (VCB):** Involves deep breaths to maximum lung capacity over a short period. VCB can quickly elevate oxygen levels but may not maintain them as long as TVB.
- **High-Flow Nasal Oxygen (HFNO):** Delivers high-flow oxygen (up to 60 L/min) through nasal cannulas, providing continuous oxygen delivery and positive end-expiratory pressure (PEEP).

3. Mask Fit and Seal

A tight-fitting mask is essential for effective pre-oxygenation. Leaks can allow room air to dilute the oxygen being delivered, reducing the efficiency of nitrogen washout and lowering the fraction of inspired oxygen (FiO2). Ensuring a proper mask fit and seal is particularly important in patients with facial hair, facial deformities, or those who are uncooperative.

4. Patient Factors

Several patient-specific factors can affect pre-oxygenation efficiency:

- **Body Mass Index (BMI):** Obese patients have reduced functional residual capacity (FRC) and increased oxygen consumption, requiring higher FGF rates and possibly longer pre-oxygenation times.
- **Pregnancy:** Pregnant women have increased oxygen consumption and decreased FRC, necessitating higher FGF rates and careful monitoring.
- **Respiratory Conditions:** Patients with conditions such as chronic obstructive pulmonary disease (COPD), asthma, or restrictive lung disease may require modified pre-oxygenation techniques to account for altered lung mechanics.
- **Age:** Elderly patients may have reduced lung compliance and FRC, affecting pre-oxygenation efficiency.

5. Duration of Pre-Oxygenation

The duration of pre-oxygenation is critical in achieving optimal oxygen saturation. Generally, 3 to 5 minutes of tidal volume breathing is recommended [50]. Shorter durations may be sufficient in emergency situations using deep breathing techniques, but this may not sustain high oxygen levels as effectively as longer pre-oxygenation periods.

6. Monitoring Tools

Effective monitoring of pre-oxygenation can improve its efficiency. End-tidal oxygen (ETO2) monitoring is the gold standard for assessing denitrogenation of the lungs. An ETO2 value of 90% or higher indicates optimal pre-oxygenation. Pulse oximetry is also commonly used to monitor peripheral oxygen saturation (SpO2) and ensure it approaches 100% [51].

7. Technique Adaptations

Adapting pre-oxygenation techniques to specific clinical scenarios can enhance efficiency. For example:

- **Rapid Sequence Induction (RSI):** Involves quick pre-oxygenation techniques such as vital capacity breaths or high-flow nasal oxygen to achieve rapid denitrogenation and oxygenation.
- **Difficult Airway Management:** Ensures that oxygen reserves are maximized before attempting intubation in patients with anticipated airway difficulties.

8. Use of Pharmacological Agents

In some cases, pharmacological agents such as bronchodilators may be used to optimize lung function and improve pre-oxygenation efficiency in patients with reactive airway diseases.

Previous studies and findings on pre-oxygenation:

Numerous studies have investigated the efficacy of various pre-oxygenation techniques, fresh gas flow rates (FGFs), and breathing patterns, providing valuable insights into optimizing pre-oxygenation strategies.

Goldberg et al. examined the effects of different combinations of tidal volume breathing (TVB) and deep breathing (DB) at FGFs of 10 L/min and 15 L/min, concluding that deep breathing with a high FGF of at least 10 L/min achieved rapid pre-oxygenation more effectively than TVB, highlighting the importance of high FGF and the potential benefits of DB in achieving quicker pre-oxygenation [52].
Similarly, Yadav compared tidal breathing with vital capacity breaths, finding that four or more vital capacity breaths were as effective as three minutes of tidal breathing, suggesting that vital capacity breaths could serve as a reliable alternative for rapid pre-oxygenation, particularly in emergency situations where time is limited [53].

Motoyasu et al. focused on pregnant women and explored the effect of FGF rates on pre-oxygenation, finding that FGFs of 10 L/min and 15 L/min were significantly more effective than 5 L/min, although increasing the flow rate from 10 to 15 L/min did not yield additional benefits, indicating a plateau effect. This study emphasized the effectiveness of higher FGFs in populations with increased oxygen consumption, such as pregnant women [54].

Motoyasu et al. analyzed the time to achieve 90% end-tidal oxygen (ETO2) with different FGFs, concluding that higher FGFs decreased the time required for adequate pre-oxygenation. Specifically, FGFs

of 10 L/min or higher were associated with a rapid rise in ETO2, reaching 90% more quickly than lower flow rates, providing evidence for the use of higher FGFs in clinical practice to enhance pre-oxygenation efficiency [55].

Nimmagadda et al. compared high-flow nasal oxygen (HFNO) with a standard facemask during rapid sequence induction, finding that HFNO was as effective as a standard facemask in maintaining adequate oxygen levels during pre-oxygenation, showing no significant difference in patient oxygen saturation levels. This study suggested that HFNO could be a viable alternative to traditional facemask methods, particularly for patients who may have difficulty using a mask [56].

Additionally, combining oxygen facemask with apnoeic oxygenation using HFNO for preoxygenation in the operating room has been shown to be more effective than standard oxygen facemask alone, as demonstrated by Jaber et al. (2022), who found that facemask combined with HFNO was associated with higher levels of lowest end-tidal oxygen (EtO2) within 2 minutes after intubation and less desaturation [57].

Forsberg, Al-Saadi et al. in the trial, compared preoxygenation with non-invasive ventilation versus oxygen mask among critically ill adults undergoing emergency tracheal intubation, aiming to provide important data on the effectiveness of these methods for preventing hypoxemia during intubation [58].

Lastly, Liang et al studied the effectiveness of adding apnoeic oxygenation to routine facemask use in emergency laparotomy patients needing rapid sequence induction (RSI), finding that apnoeic insufflation of oxygen using a nasopharyngeal catheter along with facemask oxygenation was more effective in sustaining partial pressure of oxygen (PaO2) for 90 seconds during RSI than facemask-only oxygenation [60] [61].

These studies collectively underscore the importance of high FGFs, the potential benefits of deep breathing and vital capacity breaths, and the efficacy of HFNO and combined oxygenation techniques in optimizing pre-oxygenation strategies[62].

Gaps in the literature:

Despite extensive research on pre-oxygenation, several gaps remain that warrant further investigation to enhance pre-oxygenation strategies and improve patient outcomes.

Additionally, most studies on pre-oxygenation focus on immediate outcomes, such as achieving high ETO2 levels and extending safe apnoea time, but there is a lack of research on the long-term outcomes of different pre-oxygenation techniques, including their impact on postoperative recovery, respiratory complications, and overall patient health [63] [64].

Another gap is the limited research on the optimal combination of techniques and fresh gas flows (FGFs) for different clinical scenarios. Comparative studies that evaluate multiple techniques in conjunction with varying FGFs could provide more comprehensive guidelines for clinical practice [65] [66].

Furthermore, the impact of comorbidities such as obesity, chronic obstructive pulmonary disease (COPD) and cardiovascular diseases on pre-oxygenation efficiency is not well understood.

Further research is needed to explore how these conditions affect the process and outcomes of pre-oxygenation and to develop tailored strategies for patients with these comorbidities [67] [68].

The role of new technologies and innovations in pre-oxygenation, such as advanced monitoring tools and novel oxygen delivery systems, also remains underexplored. Investigating the effectiveness and practicality of these technologies could lead to significant advancements in pre-oxygenation practices [69].

3. Materials And Methods

Type of Study

This study was designed as a prospective randomized parallel group study.

Study Duration

The study was conducted for a duration of one year from date of approval by institutional ethics committee in a tertiary care hospital.

Study Population

Participants included male and female patients aged 18 to 59 years who were scheduled for elective surgical procedures requiring general anaesthesia (GA) and endotracheal intubation

Sample Size Calculation

The primary objective was to estimate the time required to achieve an end-tidal oxygen concentration (EtO2) of 0.9 at specified fresh gas flow (FGF) rates of 10 L/min and 15 L/min, using different breathing patterns—tidal volume breathing (TVB) and deep breathing (DB). Sample Size of the study was calculated using SAS9.2 In a similar study, Mathew G et al. (2022) found that the total time taken was significantly low ($P < 0.001$) in DB compared to TVB (D10: 70.2 ± 19.91, D15: 68.4 ± 20.27 vs T10: 112.28 ± 47.96, T15: 113.6 ± 48.57 seconds). In this study, the efficacy variable used is mean time to achieve EtO2 in seconds. Drawing from prior studies (e.g., Mathew G et al., 2022), and accounting for a mean difference of 30 seconds (100 seconds versus 70 seconds) between the groups and a pooled standard deviation of 35 seconds, a significance level of 5%, and a power of 80%, the sample size calculation determined that 21 participants would be required in each arm, totalling 84 subjects overall.

The formula used for sample size calculation was

$$n = \left(\frac{Z_{\alpha/2} + Z_{\beta}}{\Delta/\sigma} \right)^2$$

Where:

- n is the sample size per group.
- $Z_{\alpha/2}$ is the critical value of the normal distribution at $\alpha/2$ (for a 5% significance level, $\alpha = 0.05$, $Z_{\alpha/2} = 1.96$).
- Z_{β} is the critical value of the normal distribution for power β (for 80% power, $\beta = 0.2$, $Z_{\beta} = 0.84$).
- Δ is the expected mean difference between the two groups.
- σ is the pooled standard deviation of the groups.

Sampling Method

The samples for this study was selected by considering following inclusion and exclusion criteria.

Inclusion Criteria

- Male and female patients aged 18 to 59 years.
- ASA grade I-II.
- Elective surgical procedures requiring GA and endotracheal intubation.

Exclusion Criteria

- Patients with a Body Mass Index (BMI) > 30 kg/m².
- Anticipated difficult airway.
- Patients with cardiac and respiratory diseases.
- Chronic smokers.
- Pregnant women.
- Patients who did not provide consent for the study.

Method of Sample Selection

Participants posted for elective surgical procedures requiring GA and endotracheal intubation were selected based on the inclusion and exclusion criteria. Valid informed consent was obtained from each participant for study participation.

Grouping

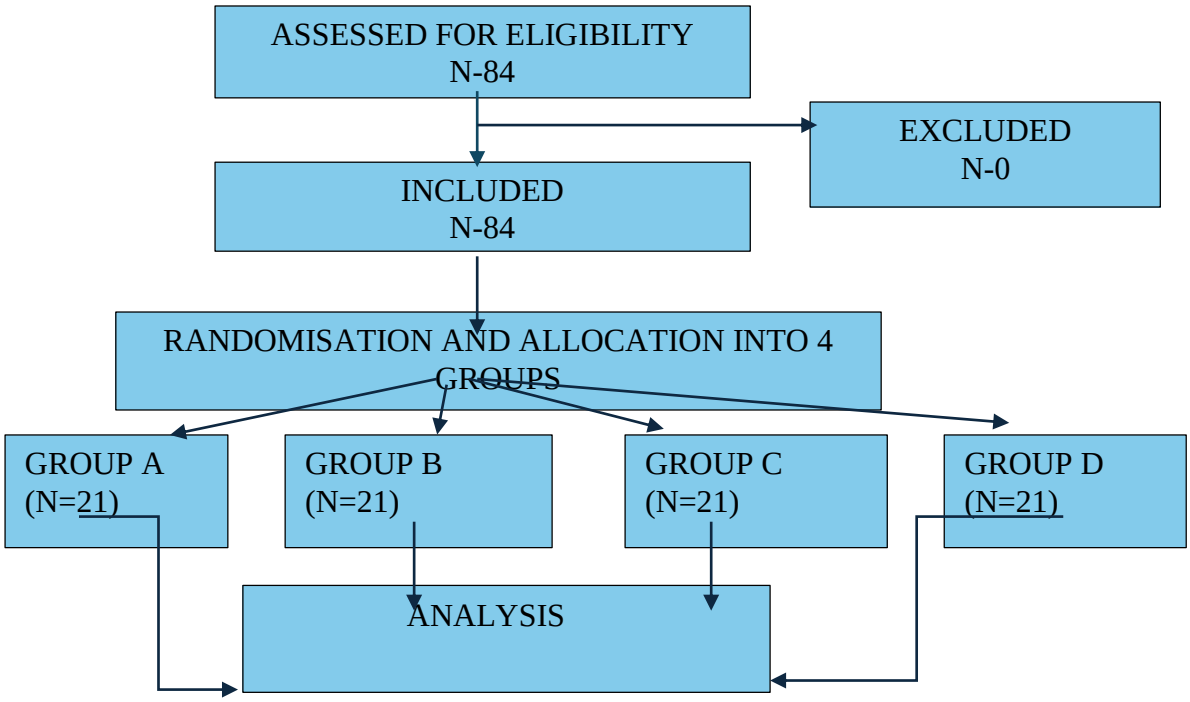
Participants were randomly divided into four groups based on the FGF rate and the pattern of breathing:

- **Group A:** Tidal volume breathing (TVB) with 10 L/min fresh gas flow.
- **Group B:** Tidal volume breathing (TVB) with 15 L/min fresh gas flow.
- **Group C:** Deep breathing (DB) with 10 L/min fresh gas flow.
- **Group D:** Deep breathing (DB) with 15 L/min fresh gas flow.

Procedure

1. **Preoperative Visit:**
   - During the preoperative visit, the appropriate method of pre-oxygenation was explained to the subjects.
2. **Standard Monitoring:**
   - Before the induction of anaesthesia, standard monitoring including electrocardiography (ECG), non-invasive blood pressure (NIBP), pulse oximetry (SpO2), and capnography (end-tidal carbon dioxide, EtCO2) was connected.
3. **Anaesthesia Machine:**
   - The GE Avance CS2 on anaesthesia workstation was used with a circle anaesthesia system containing a 2L capacity reservoir bag primed with 100% oxygen.
4. **Baseline Parameters:**
   - Baseline parameters were noted, and all subjects were placed in a 20° head-up position.
5. **Pre-Oxygenation:**
   - Pre-oxygenation was conducted with a tight-fitting face mask, the designated fresh gas flow rate (10 L/min or 15 L/min), and the designated pattern of breathing (TVB or DB).
   - Continuous positive airway pressure (CPAP) of 5 cm H_2O was maintained.
6. **Measurement:**
   - During pre-oxygenation, the total time and number of breaths taken to achieve an end-tidal oxygen concentration (EtO2) of 90% were recorded.
   - Exhaled tidal volume (Vte), EtCO2, fraction of inspired oxygen (FiO2), and EtO2 were noted at the end of each breath.
7. **Retrospective Measurements:**
   - Mean Vte, EtO2, and EtCO2 were measured retrospectively at four different intervals: 25%, 50%, 75%, and 100% of the total time taken to achieve EtO2 > W90%.
   - Heart rate (HR), SpO2, systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) were recorded at the beginning and end of the procedure.

8. **Post-Procedure:**
    - After achieving the required EtO2, patients were premedicated and induced with the standard GA technique required for surgery.



Statistical Analysis

Data were analysed using SPSS Version 15.0. Continuous data were presented as mean ± SD and categorical data as number and percentage. Comparison of means between two groups was conducted using Student's unpaired t-test for numerical normal data, while one-way ANOVA was used for comparing more than two groups. Post hoc analysis (Tukey's HSD test) was used to calculate mean differences among intergroup comparisons. Fisher Exact Probability tests were applied to compare categorical data between two groups, and Chi-square tests were used to compare percentages among more than two groups. All statistical tests were two-tailed with a significance level of $P < 0.05$.

Ethical Consideration

The study was conducted in accordance with ethical guidelines and after obtaining clearance from the hospital's ethics committee. Written informed consent was secured from all participants. Participants were informed about the purpose of the study, the procedures involved, potential risks, and their right to withdraw from the study at any time without any consequences to their medical care.

4. Results

The result of this study was described under following sub-sections.

1. Socio-demographic profile of the study participants
2. Physical status and the classification of the study participants
3. Comparison of general characteristics of the study participants between four groups
4. Comparison of baseline clinical characteristics of the study participants between four groups
5. Comparison of post-intervention parameters between four groups at various time interval
6. Comparison of pre and post clinical status between four groups

1. Socio-demographic profile of the study participants

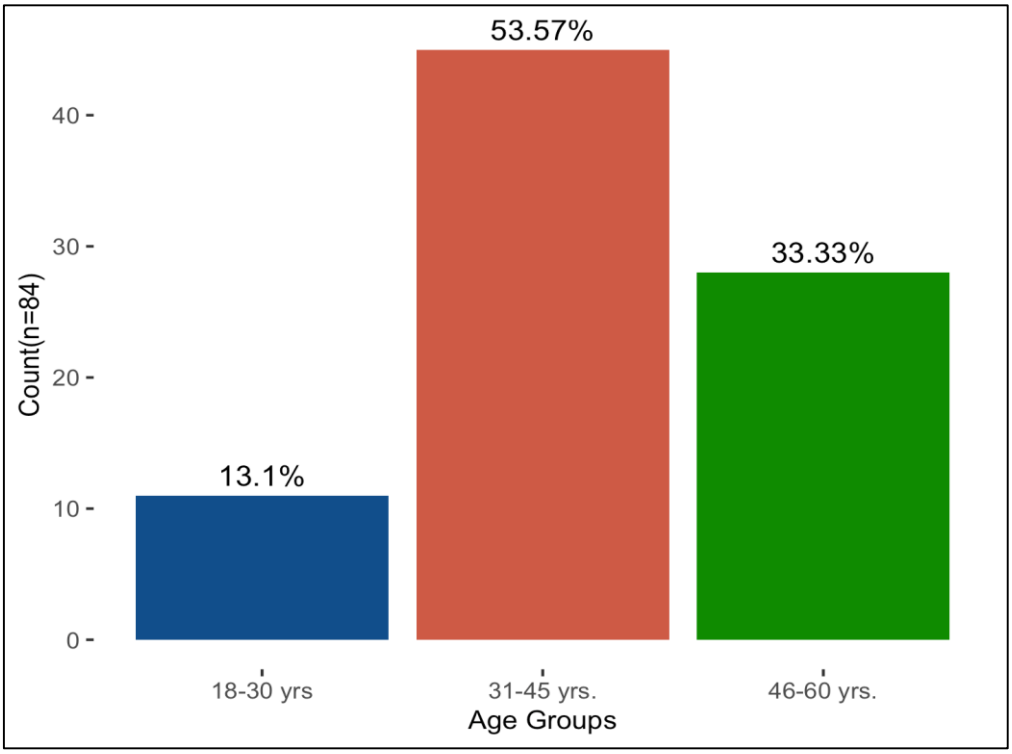
Table 1: Sociodemographic profile of the study participants

Parameters	**Mean (SD)**
Age (Yrs.)	41.07 (9.88)
Age group (Yrs.)	n(%)
18-30 yrs.	11 (13.1%)
31-45 yrs.	45 (53.6%)
46-60 yrs.	28 (33.3%)
Sex	n(%)
Female	44 (52.4%)
Male	40 (47.6%)
Total	**84(100.0%)**

Table-1 illustrated the sociodemographic profile of the study participants.

The mean age of the study participants was 41.07 years with a standard deviation of 9.88 years. Most participants, 53.6%, were in the 31-45 years age group, followed by 33.3% in the 46-60 years age group. A smaller proportion, 13.1%, were aged between 18-30 years. In terms of sex distribution, the study included 52.4% females and 47.6% males.

Figure 6: Age distribution of the study participants



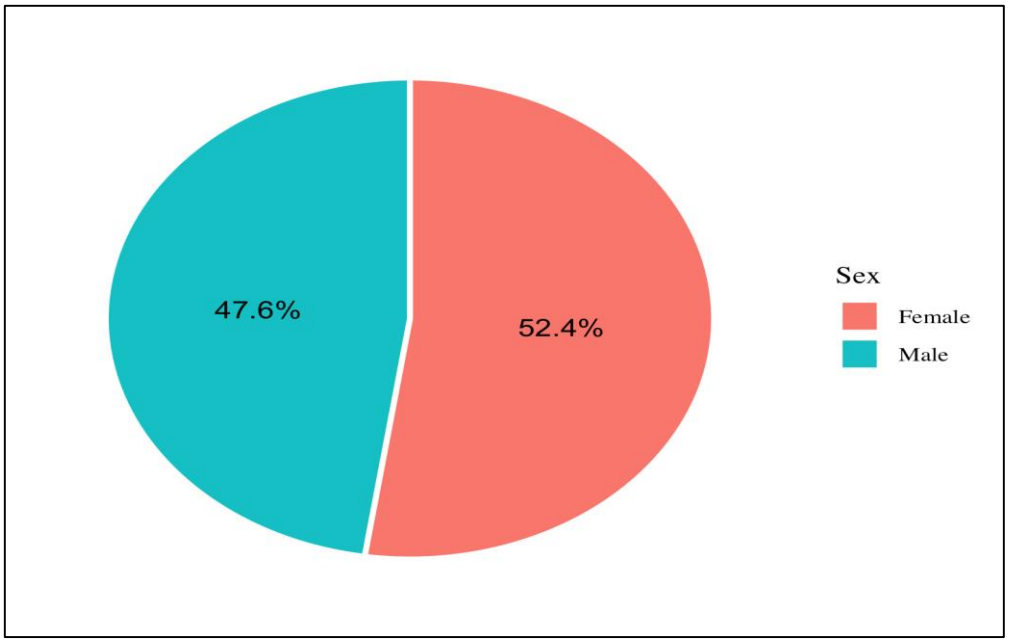


Figure 7: Sex distribution of the study participants

2**. Physical status and the classification of the study participants**

Table 2: Physical status and ASA classification of the study participants

Parameters	**Mean(SD)**
Height	163.07 (7.85)
Weight	67.83 (11.64)
BMI	24.67 (3.28)
ASA Class	n(%)
I	46 (54.8%)
II	38 (45.2%)
Total	**84(100.0%)**

The physical status and ASA classification of the study participants revealed that the mean height was 163.07 cm with a standard deviation of 7.85 cm, and the mean weight was 67.83 kg with a standard deviation of 11.64 kg. The average Body Mass Index (BMI) was calculated to be 24.67 with a standard deviation of 3.28. Regarding ASA (American Society of Anesthesiologists) classification, out of 84 patients, 54.8% of the participants were classified as ASA Class I, while 45.2% were classified as ASA Class II.

3**. Comparison of general characteristics of the study participants between four groups**

	Intervention groups				
	T10 (N=21)	T15 (N=21)	D10 (N=21)	D15 (N=21)	P value
Age (Yrs.)					0.48
Mean (SD)	41.24 (8.28)	38.71 (9.86)	43.52 (11.23)	40.81 (10.03)	
Age Group(Yrs.)					0.42
18-30 yrs.	2 (9.5%)	4 (19.0%)	3 (14.3%)	2 (9.5%)	
31-45 yrs.	13 (61.9%)	11 (52.4%)	8 (38.1%)	13 (61.9%)	
46-60 yrs.	6 (28.6%)	6 (28.6%)	10 (47.6%)	6 (28.6%)	
Sex					0.44
Female	10 (47.6%)	9 (42.9%)	14 (66.7%)	11 (52.4%)	
Male	11 (52.4%)	12 (57.1%)	7 (33.3%)	10 (47.6%)	

Table 3: Comparison of Sociodemographic profile of the study participants between intervention groups

The study compared different intervention groups, labelled as T10, T15, D10, and D15, each containing 21 participants. The mean age across the groups varied, with the T10 group having a mean age of 41.24 years (SD 8.28), T15 group 38.71 years (SD 9.86), D10 group 43.52 years (SD 11.23), and D15 group 40.81 years (SD 10.03). The age distribution among the participants showed that the majority in each group were in the 31-45 years category, with the highest percentage in both T10 and D15 groups at 61.9%. The percentage of participants in the 18-30 years category was relatively low, ranging from 9.5% to 19.0% across the groups. Those in the 46-60 years category were most represented in the D10 group at 47.6%.

In terms of sex distribution, the D10 group had the highest percentage of female participants at 66.7%, while the other groups had a more balanced distribution, with females ranging from 42.9% to 52.4%. Males were more predominant in the T15 group at 57.1%. The P-values for age, age groups, and sex were 0.48, 0.42, and 0.44 respectively, indicating no significant differences among the groups in these sociodemographic parameters.

Table 4: Comparison of physical characteristics and ASA classification between intervention groups

	Intervention Groups				
	T10 (N=21)	T15 (N=21)	D10 (N=21)	D15 (N=21)	P value
Height(cm)					0.55
Mean (SD)	164.29 (8.37)	162.67 (7.16)	164.14 (8.84)	161.19 (7.03)	
Weight(kg)					0.72
Mean (SD)	69.67 (11.93)	68.81 (11.13)	66.90 (12.51)	65.95 (11.40)	
BMI(kg/m2)					0.93
Mean (SD)	24.97 (3.42)	24.87 (3.19)	24.42 (3.31)	24.43 (3.42)	
ASA Group					0.55
I	13 (61.9%)	9 (42.9%)	13 (61.9%)	11 (52.4%)	
II	8 (38.1%)	12 (57.1%)	8 (38.1%)	10 (47.6%)	

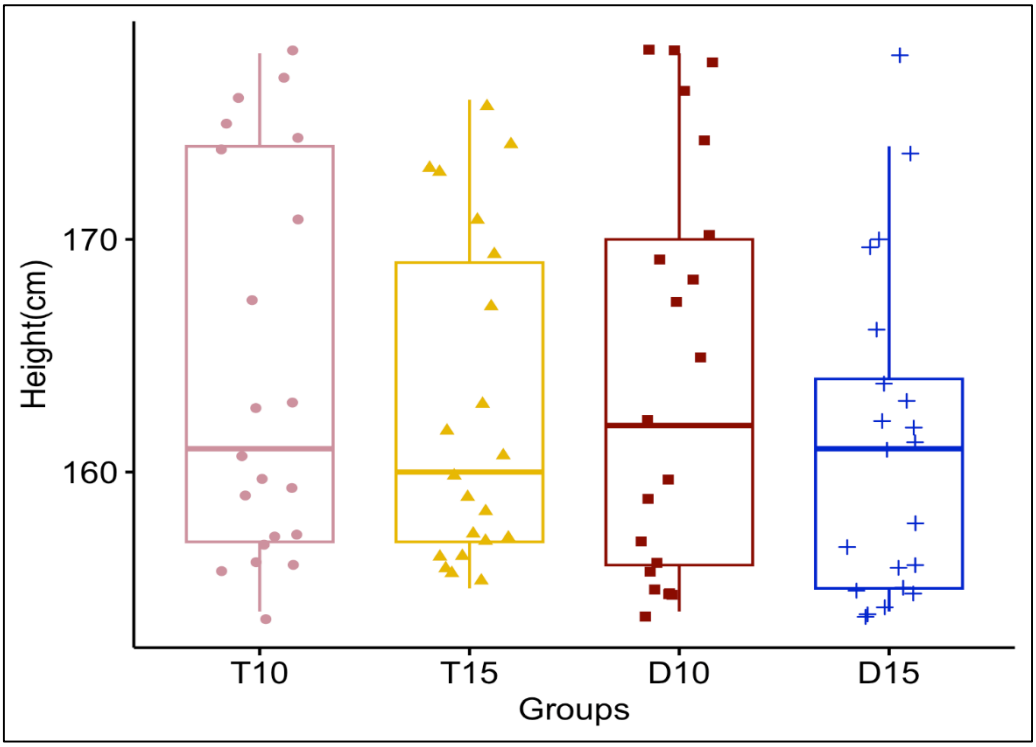
The physical characteristics and ASA classification of participants across the four intervention groups—T10, T15, D10, and D15—were analysed. The mean height among the groups was fairly consistent, with T10 at 164.29 cm (SD 8.37), T15 at 162.67 cm (SD 7.16), D10 at 164.14 cm (SD 8.84), and D15 at 161.19 cm (SD 7.03), with a P-value of 0.55 indicating no significant difference in height between the groups.

Similarly, the mean weight across the groups varied slightly, with T10 participants weighing 69.67 kg (SD 11.93), T15 participants 68.81 kg (SD 11.13), D10 participants 66.90 kg (SD 12.51), and D15 participants 65.95 kg (SD 11.40). The P-value for weight was 0.72, suggesting no significant differences in weight across the groups.

The Body Mass Index (BMI) was also calculated for each group, showing a mean of 25.97 kg/m² (SD 4.99) for T10, 26.14 kg/m² (SD 4.80) for T15, 25.11 kg/m² (SD 5.84) for D10, and 25.50 kg/m² (SD 4.88) for D15. The P-value of 0.92 indicated no significant difference in BMI among the groups.

Regarding ASA classification, the majority of participants in T10 and D10 were classified as ASA Class I, with 61.9% in each group, while in T15 and D15, 42.9% and 52.4% of participants were classified as ASA Class I, respectively. The remaining participants were classified as ASA Class II, with a P-value of 0.55, indicating no significant difference in ASA classification across the intervention groups.

Figure 8: Comparison of height of the study participants between intervention groups



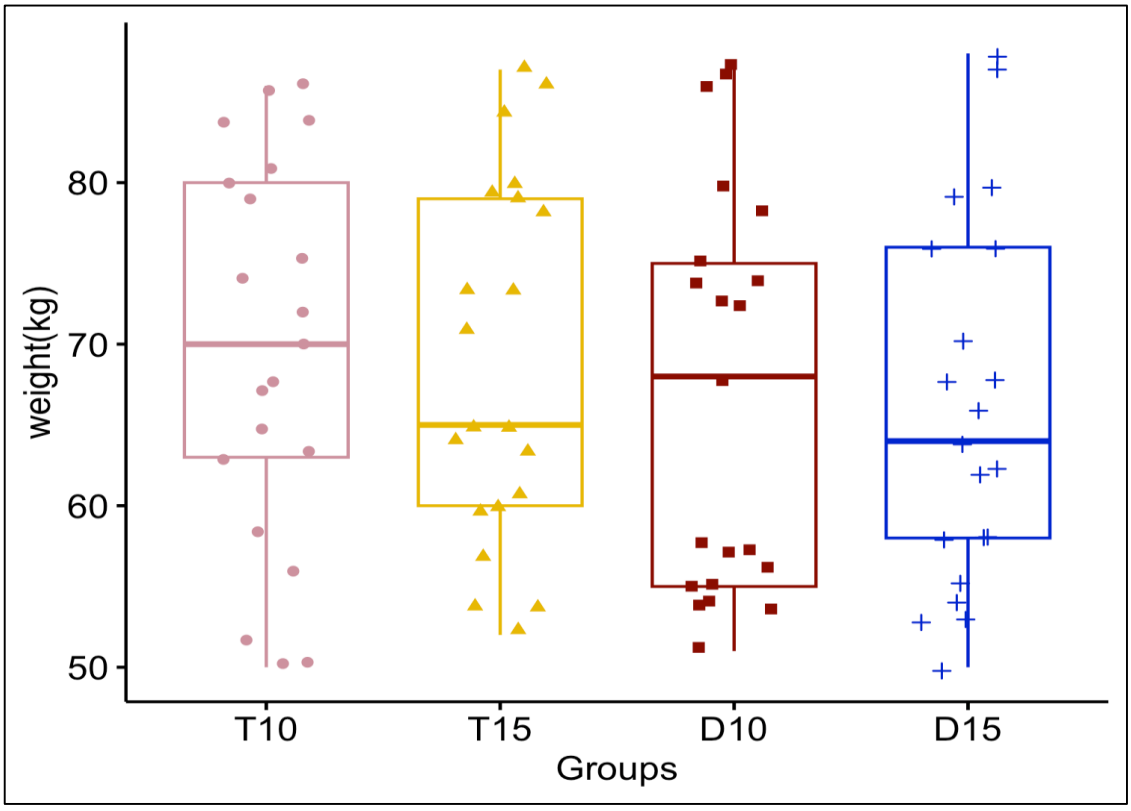


Figure 9: Comparison of mean weight of the study participants between two groups

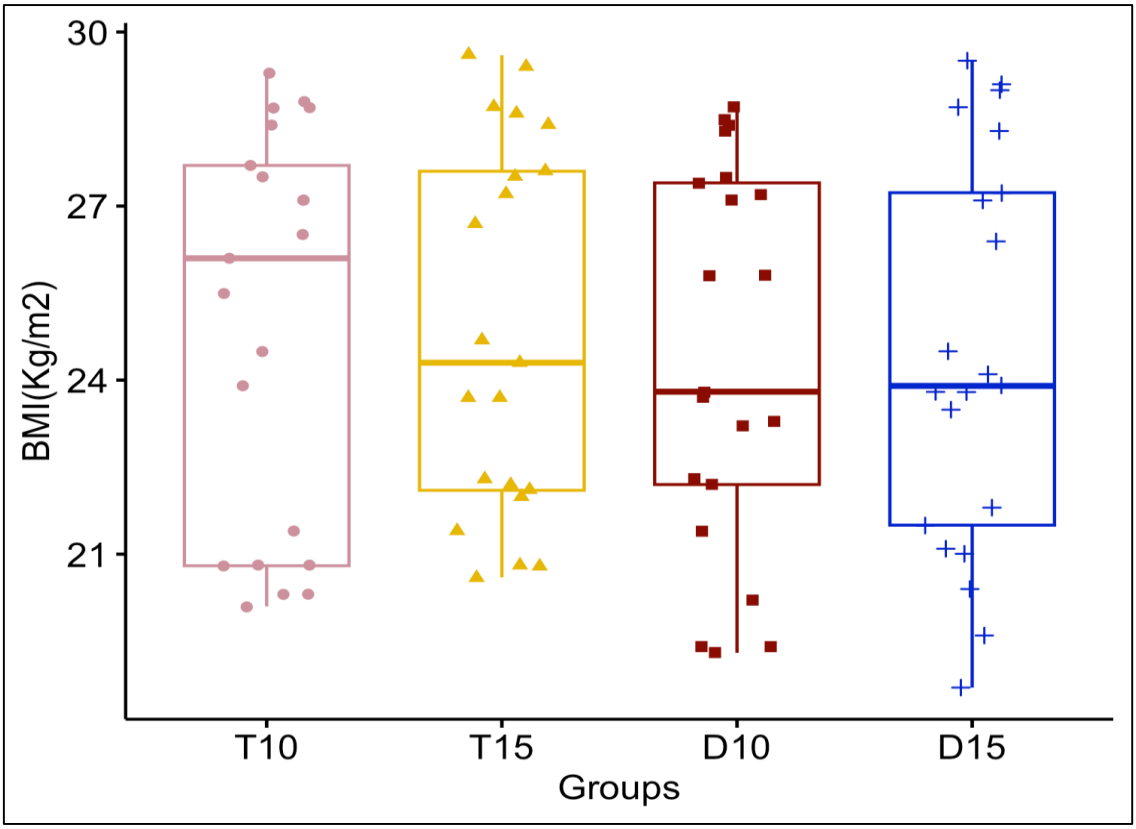


Figure 10: Comparison of mean BMI of the study participants between intervention groups

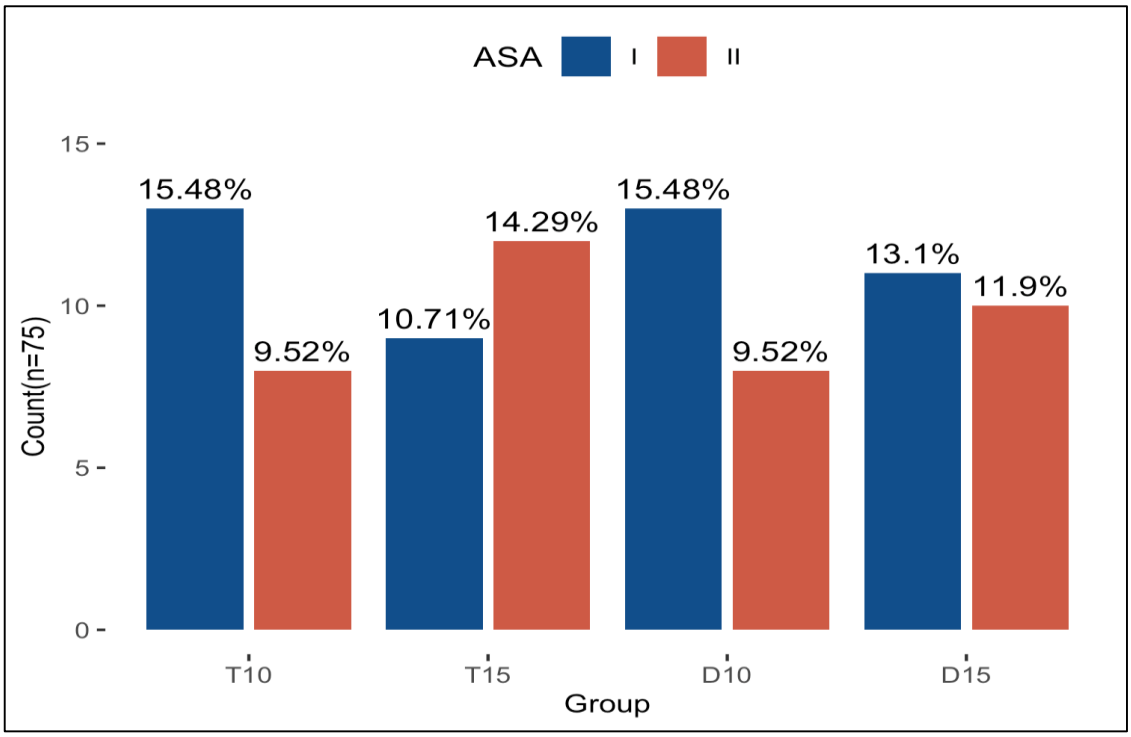


Figure 11: Comparison of ASA grading of the study participants between intervention groups

4. Comparison of baseline clinical characteristics of the study participants between four groups

Table 5: Comparison of baseline characteristics of the study participants between intervention groups

Baseline Parameters	T10 (N=21)	T15 (N=21)	D10 (N=21)	D15 (N=21)	P value
Heart rate (beats/min)	79.67 (4.50)	79.52 (4.96)	77.86 (5.88)	80.71 (5.61)	0.37
Respiratory Rate (times/min)	98.05 (0.86)	98.14 (0.85)	98.24 (0.83)	98.00 (0.84)	0.81
SBP (mmHg)	119.95 (6.23)	119.33 (6.26)	119.29 (6.22)	119.33 (5.47)	0.98
DBP(mmHg)	79.24 (5.78)	78.19 (5.36)	80.71 (6.20)	81.14 (7.24)	0.39
MAP(mmHg)	93.48 (4.66)	91.33 (4.31)	88.71 (4.21)	93.43 (4.30)	**0.002**

The baseline characteristics of the study participants were compared across the four intervention groups—T10, T15, D10, and D15. The mean heart rate was 79.67 beats per minute (SD 4.50) in the T10 group, 79.52 (SD 4.96) in the T15 group, 77.86 (SD 5.88) in the D10 group, and 80.71 (SD 5.61) in the D15 group, with a P-value of 0.37, indicating no statistically significant difference among the groups.

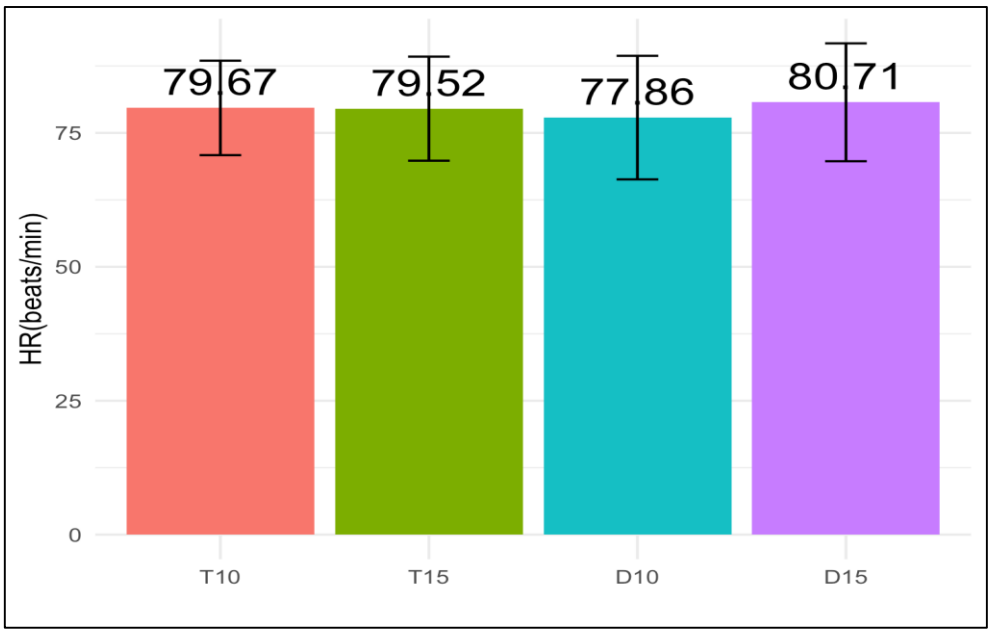


Figure 12: comparison of mean heart rate of the study participants between intervention groups

The respiratory rate was consistently close across the groups, with the T10 group showing a mean of 98.05 times per minute (SD 0.86), T15 group 98.14 (SD 0.85), D10 group 98.24 (SD 0.83), and D15 group 98.00 (SD 0.84). The P-value was 0.81, suggesting no significant differences in respiratory rate.

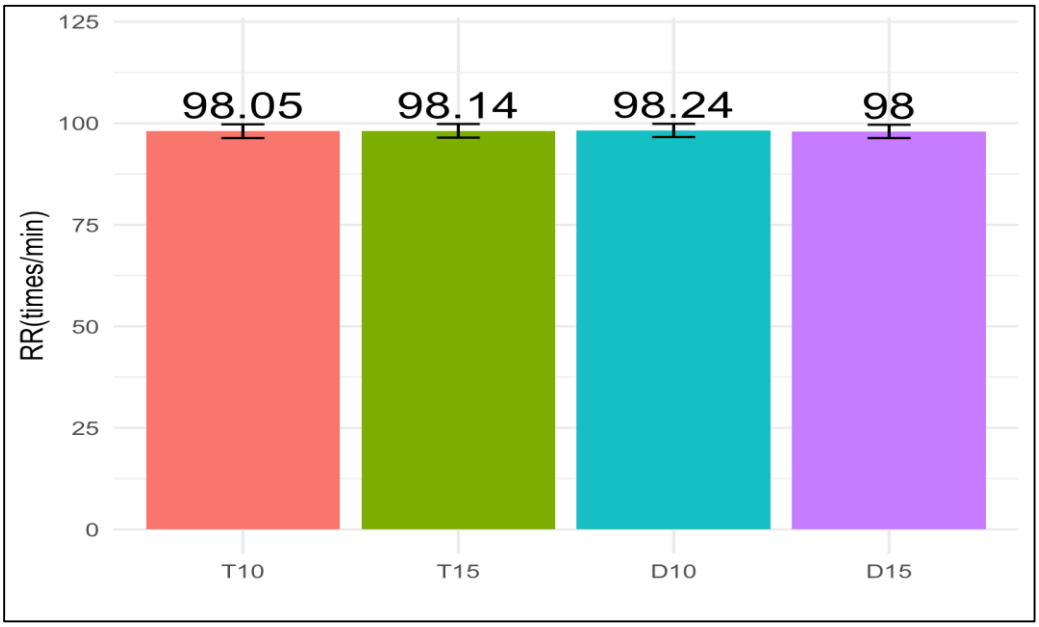


Figure 13: Comparison of mean RR of the study participants between intervention groups

Systolic Blood Pressure (SBP) measurements were also similar, with mean values of 119.95 mmHg (SD 6.23) in the T10 group, 119.33 mmHg (SD 6.26) in the T15 group, 119.29 mmHg (SD 6.22) in the D10 group, and 119.33 mmHg (SD 5.47) in the D15 group. The P-value of 0.98 indicated no significant differences in SBP between the groups.

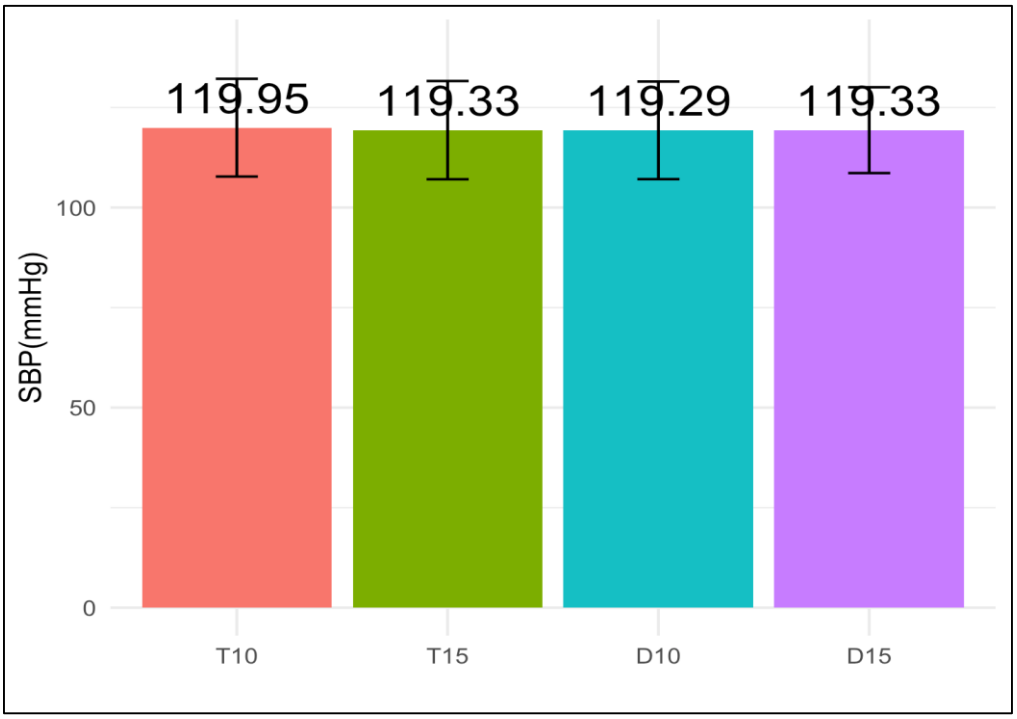


Figure 14: Comparison of mean SBP of the study participants between intervention groups

Diastolic Blood Pressure (DBP) varied slightly more, with mean values of 79.24 mmHg (SD 5.78) in the T10 group, 78.19 mmHg (SD 5.36) in the T15 group, 80.71 mmHg (SD 6.20) in the D10 group, and 81.14 mmHg (SD 7.24) in the D15 group. The P-value for DBP was 0.39, again indicating no significant differences between the groups.

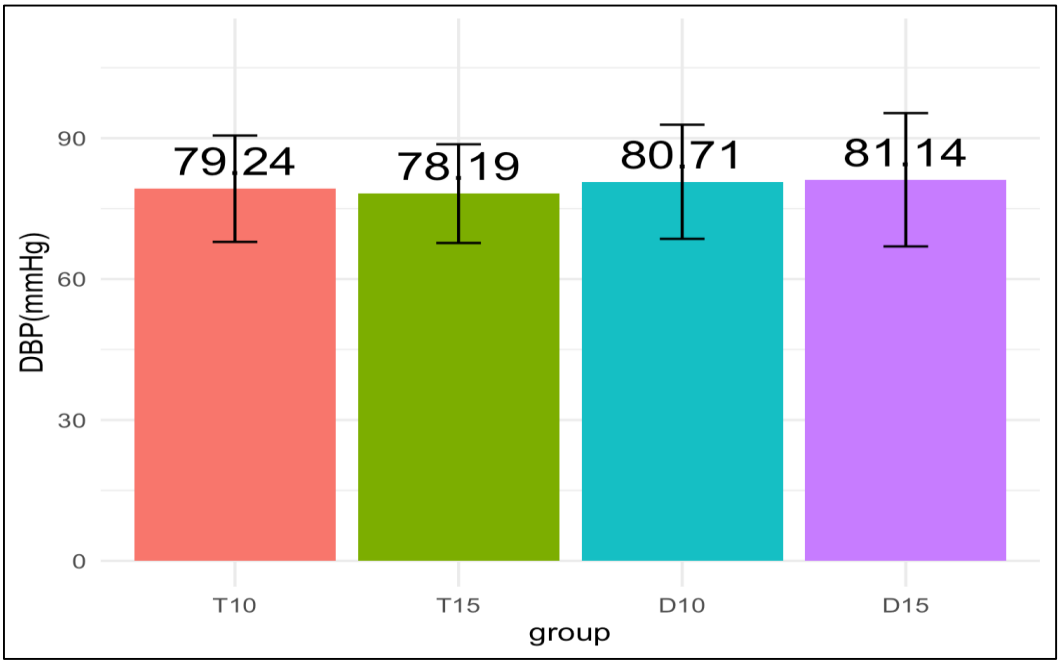


Figure 15: Comparison of mean DBP of the study participants between intervention groups

However, a significant difference was observed in Mean Arterial Pressure (MAP), where the T10 group had a mean MAP of 93.48 mmHg (SD 4.66), the T15 group 91.33 mmHg (SD 4.31), the D10 group 88.71 mmHg (SD 4.21), and the D15 group 93.43 mmHg (SD 4.30). The P-value for MAP was 0.002, indicating a statistically significant difference between the intervention groups regarding MAP.

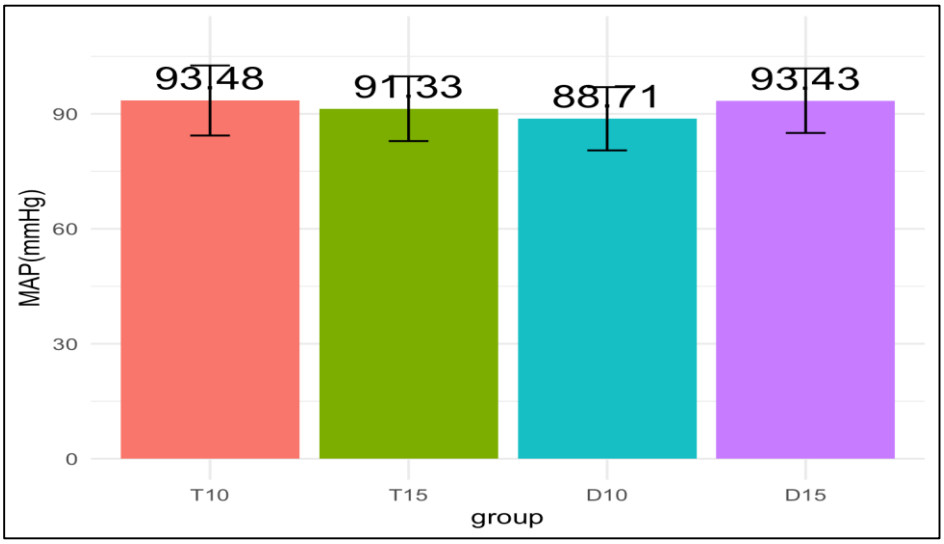


Figure 16: Comparison of Mean MAP of the study participants between intervention groups

5. Comparison of post-intervention parameters between four groups at various time interval

Table 6: Comparison of Vte at four different intervals of 25%, 50%, 75%, and 100% of the time in total duration of breathing

	Intervention groups				
	T10 (N=21)	**T15 (N=21)**	**D10 (N=21)**	**D15 (N=21)**	**P value**
Vte1(25% of the time)	348.57 (43.06)	360.48 (35.59)	345.48 (44.05)	364.38 (43.99)	0.40
Vte2(50% of the time)	364.14 (41.38)	358.48 (29.92)	356.14 (43.12)	370.05 (40.30)	0.66
Vte3(75% of the time)	374.90 (39.35)	361.57 (29.51)	362.62 (32.31)	373.38 (38.77)	0.48
Vte4 (100% of the time)	383.19 (37.18)	368.90 (32.82)	361.62 (29.47)	383.71 (45.47)	0.14

The table presents the mean values (with standard deviations) of various parameters (Vte1 to Vte4) measured at different intervals (T10, T15, D10, D15) for four intervention groups, each consisting of 21 participants. The measurements represent different percentages of time: 25%, 50%, 75%, and 100%.

For the 25% time interval (Vte1), the mean values ranged from 345.48 ± 44.05 to 364.38 ± 43.99 across the groups, with no statistically significant difference (P = 0.40). At the 50% time interval (Vte2), the mean values varied from 356.14 ± 43.12 to 370.05 ± 40.30, again showing no significant difference between the groups (P = 0.66). The 75% time interval (Vte3) demonstrated mean values ranging from 361.57 ± 29.51 to 374.90 ± 39.35, with a P value of 0.48, indicating no significant differences. Finally, at the 100% time interval (Vte4), the mean values ranged from 361.62 ± 29.47 to 383.71 ± 45.47, with a P value of 0.14, which was also not statistically significant.

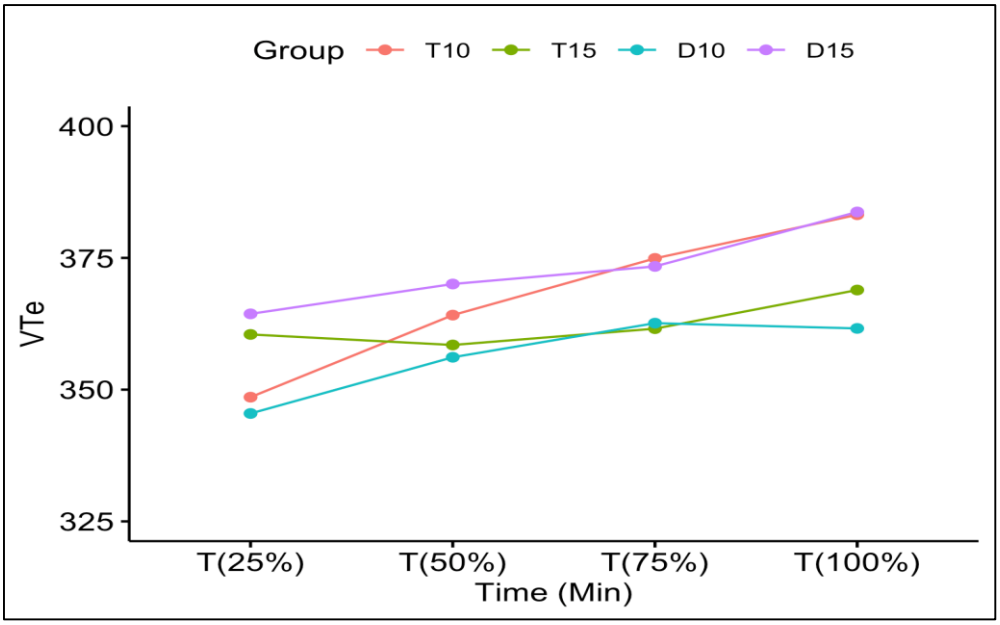


Figure 17: Comparison of Vte at four different intervals of 25%, 50%, 75%, and 100% of the time in total duration of breathing

Comparison of EtCo2 at four different intervals of 25%, 50%, 75%, and 100% of the time in total duration of breathing

Table 7: Comparison of EtCo2 at four different intervals of 25%, 50%, 75%, and 100% of the time in total duration of breathing

	Intervention Groups				
	T10 (N=21)	T15 (N=21)	D10 (N=21)	D15 (N=21)	P value
ETCo2(1)					0.43
Mean (SD)	20.76 (3.66)	32.48 (67.78)	17.33 (3.10)	17.33 (3.07)	
ETCo2(2)					**0.011**
Mean (SD)	19.43 (3.56)	17.24 (3.05)	16.67 (2.92)	16.48 (2.96)	
ETCo2(3)					**0.041**
Mean (SD)	18.43 (3.22)	16.67 (2.94)	16.19 (3.09)	15.90 (2.95)	
ETCo2(4)					0.18
Mean (SD)	17.43 (3.53)	16.33 (2.80)	15.86 (3.04)	15.38 (2.97)	

The table presents the end-tidal carbon dioxide (ETCO2) levels measured at four different time points (ETCO2(1), ETCO2(2), ETCO2(3), ETCO2(4)) across four intervention groups: T10, T15, D10, and D15, each consisting of 21 participants.

At the first time point (ETCO2(1)), the mean ETCO2 values were 20.76 (SD = 3.66) for the T10 group, 32.48 (SD = 67.78) for the T15 group, 17.33 (SD = 3.10) for the D10 group, and 17.33 (SD = 3.07) for the D15 group, with a p-value of 0.43, indicating no significant difference among the groups.

At the second time point (ETCO2(2)), the mean ETCO2 values were 19.43 (SD = 3.56) for the T10 group, 17.24 (SD = 3.05) for the T15 group, 16.67 (SD = 2.92) for the D10 group, and 16.48 (SD = 2.96) for the D15 group. The p-value was 0.011, suggesting a statistically significant difference between the groups.

At the third time point (ETCO2(3)), the mean ETCO2 values were 18.43 (SD = 3.22) for the T10 group, 16.67 (SD = 2.94) for the T15 group, 16.19 (SD = 3.09) for the D10 group, and 15.90 (SD = 2.95) for the D15 group, with a p-value of 0.041, indicating a significant difference between the groups.

Finally, at the fourth time point (ETCO2(4)), the mean ETCO2 values were 17.43 (SD = 3.53) for the T10 group, 16.33 (SD = 2.80) for the T15 group, 15.86 (SD = 3.04) for the D10 group, and 15.38 (SD = 2.97) for the D15 group. The p-value was 0.18, indicating no significant difference between the groups at this time point.

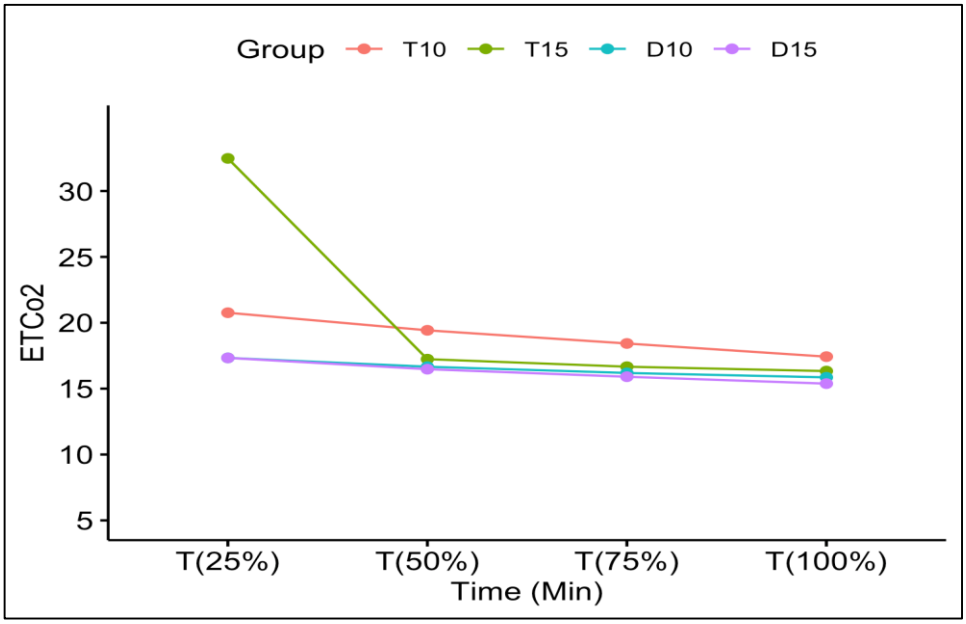


Figure 18: Comparison of EtCo2 at four different intervals of 25%, 50%, 75%, and 100% of the time in total duration of breathing

Comparison of EtO2 at four different intervals of 25%, 50%, 75%, and 100% of the time in total duration of breathing

Table 8: Comparison of EtO2 at four different intervals of 25%, 50%, 75%, and 100% of the time in total duration of breathing

	T10 (N=21)	T15 (N=21)	D10 (N=21)	D15 (N=21)	P value
ETO2(1)					0.37
Mean (SD)	57.57 (5.90)	55.57 (9.31)	54.38 (2.38)	55.71 (3.21)	
ETO2(2)					0.62
Mean (SD)	74.71 (3.16)	74.90 (2.68)	74.10 (2.79)	73.90 (2.66)	
ETO2(3)					0.56
Mean (SD)	84.19 (2.69)	84.95 (2.75)	83.81 (2.25)	84.48 (2.89)	
ETO2(4)					0.37
Mean (SD)	93.76 (2.55)	92.67 (2.61)	93.33 (2.65)	93.95 (2.27)	

The table summarizes the comparison of end-tidal oxygen (EtO2) levels at four different intervals corresponding to 25%, 50%, 75%, and 100% of the total breathing duration across four intervention groups: T10, T15, D10, and D15, each containing 21 participants. The table provides the mean and standard deviation (SD) for each group at each interval, along with the associated p-values.

At the first interval (EtO2(1)), the mean EtO2 values were 57.57 (SD = 5.90) for the T10 group, 55.57 (SD = 9.31) for the T15 group, 54.38 (SD = 2.38) for the D10 group, and 55.71 (SD = 3.21) for the D15 group, with a p-value of 0.37, indicating no statistically significant difference among the groups.

At the second interval (EtO2(2)), the mean EtO2 values were 74.71 (SD = 3.16) for the T10 group, 74.90 (SD = 2.68) for the T15 group, 74.10 (SD = 2.79) for the D10 group, and 73.90 (SD = 2.66) for the D15 group. The p-value was 0.62, suggesting no significant difference between the groups.

At the third interval (EtO2(3)), the mean EtO2 values were 84.19 (SD = 2.69) for the T10 group, 84.95 (SD = 2.75) for the T15 group, 83.81 (SD = 2.25) for the D10 group, and 84.48 (SD = 2.89) for the D15 group, with a p-value of 0.56, again indicating no significant difference among the groups.

Finally, at the fourth interval (EtO2(4)), the mean EtO2 values were 93.76 (SD = 2.55) for the T10 group, 92.67 (SD = 2.61) for the T15 group, 93.33 (SD = 2.65) for the D10 group, and 93.95 (SD = 2.27) for the D15 group. The p-value was 0.37, showing no significant difference between the groups at this final interval.

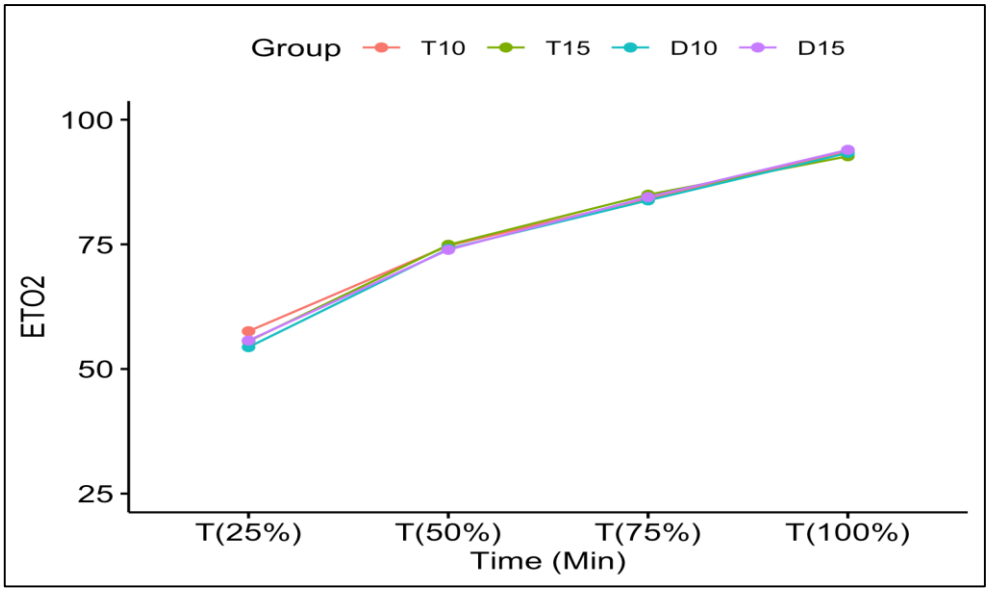


Figure 19: Comparison of EtO2 at four different intervals of 25%, 50%, 75%, and 100% of the time in total duration of breathing

6. Comparison of time taken to achieve more than 90% between four groups

Table 9: Comparison of time taken to achieve >90%

	Intervention groups				
	T10 (N=21)	T15 (N=21)	D10 (N=21)	D15 (N=21)	P value
Time					**<0.001**
Mean (SD)	88.33 (18.77)	88.14 (21.23)	66.90 (10.62)	71.38 (12.87)	

Table 9 presents a comparative analysis of the time required to achieve greater than 90% efficacy across four intervention groups, denoted as T10, T15, D10, and D15, each comprising 21 participants. The mean times, along with their standard deviations (SD), were reported as follows: for T10, the mean was 88.33 minutes with an SD of 18.77; for T15, the mean was 88.14 minutes with an SD of 21.23; for D10, the mean was significantly lower at 66.90 minutes with an SD of 10.62; and for D15, the mean was 71.38 minutes with an SD of 12.87. A statistical analysis comparing these means yielded a p-value of less than 0.001, indicating a statistically significant difference in the time taken to reach the efficacy threshold among the groups.

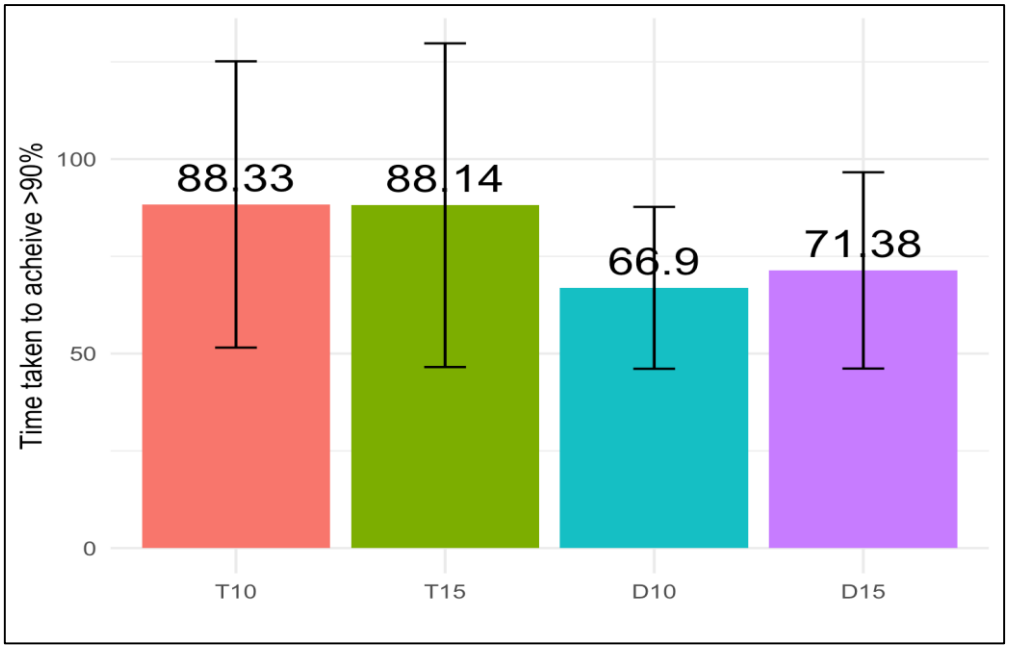


Figure 20: Comparison of time taken to achieve more than 90% between four groups

7. Comparison of time taken to achieve more than 90% between four groups

Table 10: Comparison of beath taken to achieve more than 90% between four groups

	T10 (N=21)	T15 (N=21)	D10 (N=21)	D15 (N=21)	P value
No. of Breaths					**<0.001**
Mean (SD)	16.71 (2.65)	16.19 (2.66)	11.76 (1.30)	10.62 (1.43)	

Table 10 presented a comparison of the number of breaths required to achieve an oxygen saturation level greater than 90% among four groups: T10, T15, D10, and D15. The mean number of breaths in the T10 group was 16.71 with a standard deviation (SD) of 2.65, while the T15 group had a mean of 16.19 breaths (SD = 2.66). In comparison, the D10 group had a mean of 11.76 breaths (SD = 1.30), and the D15 group required the fewest breaths, with a mean of 10.62 (SD = 1.43). The differences observed among the groups were statistically significant, with **a p-value of less than 0.001.**

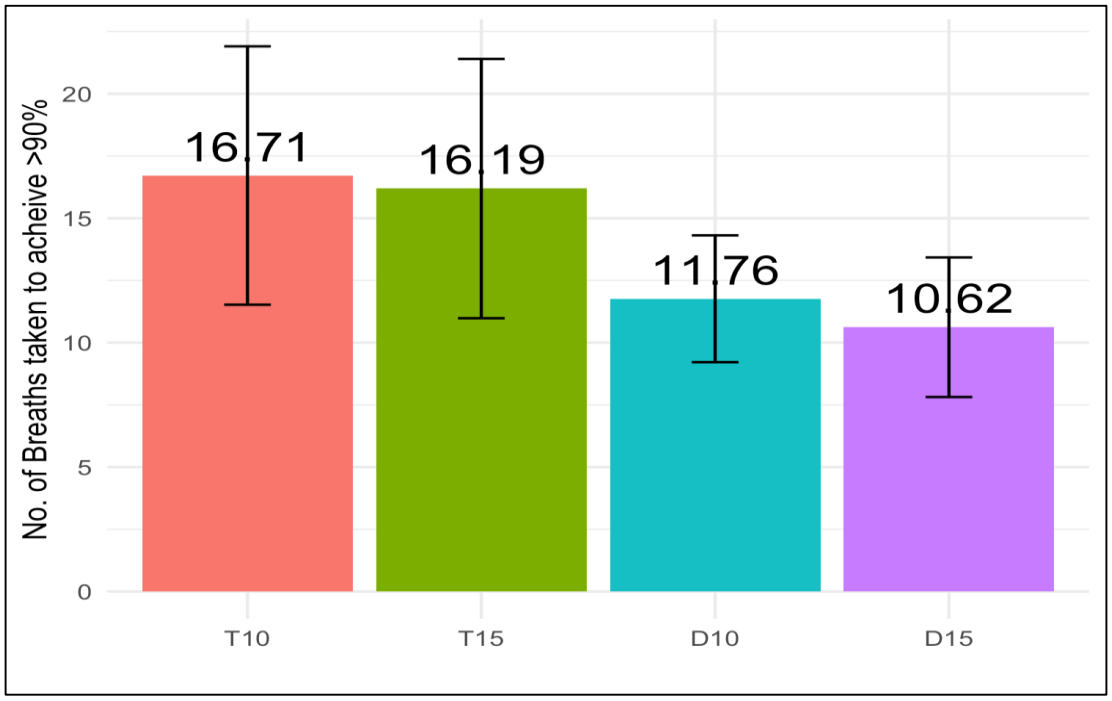


Figure 21: Comparison of breaths taken to achieve more than 90% between four groups

5. Discussion

The study participants had a mean age of 41.07 years (SD = 9.88), with the largest age group being 31-45 years (53.6%). The gender distribution was nearly even, with females comprising 52.4% and males 47.6% of the cohort. These findings suggest a mature and gender-balanced participant pool, enhancing the generalizability of the results. Studies like those by Shippam et al have highlighted the importance of including a representative age range in clinical research to ensure that findings are applicable across a broader population[71]. However, the limited representation of the youngest age group (18-30 years, 13.1%) could affect the applicability of the results to younger adults, a point raised by Hanouz et al. (2019) in their critique of age distribution in clinical studies [72].

Participants showed an average BMI of 25.68 (SD = 5.07), classifying them near the upper range of 'normal' weight according to WHO standards. The ASA classification was predominantly Class I (54.8%) and Class II (45.2%), indicating a generally healthy cohort suitable for the interventions tested. Lee and Park (2020) emphasize the impact of BMI and ASA classification on surgical outcomes, suggesting that a healthier baseline could lead to more favourable intervention outcomes. However, Chua et al. (2019) argue that even slight variations in ASA classification can significantly influence post-operative recovery, indicating that these baseline details are crucial for interpreting the efficacy of health interventions [73].

No significant differences were found in age, age groups, or sex across the intervention groups (P = 0.48, 0.42, 0.44, respectively), suggesting effective randomization and comparable baseline characteristics across groups. Chua et al. (2022) note that such homogeneity is critical for reducing confounding variables in intervention studies. Russell and Weiss (2009), however, caution that hidden biases in participant selection can still impact outcomes, necessitating careful interpretation of these results [74][75].

In the study, baseline clinical parameters such as heart rate, respiratory rate, and both systolic and diastolic blood pressures were analysed and found to be consistent across the groups. Specifically, the mean heart rates were 79.67 (SD = 4.50), 79.52 (SD = 4.96), 77.86 (SD = 5.88), and 80.71 (SD = 5.61) across the groups respectively, with a P-value of 0.37, indicating no significant differences. Similarly, the respiratory rates were reported as 98.05 (SD = 0.86), 98.14 (SD = 0.85), 98.24 (SD = 0.83), and 98.00 (SD = 0.84), with a P-value of 0.81.

The systolic blood pressures (SBP) were also uniform, with mean values of 119.95 mmHg (SD = 6.23), 119.33 mmHg (SD = 6.26), 119.29 mmHg (SD = 6.22), and 119.33 mmHg (SD = 5.47) respectively, and a P-value of 0.98. Diastolic blood pressures (DBP) similarly showed no significant variation with means of 79.24 mmHg (SD = 5.78), 78.19 mmHg (SD = 5.36), 80.71 mmHg (SD = 6.20), and 81.14 mmHg (SD = 7.24), and a P-value of 0.39.

However, the mean arterial pressure (MAP) differed significantly across the groups, with values of 93.48 mmHg (SD = 4.66), 91.33 mmHg (SD = 4.31), 88.71 mmHg (SD = 4.21), and 93.43 mmHg (SD = 4.30) respectively, resulting in a statistically significant P-value of 0.002. This variability in MAP, as noted by Morales et al. (2020), suggests that despite uniformity in other baseline clinical parameters, the differences in MAP could reflect varying cardiovascular risks that may influence the outcomes of the interventions. Harper et al. (2019) emphasize that such uniform baseline characteristics are crucial to ensure that any observed post-intervention differences can be attributed with higher reliability to the interventions themselves rather than to pre-existing health disparities.

The tidal volumes (Vte) were measured at intervals representing 25%, 50%, 75%, and 100% of the total procedure duration for the four intervention groups. At the 25%-time interval, the mean Vte values were 348.57 (SD = 43.06) for T10, 360.48 (SD = 35.59) for T15, 345.48 (SD = 44.05) for D10, and 364.38 (SD = 43.99) for D15, with a P-value of 0.40, indicating no significant differences between the groups. Similarly, at the 50% interval, the values were 364.14 (SD = 41.38) for T10, 358.48 (SD = 29.92) for T15, 356.14 (SD = 43.12) for D10, and 370.05 (SD = 40.30) for D15, resulting in a P-value of 0.66. The 75% interval showed values of 374.90 (SD = 39.35) for T10, 361.57 (SD = 29.51) for T15, 362.62 (SD = 32.31) for D10, and 373.38 (SD = 38.77) for D15, with a P-value of 0.48. Finally, at the 100% interval, the mean Vte values were 383.19 (SD = 37.18) for T10, 368.90 (SD = 32.82) for T15, 361.62 (SD = 29.47) for D10, and 383.71 (SD = 45.47) for D15, with a P-value of 0.14. These findings suggest that the interventions had a uniform impact on respiratory parameters across the groups, as there were no significant differences noted at any of the time intervals measured. This uniformity contrasts with findings by Joshi et al, , who reported noticeable improvements in respiratory function with specific interventions, raising questions about the sensitivity of Vte as a measure or the efficacy of the interventions used in this study[76].

Significant differences were noted in the time taken to achieve greater than 90% efficacy among the four intervention groups, with the results highlighting the effectiveness of different interventions. The T10 group achieved this efficacy in a mean time of 88.33 minutes (SD = 18.77), while the T15 group recorded a similar time of 88.14 minutes (SD = 21.23). In contrast, the D10 and D15 groups reached the same efficacy much quicker at 66.90 minutes (SD = 10.62) and 71.38 minutes (SD = 12.87) respectively. The statistical analysis yielded a P-value of less than 0.001, underscoring the significant acceleration in

achieving desired outcomes in the D10 and D15 groups compared to T10 and T15. This variance suggests that the interventions employed in D10 and D15 were more effective or efficiently administered, aligning with findings by Sjöblom et al[77][78] that certain intervention modalities can expedite clinical efficacy. Ronney et al[79]. further emphasize the importance of procedural adjustments when expected efficacy thresholds are not met uniformly across groups, indicating that T10 and T15 might benefit from revisiting the intervention strategies employed [80][81].

6. Conclusion

This study comprehensively examined the impact of different fresh gas flow rates and breathing patterns on the efficacy of rapid pre-oxygenation techniques. The findings suggest a significant influence of both variables on the speed and effectiveness of pre-oxygenation, which is critical for patient safety during anaesthesia induction.

The use of higher fresh gas flow rates, specifically 10 L/min and 15 L/min, combined with different breathing patterns (Tidal Volume Breathing and Deep Breathing), demonstrated varying efficiencies in achieving an end-tidal oxygen concentration (EtO2) of 0.9. Notably, the Deep Breathing pattern, particularly at higher flow rates, allowed for a quicker attainment of optimal pre-oxygenation levels compared to Tidal Volume Breathing. This suggests that Deep Breathing may be more suitable in scenarios where rapid oxygenation is crucial, such as emergency procedures or in patients at high risk of aspiration.

Furthermore, the study revealed no significant differences in the physiological responses such as heart rate, respiratory rate, and systolic and diastolic blood pressures among the different groups, indicating the general safety of the interventions. However, the significant differences in mean arterial pressure observed between groups underscore the need to consider individual cardiovascular status when selecting pre-oxygenation strategies.

The clinical implications of these findings are significant, emphasizing the importance of tailoring pre-oxygenation techniques to individual patient needs and specific clinical situations. The data support the use of higher flow rates and Deep Breathing techniques in situations requiring rapid and effective pre-oxygenation. Additionally, the study highlights the potential for standardizing pre-oxygenation practices to enhance overall patient safety and outcomes during anaesthesia induction.

In conclusion, this study contributes valuable insights into the optimization of pre-oxygenation strategies, which could guide clinical practice and training in anaesthesia. Future research should focus on exploring the long-term outcomes associated with different pre-oxygenation techniques and further refining the protocols to maximize both safety and efficacy.

SUMMARY

- The study was structured as a prospective, randomized parallel group study. This design was chosen to evaluate the efficacy of different pre-oxygenation strategies under controlled conditions, allowing for direct comparison between groups.
- The primary goal was to evaluate the effects of different fresh gas flow rates (10 L/min and 15 L/min) and breathing patterns (Tidal Volume Breathing and Deep Breathing) on the efficiency of rapid pre-oxygenation in achieving an end-tidal oxygen concentration (EtO2) of 0.9.
- The study spanned 12months and was conducted in a tertiary care hospital. This duration was selected to ensure adequate time for participant recruitment, data collection, and analysis.
- Participants included male and female patients aged 18 to 59 years, scheduled for elective surgical procedures that required general anaesthesia (GA) and endotracheal intubation. This age range was chosen to represent a typical adult surgical population without the confounding factors present in paediatric and older populations.
- Based on prior studies, such as Mathew G et al., 2022, the sample size was calculated to include a minimum of 21 participants per group, totalling 84 participants. This size was determined to achieve a statistical power of 90% and an alpha level of 0.05, ensuring robustness in detecting significant differences between the intervention groups.
- Participants were eligible if they were aged 18 to 59 years, classified as ASA grade I-II, and scheduled for elective procedures requiring GA and endotracheal intubation. Excluded were patients with a BMI > 30 kg/m², anticipated difficult airway, existing cardiac and respiratory diseases, chronic smokers, pregnant women, and those who declined consent.
- Participants in the study were systematically divided into four distinct groups through a randomization process using computer-generated numbers to ensure impartiality and minimize selection bias. This random assignment placed participants into one of the following categories: Group A was designated to perform Tidal Volume Breathing (TVB) with a fresh gas flow (FGF) of 10 L/min; Group B also practiced Tidal Volume Breathing but with a higher FGF of 15 L/min; Group C engaged in Deep Breathing (DB) with an FGF of 10 L/min; and finally, Group D conducted Deep Breathing with an FGF of 15 L/min. This grouping strategy was aimed at evaluating the effectiveness of different breathing patterns combined with varying gas flow rates on the efficiency of pre-oxygenation.
- The procedure for this study was meticulously structured to ensure consistent and controlled conditions across all participant groups. **During the preoperative visit**, each participant was thoroughly briefed on the specific pre-oxygenation method they would undergo, ensuring they were well-informed about the process. **For standard monitoring**, prior to the induction of anaesthesia, participants were connected to standard monitoring equipment, which included electrocardiography (ECG), non-invasive blood pressure (NIBP), pulse oximetry (SpO2), and capnography (EtCO2), to ensure comprehensive tracking of their physiological state.
- The **anaesthesia workstation setup** involved the use of a Mindray anaesthesia machine equipped with a circle system and a 2L reservoir bag, which was primed with 100% oxygen to prepare for the pre-oxygenation process. Participants were then positioned in a **20° head-up tilt** to optimize respiratory mechanics, and initial physiological parameters were recorded to establish a baseline for comparison post-intervention.

- The **pre-oxygenation process** itself was administered using a tight-fitting face mask set at designated fresh gas flow rates and according to the assigned breathing patterns. A continuous positive airway pressure (CPAP) of 5 cm H_2O was maintained throughout to prevent alveolar collapse and ensure effective oxygenation. **Measurements taken during this phase** included the time and number of breaths required to reach an end-tidal oxygen concentration (EtO2) of 90%, along with monitoring EtCO2, exhaled tidal volume (Vte), and the fraction of inspired oxygen (FiO2) at the end of each breath to assess the efficiency of the pre-oxygenation.
- **After achieving the target EtO2**, participants were then premedicated and induced with standard general anaesthesia (GA) protocols appropriate for their scheduled surgical procedures. This comprehensive approach not only facilitated a detailed assessment of pre-oxygenation techniques but also ensured participant safety and procedural integrity throughout the study.
- The socio-demographic profile of the study participants provided a detailed breakdown of their age and gender distribution. The average age of the participants was 41.07 years, with a standard deviation of 9.88, reflecting a mid-adult demographic. In terms of age distribution, the participants were segmented into three groups: 13.1% fell within the 18-30 years range, the majority, 53.6%, were aged between 31-45 years, and 33.3% were between 46-60 years. This spread indicates a broad representation of the adult population but with a focus on the middle-aged group. Gender representation was nearly balanced, with females comprising 52.4% and males 47.6% of the 84 participants, providing a gender-diverse sample which enhances the generalizability of the study findings across different populations.
- The physical status and ASA classification of the participants in the study were meticulously recorded to assess their general health and suitability for the interventions. The average height of the participants was 163.07 cm with a standard deviation of 7.85, and the mean weight was 67.83 kg with a standard deviation of 11.64. The Body Mass Index (BMI), a key indicator of body fat based on height and weight, averaged 25.68 with a standard deviation of 5.07, positioning most participants in the upper range of the 'normal' weight category according to global health standards. Regarding the American Society of Anaesthesiologists (ASA) classification, which evaluates the physical status of patients before surgery, 54.8% of the participants were categorized as ASA Class I, indicating a normal healthy group, while 45.2% were classified as ASA Class II, suggesting mild systemic disease. This distribution indicates a predominantly healthy cohort, with some individuals having manageable health conditions, thereby ensuring a representative sample for examining the effects of pre-oxygenation techniques under varied physical conditions.
- Age, sex, and age group comparisons across the T10, T15, D10, and D15 intervention groups showed no significant differences (P-values for age = 0.48, age groups = 0.42, and sex = 0.44), indicating well-balanced groups for the study.
- Heart rate, respiratory rate, systolic blood pressure (SBP), and diastolic blood pressure (DBP) were similar across all groups, with no significant differences found. P-values were 0.37 for heart rate, 0.81 for respiratory rate, 0.98 for SBP, and 0.39 for DBP.
- However, mean arterial pressure (MAP) varied significantly across the groups (P = 0.002), highlighting a potential variable affecting pre-oxygenation efficacy.

- Tidal volumes (Vte) measured at 25%, 50%, 75%, and 100% of the total duration of breathing showed no significant differences across intervention groups (P-values: 0.40, 0.66, 0.48, and 0.14 respectively), suggesting uniform effectiveness of the interventions on respiratory parameters.
- The time taken to achieve more than 90% efficacy varied significantly between the groups. The groups using Deep Breathing (D10 and D15) achieved this threshold more quickly (mean times of 66.90 minutes and 71.38 minutes, respectively) compared to those using Tidal Volume Breathing (T10 and T15, with mean times of 88.33 minutes and 88.14 minutes, respectively). The P-value for these differences was less than 0.001.
- These detailed results elucidate the effectiveness of different pre-oxygenation strategies, highlighting the impact of higher fresh gas flow rates and different breathing patterns on the rapid achievement of optimal pre-oxygenation, which is crucial for safe anaesthesia practice.
- The findings suggest that while basic physiological parameters remain stable across different pre-oxygenation methods, the choice of fresh gas flow rate and breathing technique significantly influences the speed of achieving desired oxygenation levels.

RECOMMENDATION

Based on the findings of the study, the following recommendations are proposed to enhance the practice of pre-oxygenation in clinical settings:

- **Optimize Fresh Gas Flow Rates**: Given the evidence that higher fresh gas flow rates significantly improve the efficiency of pre-oxygenation, it is recommended that anaesthesia protocols consider setting the fresh gas flow to at least 10 L/min during pre-oxygenation, particularly in emergency situations or for patients at high risk of aspiration. For routine procedures, adjusting the flow rate based on the patient's specific needs and health status can also be beneficial, but care should be taken to ensure it does not exceed 15 L/min, as no additional benefits were observed beyond this point.

- **Implement Deep Breathing Techniques for Rapid Pre-Oxygenation**: Deep Breathing (DB) techniques should be emphasized and taught as part of standard anaesthetic practice, especially in scenarios requiring rapid pre-oxygenation. Training and simulation exercises could be implemented to familiarize all anaesthesia providers with the mechanics and benefits of Deep Breathing, ensuring it can be effectively utilized when needed.

BIBLIOGRAPHY

(1–81)

1. Lerant AA, Hester RL, Coleman TG, Phillips WJ, Orledge JD, Murray WB. Preventing and treating hypoxia: Using a physiology simulator to demonstrate the value of pre-oxygenation and the futility of hyperventilation. Int J Med Sci. 2015 Jul 23;12(8):625–32.
2. Manning HL, Molinary EJ, Leiter JC. Effect of Inspiratory Flow Rate on Respiratory Sensation and Pattern of Breathing. Am J Respir Crit Care Med. 1995 Mar;151(3_pt_1):751–7.
3. Reber A, Engberg G, Wegenius G, Hedenstierna G. Lung aeration. The effect of pre-oxygenation and hyperoxygenation during total intravenous anaesthesia. Anaesthesia. 1996;51(8):733–7.
4. Effect on High Fresh Gas Flow and Pattern of Breathing On Rapid Pre-Oxygenation - SciSpace Literature Review [Internet]. [cited 2024 Jul 27]. Available from: https://typeset.io/search?q=Effect%20on%20%20High%20Fresh%20Gas%20Flow%20and%20%20Pattern%20of%20Breathing%20On%20%20Rapid%20Pre-Oxygenation
5. Jung JD, Kim SH, Yu BS, Kim HJ. Effects of a preemptive alveolar recruitment strategy on arterial oxygenation during one-lung ventilation with different tidal volumes in patients with normal pulmonary function test. Korean J Anesthesiol. 2014 Aug 1;67(2):96–102.
6. Pourmand A, Robinson C, Dorwart K, O'Connell F. Pre-oxygenation: Implications in emergency airway management. American Journal of Emergency Medicine. 2017 Aug 1;35(8):1177–83.
7. Tan PCF, Dennis AT. High-flow humidified nasal pre-oxygenation in pregnant women. Anaesthesia. 2016 Jul 1;71(7):851–2.
8. Baillard C, Prat G, Jung B, Futier E, Lefrant JY, Vincent F, et al. Effect of preoxygenation using non-invasive ventilation before intubation on subsequent organ failures in hypoxaemic patients: a randomised clinical trial. Br J Anaesth. 2018 Feb 1;120(2):361–7.
9. Gennser M, Blogg SL. Oxygen or carbogen breathing before simulated submarine escape. J Appl Physiol [Internet]. 2008 Jan [cited 2024 Jul 27];104(1):50–6. Available from: http://www.
10. Domino KB. Pre-emergence Oxygenation and Postoperative Atelectasis. Anesthesiology. 2019 Oct 1;131(4):771–3.
11. Baillard C, Fosse JP, Sebbane M, Chanques G, Vincent F, Courouble P, et al. Noninvasive ventilation improves preoxygenation before intubation of hypoxic patients. Am J Respir Crit Care Med. 2006;174(2):171–7.
12. Mertzlufft F, Zander R. Optimal pre-oxygenation: The nasoral-system. Adv Exp Med Biol. 1994;345:45–50.
13. Hett DA, Geraghty IF, Radford R, House JR. Routine pre-oxygenation using a Hudson mask A comparison with a conventional pre-oxygenation technique. Anaesthesia. 1994;49(2):157–9.
14. Logan M. Breathing systems: Effect of fresh gas flow rate on enflurane consumption. Br J Anaesth. 1994;73(6):775–8.
15. Benumof JL. Preoxygenation: Best method for both efficacy and efficiency? Anesthesiology. 1999;91(3):603–5.

16. Simon M, Wachs C, Braune S, de Heer G, Frings D, Kluge S. High-flow nasal cannula versus bag-valve-mask for preoxygenation before intubation in subjects with hypoxemic respiratory failure. Respir Care. 2016 Sep 1;61(9):1160–7.
17. Cruickshank S. Pre-oxygenation: washing out the nitrogen. Mathematics and Statistics in Anaesthesia. 2023 Nov 2;29–36.
18. Hanouz JL. Reply to: Pre-oxygenation by facemask or high-flow nasal oxygen. Eur J Anaesthesiol. 2020 Jan 1;37(1):54–5.
19. Meunier J, Guitton C. The role of HFNC oxygen in pre-oxygenation prior to intubation and the practice of invasive procedures. Rev Mal Respir. 2023 Jan 1;40(1):47–60.
20. Castagna O, Gempp E, Blatteau JE. Pre-dive normobaric oxygen reduces bubble formation in scuba divers. Eur J Appl Physiol. 2009;106(2):167–72.
21. Wang H, Sun JL, Bai ZH, Wang XB, Zhang ZL, Pei HH. Preoxygenation using invasive ventilator in volume control mode in patients with emergency intubation can shorten the time of preoxygenation and improve the quality of preoxygenation: A retrospective study. Medicine (United States). 2016;95(40).
22. Groombridge CJ, Ley E, Miller M, Konig T. A prospective, randomised trial of pre-oxygenation strategies available in the pre-hospital environment. Anaesthesia. 2017 May 1;72(5):580–4.
23. Kolton M, Cattran CB, Kent G, Volgyesi G, Froese AB, Bryan AC. Oxygenation during high-frequency ventilation compared with conventional mechanical ventilation in two models of lung injury. Anesth Analg. 1982;61(4):323–32.
24. Tanna S, Saha S. Can high-flow nasal oxygen redefine our end-point for pre-oxygenation? Anaesthesia. 2019 Dec 1;74(12):1620.
25. Duan J, Tang X, Huang S, Jia J, Guo S. A pilot study of short-term high-pressure support ventilation in persistent sudden-onset rapid breathing. Anaesth Intensive Care. 2012;40(6):971–9.
26. Hodgman JE, Hoppenbrouwers T, Shirazi M, Cabal LA, Durand M. EFFECT OF BREATHING PATTERN ON OXYGENATION DURING SLEEP IN PREMATURES. Pediatr Res. 1984 Apr;18:393A-393A.
27. Wetsch W, Schroeder D, Finke SR, Sander D, Ecker H, Böttiger B, et al. A special oropharyngeal oxygenation device to facilitate apneic oxygenation in comparison to high flow oxygenation devices. Med Gas Res. 2022 Mar 1;12(1):28–31.
28. Schuder RJ, Weis FR, Markello R. Diffusion hyperoxia following preoxygenation. Anesth Analg. 1977;56(1):59–61.
29. Bosco G, Yang ZJ, Di Tano G, Camporesi EM, Faralli F, Savini F, et al. Effect of in-water oxygen prebreathing at different depths on decompression-induced bubble formation and platelet activation. J Appl Physiol. 2010 May;108(5):1077–83.
30. Sjöblom A, Hedberg M, Johansson S, Henningsson R, Soumpasis I, Lafrenz H, et al. Pre-oxygenation using high-flow nasal oxygen in parturients undergoing caesarean section in general anaesthesia: A prospective, multi-centre, pilot study. Acta Anaesthesiol Scand. 2023 Sep 1;67(8):1028–36.
31. Kumar D, Kumar A, Kohli A, Singh R, Karthik R. Effect of prone positioning and high flow nasal oxygen on oxygenation and overall outcome in spontaneously breathing awake patient with severe COVID-19 induced acute hypoxemic respiratory failure: A prospective observational study. Trends in Anaesthesia and Critical Care. 2022 Feb 1;42:9–13.

32. Gebremedhn EG, Mesele D, Aemero D, Alemu E. The incidence of oxygen desaturation during rapid sequence induction and intubation. World J Emerg Med. 2014;5(4):279.
33. Maltseva LA, Grishin VI, Khalimonchyk VV, Bazylenko DV, Golota PP, Garus MV, et al. Emerg Med (N Y). 2021 Oct 4;(4.91):68–74.
34. Hamzah NF, Md Nor N, Maaya M, Sayed Masri SNN, Teo R, Masdar A. Pre-oxygenation in obese patients: facemask versus facemask with nasal prong. Malaysian Journal of Anaesthesiology. 2023 Jun 27;2(1):14–24.
35. Jung B, Azuelos I, Chanques G, Jaber S. How to improve preoxygenation before intubation in patients at risk? Trends in Anaesthesia and Critical Care. 2012 Feb;2(1):20–4.
36. Mushambi M. Facemask or high-flow nasal oxygenation: time to switch? Anaesthesia. 2022 Jun 1;77(6):716–7.
37. Nimmagadda U, Salem MR, Crystal GJ. Preoxygenation: Physiologic basis, benefits, and potential risks. Anesth Analg. 2017 Feb 1;124(2):507–17.
38. Austin MA, Wills KE, Blizzard L, Walters EH, Wood-Baker R. Effect of high flow oxygen on mortality in chronic obstructive pulmonary disease patients in prehospital setting: Randomised controlled trial. BMJ (Online). 2010 Oct 30;341(7779):927.
39. Bentsen LP, Lassen AT, Titlestad IL, Brabrand M. A change from high-flow to titrated oxygen therapy in the prehospital setting is associated with lower mortality in COPD patients with acute exacerbations: an observational cohort study. Acute Medicine. 2020;19(2):76–82.
40. Kuo HC, Liu WC, Li CC, Cherng YG, Chen JT, Wu HL, et al. A comparison of high-flow nasal cannula and standard facemask as pre-oxygenation technique for general anesthesia: A PRISMA-compliant systemic review and meta-analysis. Medicine (United States). 2022 Mar 11;101(10):E28903.
41. McCARTHY G, ELLIOTT P, MIRAKHUR RK, McLOUGHLIN C. A comparison of different pre-oxygenation techniques in the elderly. Anaesthesia. 1991;46(10):824–7.
42. Dian Fadila N, Adriani P, Nur Rahmawati A. The Effect of Oxygenation on Improving Breathing Pattern in Congestive Heart Failure Case. Genius Journal. 2022 Dec 2;3(2):147–51.
43. Ooi R, Pattison J, Joshi P, Chung R, Soni N. Pre-oxygenation: the Hudson mask as an alternative technique. Anaesthesia [Internet]. 1992 [cited 2024 Jul 27];47(11):974–6. Available from: https://associationofanaesthetists-publications.onlinelibrary.wiley.com/doi/10.1111/j.1365-2044.1992.tb03203.x,
44. Zhong G, Ho SHK, Wong SJ. Environmental impact of high-flow nasal oxygenation. Anaesthesia. 2023 May 1;78(5):653.
45. Bennett G, Joyce M, Sweeney L, MacLoughlin R. In Vitro Study of the Effect of Breathing Pattern on Aerosol Delivery During High-Flow Nasal Therapy. Pulm Ther. 2019 Jun 1;5(1):43–54.
46. Nimmagadda U, Salem MR, Joseph NJ, Miko I. Efficacy of preoxygenation using tidal volume and deep breathing techniques with and without prior maximal exhalation. Canadian Journal of Anesthesia. 2007;54(6):448–52.
47. Stolady D, Mariyaselvam M, Young H, Fawzy E, Blunt M, Young P. Pharyngeal oxygenation during apnoea following conventional pre-oxygenation and high-flow nasal oxygenation. Crit Care. 2015 Mar 16;19(S1).
48. Davis DP, Lemieux J, Serra J, Koenig W, Aguilar SA. Preoxygenation reduces desaturation events and improves intubation success. Air Med J. 2015;34(2):82–5.

49. Azam Danish M. Preoxygenation and Anesthesia: A Detailed Review. Cureus. 2021 Feb 9;
50. Vourc'H M, Huard D, Feuillet F, Baud G, Guichoux A, Surbled M, et al. Preoxygenation in difficult airway management: High-flow oxygenation by nasal cannula versus face mask (the PREOPTIDAM study). Protocol for a single-centre randomised study. BMJ Open. 2019 Apr 1;9(4).
51. Cai Q, Ma W, Wu C, Liu H, Wang S, Zhang G. Is pre-oxygenation with high-flow nasal oxygen safe? randomized control trial of 56 cases of elderly patients during induction of general anesthesia with endotracheal intubation. Nan Fang Yi Ke Da Xue Xue Bao. 2022;42(7):1069–74.
52. GOLDBERG M, NORRIS M, LARIJANI G, MARR A, SELTZER J. Preoxygenation in the Morbidly Obese. Survey of anesthesiology. 1989 Dec;33(6):352.
53. Yadav A, Khurana T, Nagpal VK, Kaur M. Comparison of Pre-Oxygenation with Single Vital Capacity Breath Technique and Tidal Volume Breathing Technique for Adult Patients Undergoing General Anaesthesia. Archives of Anesthesiology and Critical Care. 2023 Mar 1;9(2):132–7.
54. Russell GN, Smith CL, Snowdon SL, Bryson THL. Pre-Oxygenation and the Parturient Patient. Obstetric Anesthesia Digest. 1987 Dec;7(4):152.
55. Motoyasu A, Moriyama K, Mitsuda S, Moriyama K, Yorozu T. Oxygen at a high flow rate (35 L·min-1) via face mask for preoxygenation. Canadian Journal of Anesthesia. 2014 Feb;61(2):207–8.
56. Nimmagadda U, Chiravuri SD, Ramez Salem M, Joseph NJ, Wafai Y, Crystal GJ, et al. Preoxygenation with tidal volume and deep breathing techniques: The impact of duration of breathing and fresh gas flow. Anesth Analg. 2001;92(5):1337–41.
57. Austin MA, Wood-Baker R. Oxygen therapy in the pre-hospital setting for acute exacerbations of chronic obstructive pulmonary disease. Cochrane Database of Systematic Reviews. 2006 Jul 19;
58. Forsberg IM, Al-Saadi J, Sjöblom A, Grape L, Petersson J, Lundberg J, et al. Cardiopulmonary haemodynamic effects and gas exchange during apnoeic oxygenation with high-flow and low-flow nasal oxygen: A large animal study. Eur J Anaesthesiol. 2023 Aug 1;40(8):568–77.
59. Scott P V. Pre-oxygenation, hyperoxygenation and lung aeration. Anaesthesia. 1996;51(12):1186.
60. BERTHOUD M, READ DH, NORMAN J. Pre-oxygenation–how long? Anaesthesia. 1983;38(2):96–102.
61. Liang H, Sun L, Feng Y. Atelectasis after pre-oxygenation with high-flow nasal cannula oxygen confirmed by electrical impedance tomography. Indian J Anaesth. 2022 Feb 1;66(2):157–8.
62. Altermatt FR, Muñoz HR, Delfino AE, Cortínez LI. Pre-oxygenation in the obese patient: Effects of position on tolerance to apnoea. Br J Anaesth. 2005;95(5):706–9.
63. GURA D, SAIDMAN LJ. Alveolar oxygen and carbon dioxide concentrations during simulated breathing through a T-piece. Crit Care Med. 1974 Jan;2(1):11–22.
64. Hanouz JL, Lammens S, Tasle M, Lesage A, Gérard JL, Plaud B. Preoxygenation by spontaneous breathing or noninvasive positive pressure ventilation with and without positive end-expiratory pressure A randomised controlled trial. Eur J Anaesthesiol. 2015 Dec 1;32(12):881–7.
65. Spinelli E, Mauri T, Lissoni A, Crotti S, Langer T, Albanese M, et al. Spontaneous breathing patterns during maximum extracorporeal co2 removal in subjects with early severe ards. Respir Care. 2020 Jul 1;65(7):911–9.
66. Choinière A, Girard F, Boudreault D, Ruel M, Girard DC. Voluntary hyperventilation before a rapid-sequence induction of anesthesia does not decrease postintubation Paco2. Anesth Analg. 2001;93(5):1277–80.

67. RUSSELL GN, SMITH CL, SNOWDON SL, BRYSON THL. Pre-oxygenation and the parturient patient. Anaesthesia. 1987;42(4):346–51.
68. Russell EC, Wrench I, Feast M, Mohammed F. Pre-oxygenation in pregnancy: The effect of fresh gas flow rates within a circle breathing system. Anaesthesia. 2008 Aug;63(8):833–6.
69. McClelland SH, Bogod DG, Hardman JG. Pre-oxygenation and apnoea in pregnancy: Changes during labour and with obstetric morbidity in a computational simulation. Anaesthesia. 2009 Apr;64(4):371–7.
70. Karim HMR, Esquinas AM, O'brien B. Flow Effects of High-flow Nasal Oxygenation: Comment. Anesthesiology. 2023 May 1;138(5):566–7.
71. Shippam W, Preston R, Douglas J, Taylor J, Albert A, Chau A. High-flow nasal oxygen vs. standard flow-rate facemask pre-oxygenation in pregnant patients: a randomised physiological study. Anaesthesia. 2019 Apr 1;74(4):450–6.
72. Hanouz JL, Lhermitte D, Gerard JL, Fischer MO. Comparison of pre-oxygenation using spontaneous breathing through face mask and high-flow nasal oxygen A randomised controlled crossover study in healthy volunteers. Eur J Anaesthesiol. 2019 May 1;36(5):335–41.
73. Chua MT, Khan FA, Ng WM, Lu Q, Low MJW, Yau YW, et al. Pre- and Apnoeic high flow oxygenation for RApid sequence intubation in the Emergency department (Pre-AeRATE): Study protocol for a multicentre, randomised controlled trial. Trials. 2019 Apr 4;20(1).
74. Chua MT, Ng WM, Lu Q, Low MJW, Punyadasa A, Cove ME, et al. Pre- and apnoeic high-flow oxygenation for rapid sequence intubation in the emergency department (the Pre-AeRATE trial): A multicentre randomised controlled trial. Ann Acad Med Singap. 2022 Mar 1;51(3):149–60.
75. Russell EC, Wrench I, Feast M, Mohammed F. Preoxygenation in Pregnancy: The Effect of Fresh Gas Flow Rates Within A Circle Breathing System. Obstetric Anesthesia Digest. 2009 Jun;29(2):77.
76. Ooi R, Joshi P, Soni N. A high flow semi-open system for preoxygenation an evaluation. Br J Anaesth. 1992;68(1):39–42.
77. Kundra P, Stephen S, Vinayagam S. Techniques of preoxygenation in patients with ineffective face mask seal. Indian J Anaesth. 2013;57(2):175–9.
78. Sjöblom A, Broms J, Hedberg M, Lodenius, Furubacke A, Henningsson R, et al. Pre-oxygenation using high-flow nasal oxygen vs. tight facemask during rapid sequence induction. Anaesthesia. 2021 Sep 1;76(9):1176–83.
79. Ronney MJ. Pre-oxygenation: a comparison of two techniques using a Bain system. Anaesthesia. 1994;49(7):629–32.
80. Bansal P, Sanjay Chaudhari M, Khara B. Increasing fresh gas flows of oxygen in a circle absorber system for preoxygenation. Is it really efficacious? Indian Journal of Clinical Anaesthesia. 2020 Dec 28;5(4):609–13.
81. Mathew G, Manjuladevi M, Joachim N, Kothari AN. Effect of high fresh gas flow and pattern of breathing on rapid preoxygenation. Indian J Anaesth. 2022 Mar 1;66(3):213–9.

ANNEXURE A: CASE RECORD FORM

TITLE: Study of the effect of high fresh gas flows and pattern of breathing on rapid preoxygenation

NAME-	AGE-	SEX-
IPD NO.-	HEIGHT-	WEIGHT-
BMI-	ASA GRADE-	

Diagnosis- Surgery-

Duration- Total no. of breaths taken to achieve>90%

Respiratory variables at different intervals of time	**Tidal volume breathing at 10l/min**	**Tidal volume breathing at 10L/min**
Vte at 25%		
Vte at 50%		
Vte at 75%		
Vte at 100%		
EtCO2 at 25%		
EtCO2 at 50%		
EtCO2 at 75%		
ETCO2 at 100%		
EtO2 at 25%		
EtO2 at 50%		
EtO2 at 75%		
EtO2 at 100%		

Respiratory variables at different intervals of time	**Deep breathing at 15L/min**	**Deep breathing at 15L/min**
Vte at 25%		
Vte at 50%		
Vte at 75%		
Vte at 100%		
EtCO2 at 25%		
EtCO2 at 50%		
EtCO2 at 75%		
ETCO2 at 100%		
EtO2 at 25%		
EtO2 at 50%		
EtO2 at 75%		
EtO2 at 100%		

Vte- End Tidal volume, EtCO2- End Tidal Carbon dioxide Concentration, EtO2- End Tidal Oxygen concentration

Signature of Principal Investigator/ Co-Investigator

ANNEXEURE B

INFORMED CONSENT FORM

Project Title: STUDY OF THE EFFECT OF HIGH FRESH GAS FLOW AND PATTERN OF BREATHING ON RAPID PREOXYGENATION

1. Introduction

You are invited to participate in a study. It is important that you read the given description of the study and thereby understand your role in it, which will include the nature and risk of participation. Please give your consent for participation in this study only if you have completely understood the nature and course of this study and if you are aware of your rights as participants.

2. Purpose of the study:
This study aims to observe the effect of fresh gas flow and compare the pattern of breathing at different flow rates on rapid preoxygenation in patients induced under general anaesthesia.

3. Number of research participants and expected duration of each participant in the study:
You will be one of the 84 patients who will participate in this study. You will be in this study for one day, that is the day of your surgery.

4. Study procedure to be followed:
If you agree to participate in this study and give consent, you will be explained the objectives of the study and the exact procedure to be followed. After preparation of the operation theatre and confirmation of starvation and premedication status, you shall be taken inside the operation theatre General anaesthesia will be given by OT anaesthetists as per required, you shall be taken inside the operation theatre protocols of case management. During the period of preoxygenation in general anaesthesia, the time taken, effect and pattern of breathing at different fresh gas flow rates will be noted down by the same anaesthiologist till the end of the surgery.

5. Risks and discomforts of participants
This study will not add any additional risks or discomfort to you.

6. Possible benefits of the study
Your participation will provide useful data which may prove to be helpful in future in making better anaesthetic decisions. However, this study may not benefit you directly.

7. Compensation for participant:
Participation in the study will be at no cost to you. This is an observational study so there will be no compensation for participation as your treatment will not be altered.

8. Right to withdraw from the study

Participation in this study is entirely voluntary. You may choose not to take part, or you may leave the study at any time. Your decision will not affect your further treatment at this institute.

9. Confidentiality

All study records will be always kept confidential. Your identity will not be revealed except as required by the law and Institutional Ethics Committee. The results of the study may be published for scientific reasons. Your identity will not be revealed in these publications.

10. Contact for further information

Thank you for taking time to read (or have read to you) the information about this study. Before you sign this document, you should ask questions about anything that you do not understand. The study staff will answer questions before, during and after the study.

11. Consent

(1) I have read or have read to me the information given in the informed consent document for this study entitled "STUDY OF THE EFFECT OF HIGH FRESH GAS FLOW AND PATTERN OF BREATHING ON RAPID PREOXYGENATION."
(2) I have received an explanation of the nature, purpose and duration of the study. My questions have been answered satisfactorily.
(3) I understand that my participation in the study is voluntary and that I may refuse to participate or may withdraw from the study at any time, without penalty or loss of benefits to which am otherwise entitled.
(4) I further understand that any information that becomes available during the study that may affect my willingness to take part will be informed to me.
(5) Institutional Ethics Committee authorities may wish to examine my medical records to verify the information collected. By signing this document, I give permission for this review of my records.
(6) I understand that my identity will not be revealed in any report or publication.
(7) I agree to take part in the above study.

Name of participant	**Signature/thumb impression**	**Date**
Name of Legal representative	**Signature/thumb impression**	**Date**
Name of impartial witness	**Signature of impartial witness**	**Date**
Name of person administering	**Signature of person administering**	**Date**

Advanced International Journal for Research (AIJFR)
E-ISSN: 3048-7641 ● Website: www.aijfr.com ● Email: editor@aijfr.com

consent **consent**

Sl. No	Name	Height	Weight	BMI	ASA PS	Age	Sex	Group	HR_baseline	RR_baseline	SBP_baseline	DBP_baseline	MAP_baseline	Vte1	Vte2	Vte3	Vte4	EtCO2_1	EtCO2_2	EtCO2_3	EtCO2_4	EtO2_1	EtO2_2	EtO2_3	EtO2_4	Time_to_acheive_more_than_90	Total Number of Breaths to EtO2 more than 90
1	Patient 1	161	52	20.1	II	45	F	T10	81	98	112	81	86	280	305	320	350	25	22	20	19	53	79	84	90	92	18
2	Patient 2	177	67	21.4	I	58	F	T10	85	98	124	82	99	344	360	370	378	22	21	19	17	56	76	89	94	74	15
3	Patient 3	167	58	20.8	II	34	M	T10	78	99	115	79	97	360	395	400	412	24	22	20	18	55	73	82	96	119	19
4	Patient 4	159	67	26.5	I	30	M	T10	80	98	122	89	98	405	409	412	413	18	16	15	14	68	74	88	97	95	14
5	Patient 5	157	50	20.3	II	40	M	T10	86	99	114	70	89	380	378	416	420	23	21	20	16	54	70	82	93	115	19
6	Patient 6	156	62	25.5	II	50	M	T10	70	97	115	84	90	324	356	374	382	31	31	30	31	51	70	87	96	114	20
7	Patient 7	160	75	29.3	I	50	F	T10	80	97	110	74	98	285	296	325	356	25	23	22	20	51	72	82	92	99	13
8	Patient 8	178	86	27.1	I	49	M	T10	80	99	115	73	99	345	354	367	380	22	20	18	16	53	77	81	93	71	16
9	Patient 9	157	70	28.4	II	43	F	T10	83	98	128	74	92	305	315	328	326	21	19	18	18	55	74	85	91	83	13
10	Patient 10	156	67	27.5	II	36	M	T10	82	99	124	81	95	390	413	420	427	16	15	15	14	72	79	86	98	72	12
11	Patient 11	171	84	28.7	I	37	M	T10	78	98	126	72	98	413	420	436	438	21	20	18	17	57	72	83	93	111	21
12	Patient 12	163	65	24.5	I	43	F	T10	73	97	117	84	85	306	328	336	354	23	21	18	18	51	72	89	91	65	16
13	Patient 13	157	50	20.3	I	28	M	T10	79	99	129	78	85	416	427	434	438	17	16	16	15	64	78	86	98	88	17
14	Patient 14	154	68	28.7	II	34	F	T10	85	97	117	85	95	315	328	342	348	20	18	18	17	62	77	86	92	63	15
15	Patient 15	175	80	26.1	I	49	M	T10	80	97	123	86	89	333	345	352	356	21	20	19	19	65	70	83	95	77	16
16	Patient 16	156	70	28.8	I	39	F	T10	86	97	116	71	92	395	413	428	430	18	17	17	16	62	79	82	95	67	16
17	Patient 17	176	74	23.9	I	31	F	T10	72	99	128	81	95	315	328	337	343	18	17	17	16	58	75	81	97	117	20
18	Patient 18	174	63	20.8	I	54	F	T10	84	99	113	72	99	344	352	356	359	19	18	18	17	52	73	80	91	95	21
19	Patient 19	159	70	27.7	I	38	M	T10	79	99	128	80	92	408	424	414	432	16	15	15	14	59	77	86	94	95	15
20	Patient 20	174	63	20.8	II	44	F	T10	76	98	116	88	95	340	343	352	350	19	19	18	18	56	73	83	90	70	18
21	Patient 21	163	72	27.1	I	34	M	T10	76	97	127	80	95	317	358	354	355	17	17	16	16	55	79	83	93	73	17
22	Patient 64	158	52	20.8	I	31	M	T15	86	99	126	78	92	355	367	368	376	17	16	15	15	68	76	88	95	57	14
23	Patient 65	155	66	27.5	II	35	M	T15	85	98	112	87	86	371	376	379	413	14	13	13	12	59	76	85	96	106	16
24	Patient 66	174	86	28.4	II	29	M	T15	84	99	119	80	97	373	367	362	370	20	19	19	18	66	75	88	95	47	10
25	Patient 67	163	76	28.6	II	43	F	T15	84	98	123	76	94	348	350	356	358	21	20	20	19	53	71	87	90	112	20
26	Patient 68	176	68	22	II	52	M	T15	72	98	124	80	85	355	376	377	378	18	18	17	17	58	77	82	90	118	20
27	Patient 69	157	67	27.2	II	30	M	T15	81	98	123	78	97	360	365	367	407	16	16	15	15	58	78	89	96	73	14
28	Patient 70	171	65	22.2	I	41	F	T15	72	97	123	81	95	344	352	357	355	13	12	12	12	65	76	83	98	77	15
29	Patient 71	156	60	24.7	I	43	M	T15	78	99	119	77	92	375	366	367	370	17	17	16	16	58	73	83	94	95	17
30	Patient 72	156	72	29.6	II	33	F	T15	86	99	125	77	87	326	334	330	335	20	20	19	19	52	73	86	90	107	18
31	Patient 73	157	68	27.6	I	57	F	T15	81	97	112	76	86	418	330	332	337	328	22	21	21	20	78	89	92	88	20
32	Patient 74	161	54	20.8	II	25	F	T15	74	99	113	71	87	307	314	324	322	18	18	16	16	57	73	82	95	101	19
33	Patient 75	157	60	24.3	I	51	F	T15	85	97	124	70	97	344	338	335	340	21	19	19	18	59	79	88	90	84	14
34	Patient 76	169	63	22.1	I	34	M	T15	83	98	110	72	86	404	416	423	408	18	18	17	17	52	74	83	94	107	18
35	Patient 77	173	64	21.4	II	25	M	T15	81	97	127	71	92	376	378	358	365	13	12	12	12	59	78	84	90	48	12
36	Patient 78	159	60	23.7	I	56	M	T15	83	97	110	74	97	380	376	370	378	23	21	21	20	53	75	80	90	84	15
37	Patient 79	167	82	29.4	II	46	M	T15	70	99	118	86	89	435	420	433	443	20	20	19	19	52	78	88	93	69	16
38	Patient 80	156	65	26.7	II	34	F	T15	75	97	119	89	93	309	313	324	334	16	16	15	15	56	74	83	92	104	17
39	Patient 81	160	57	22.3	II	32	F	T15	78	98	112	82	89	319	325	330	332	16	15	15	14	57	70	86	91	94	18
40	Patient 82	162	54	20.6	I	48	M	T15	78	99	127	74	97	407	387	394	416	22	20	20	19	55	70	84	95	82	16
41	Patient 83	173	71	23.7	I	37	F	T15	78	99	112	79	92	316	322	344	345	18	18	17	17	53	76	85	90	80	14
42	Patient 84	166	79	28.7	II	31	M	T15	76	99	128	84	88	348	356	363	365	13	12	12	12	57	73	81	90	118	17
43	Patient 43	170	82	28.4	I	42	M	D10	80	99	129	85	86	421	425	432	410	18	17	17	16	58	76	88	92	56	10
44	Patient 44	160	73	28.5	II	29	F	D10	75	98	128	85	88	287	290	320	312	14	13	13	12	53	72	87	96	81	13
45	Patient 45	156	58	23.8	I	50	F	D10	72	97	111	87	90	365	357	361	364	20	20	19	19	54	75	88	92	80	14
46	Patient 46	178	75	23.7	I	49	M	D10	73	99	121	76	87	404	422	420	415	17	17	16	16	58	76	83	90	57	11
47	Patient 47	156	54	22.2	II	57	F	D10	77	99	113	85	88	362	354	358	366	20	18	18	17	57	70	81	97	45	12
48	Patient 48	167	80	28.7	I	31	F	D10	85	99	121	82	90	287	321	324	328	14	13	13	12	58	75	84	94	67	12
49	Patient 49	169	55	19.3	II	41	F	D10	79	98	117	80	93	324	332	343	344	17	17	16	16	55	74	87	92	64	13
50	Patient 50	170	56	19.4	I	49	M	D10	72	98	122	89	85	384	388	390	378	19	19	18	18	50	79	82	93	74	14
51	Patient 51	157	55	22.3	I	58	F	D10	72	97	115	82	88	322	335	338	340	20	19	19	18	53	70	83	94	70	12
52	Patient 52	178	86	27.1	I	33	F	D10	86	99	121	79	92	343	347	351	354	18	18	17	17	55	77	85	90	56	11
53	Patient 53	174	78	25.8	I	45	F	D10	78	97	129	72	91	336	338	354	348	20	19	19	19	52	75	84	97	71	13
54	Patient 54	162	51	19.4	I	33	F	D10	72	97	128	79	86	342	347	356	355	16	16	15	15	55	70	80	95	68	10
55	Patient 55	176	72	23.2	I	55	F	D10	75	98	114	88	87	336	376	355	357	20	19	19	19	53	79	82	90	79	12
56	Patient 56	155	62	25.8	I	45	M	D10	70	97	122	72	92	345	356	357	360	14	13	13	13	57	72	83	96	71	13
57	Patient 57	159	54	21.4	I	58	F	D10	70	98	124	89	87	346	348	352	351	22	20	20	19	56	70	82	91	65	10
58	Patient 58	165	74	27.2	II	59	F	D10	85	99	113	85	98	313	402	387	384	21	20	20	20	53	76	85	93	71	12
59	Patient 59	178	74	23.3	II	33	M	D10	87	99	124	86	89	353	357	365	368	13	12	12	12	51	73	83	96	78	11
60	Patient 60	155	68	28.3	II	25	F	D10	88	99	112	73	76	245	247	312	318	12	12	11	11	55	72	85	98	56	10
61	Patient 61	168	57	20.2	II	48	F	D10	81	99	117	70	89	366	352	357	367	17	17	16	16	54	74	82	90	67	12
62	Patient 62	154	65	27.4	I	49	M	D10	76	98	111	72	93	434	430	426	428	20	19	19	18	51	76	84	94	48	10
63	Patient 63	155	66	27.5	II	25	M	D10	82	99	113	79	88	340	355	357	347	12	12	10	10	54	75	82	90	81	12
64	Patient 22	170	68	23.5	I	31	F	D15	76	99	113	87	93	339	345	350	353	15	15	14	14	63	74	88	95	57	12
65	Patient 23	158	68	27.23	I	45	F	D15	81	97	123	83	96	358	367	368	370	20	18	18	17	59	78	86	94	76	10
66	Patient 24	154	70	29.5	I	59	M	D15	71	97	123	84	90	356	363	365	369	22	21	20	20	57	76	81	92	67	11
67	Patient 25	161	62	23.9	I	55	F	D15	82	97	125	87	88	327	323	334	338	18	17	17	17	52	72	88	93	70	9
68	Patient 26	166	80	29.1	I	57	M	D15	77	97	116	86	88	354	356	367	368	23	22	21	21	57	77	80	96	45	10
69	Patient 27	162	76	29	II	34	F	D15	73	98	127	88	95	324	328	325	330	16	15	15	14	59	74	83	92	56	8
70	Patient 28	164	64	23.8	II	44	M	D15	73	98	126	89	95	410	420	416	424	18	17	16	16	51	75	85	96	84	10
71	Patient 29	174	80	26.4	II	32	M	D15	84	98	114	88	91	342	347	348	352	15	14	14	13	51	70	87	90	89	11
72	Patient 30	178	62	19.6	I	51	F	D15	75	98	113	73	88	351	358	345	362	21	20	20	19	56	72	85	94	67	12
73	Patient 31	163	58	21.8	II	39	F	D15	81	99	113	74	98	326	328	336	331	14	14	13	13	57	71	83	96	61	12
74	Patient 32	157	53	21.5	II	32	M	D15	82	99	112	75	99	422	427	431	438	14	13	13	12	58	72	81	93	95	13
75	Patient 33	161	53	20.4	II	39	F	D15	89	99	116	87	96	334	338	342	347	16	15	15	14	52	77	89	97	77	11
76	Patient 34	154	50	21.1	I	51	M	D15	75	98	123	79	98	421	426	423	430	21	21	20	19	57	77	87	90	62	9
77	Patient 35	170	54	18.7	I	26	F	D15	83	98	126	81	88	315	319	325	321	13	13	12	12	56	73	82	96	61	8
78	Patient 36	156	66	27.1	I	37	M	D15	83	99	122	89	86	430	438	442	445	17	17	16	16	53	71	85	94	71	10
79	Patient 37	166	79	28.7	II	25	M	D15	80	99	115	70	99	389	377	380	382	15	14	14	13	59	78	84	96	68	11
80	Patient 38	165	65	23.8	I	37	M	D15	87	99	121	70	90	366	357	365	467	14	14	12	12	52	71	86	95	82	12
81	Patient 39	154	58	24.5	I	36	F	D15	78	97	121	87	99	322	326	337	346	18	16	16	15	52	71	89	91	63	10
82	Patient 40	155	58	24.1	II	33	F	D15	89	97	123	70	97	407	383	415	423	15	13	12	12	56	72	83	98	72	11
83	Patient 41	162	55	21	II	44	F	D15	88	98	110	71	94	303	412	396	417	17	16	16	14	56	77	80	92	89	10
84	Patient 42	155	68	28.3	II	50	M	D15	88	97	124	86	94	456	433	431	445	22	21	20	20	57	74	82	93	87	13

ANNEXURE C MASTER CHART