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Founder
Society of Cardio-Vascular-Thoracic Anaesthesia And Intensive Care

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Journal of The Cardiovascular Thoracic Anaesthesia and Intensive Care Society

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Journal of The Cardiovascular Thoracic Anaesthesia and Intensive Care Society

EDITORIAL BOARD

The board ensure the determination and implementation of the publication policy of the journal. It supposed toformed from editor in chief, assistant editors and academicians who will contribute to the journal policy and the academic accumulation of the journal, and how journal should be noted up-to-date. If its possible, people from different institutions should take part.

ABOUT

The Journal of Cardio-Vascular-Thoracic Anaesthesia and Intensive Care Society (GKDAYB Journal) is an official scientific journal of Cardio-Vascular-Thoracic Anaesthesia and Intensive Care Society journal (GKDA-YBD).

The journal publishes clinical and experimental studies, case reports, editorial letters, review articles and reports of scientific meetings related to fields of Thoracic, Cardiovascular Anesthesia and Intensive Care the both in English, Review articles written upon request of the editor are not accepted.

The journal is published every three months namely in March, June, September and December. One volume is completed after publication of 4 issues (one year). GKDAYB is an open access, free and peer-reviewed journal and all published content is freely available at www.gkdaybd.org Printed copies are distributed to members of the Cardio-Vascular-Thoracic Anaesthesia and Intensive Care Society free of charge.

GKDAYB Journal is included in Excerpta Medica / EMBASE, EBSCO Database, Sudoc, OpenAlex, Turkish Medline National Health Sciences Periodicals Database, Turkish Citation Index and ULAKBIM National Database (from 2016), GALE Cengage (from 2023), Scilit (from 2023), Open Ukranian Citation Index (from 2023) and Asian Science Citation Index – ASCI (from 2024).

Scopus coverage (2003-2017). Discontinued.

AIMS & SCOPE

The aim of the Journal of Thoracic-Cardiovascular Anesthesia and Intensive Care Society is to disseminate significant and cutting-edge professional information related to the fields of thoracic, cardiac, and vascular anesthesia and intensive care. The journal serves as a platform for sharing clinical and experimental studies reflecting new advancements and research in these specialized medical areas.

Our objective is not only to publish original research and findings but also to offer a comprehensive overview of contemporary topics and issues facing today's medical practitioners within these disciplines. The Journal eagerly welcomes the submission of original research, detailed and practical reviews, and clinical observations from experienced authors in the field.

Submissions can encompass a wide range of topics including, but not limited to, surgical techniques, pharmacological advancements, perioperative care, pain management, and patient safety and recovery protocols related to thoracic, cardiac, and vascular surgery anesthesia and intensive care. Case reports offering insights or novel perspectives on clinical practices and challenges are also encouraged.

By fostering collaboration and discussion among medical professionals, researchers, and practitioners, the Journal of Thoracic-Cardiovascular Anesthesia and Intensive Care Society aims to contribute to the ongoing development and enhancement of patient care and treatment outcomes in thoracic, cardiac, and vascular anesthesia and intensive care.

Journal of The Cardiovascular Thoracic Anaesthesia and Intensive Care Society

PUBLICATION POLICIES

The editorial and publication processes of the journal are shaped in accordance with the guidelines of the International Council of Medical Journal Editors (ICMJE), the World Association of Medical Editors (WAME), the Council of Science Editors (CSE), the Committee on Publication Ethics (COPE), the European Association of Science Editors (EASE), National Information Standards Organization (NISO) and Asian Science Citation Index - ASCI. The journal complies with the Principles of Transparency and Best Practice in Scholarly Publishing (doaj.org/bestpractice).

Originality, high scientific quality, and citation potential are the most important criteria for a manuscript to be accepted for publication. Manuscripts submitted for evaluation should not have been previously presented or published in an electronic or printed medium. The journal should be informed of manuscripts that have been submitted to another journal for evaluation and rejected for publication. The submission of previous reviewer reports will expedite the evaluation process. Manuscripts that have been presented in a meeting should be submitted with detailed information of the event, including the name of the organization, the date, and the location.

Journal of Thoracic-Cardiovascular Anesthesia and Intensive Care Society does not accept multiple submissions or duplicate submissions of articles published in a different language. Nevertheless, the articles will not be processed that are sending again by different new ID numbers which has been already rejected or that are still under processing (revised etc.).

REVİEW PROCESS

Manuscripts submitted to the Journal of Thoracic-Cardiovascular Anesthesia and Intensive Care Society will undergo a double-blind peer-review process. Each submission will be reviewed by at least two external, independent peer reviewers who are experts in their field in order to ensure an unbiased evaluation process.

The editorial board will invite an external and independent editor to manage the evaluation process of manuscripts submitted by editors or by the editorial board members of the journal. The editor-in-chief is the final authority in the decision-making process for all submissions.

Reviews are typically completed within one month of submission to the journal. Authors will be sent constructive reviewer comments intended to be useful. In general, the instructions, objections, and requests made by the reviewers should be followed. The revised manuscript should clearly and precisely indicate every step taken in accordance with the reviewers' notes. A list of responses and the corrections made to each comment should be provided.

OPEN ACCESS POLICY

The Journal of Cardiovascular-Thoracic Anaesthesia and Intensive Care Society supports the Budapest Open Access Initiative statement of principles that promotes free access to research literature. The declaration defines open access to academic literature as free availability on the internet, permitting users to read, record, copy, print, search, or link to the full text, examine them for indexing, use them as data for software or other lawful purposes without financial, legal, or technical barriers. Information sharing represents a public good, and is essential to the advancement of science. Therefore, articles published in this journal are available for use by researchers and other readers without permission from the author or the publisher provided that the author and the original source are cited. The articles in Journal of Cardiovascular-Thoracic Anaesthesia and Intensive Care Society are accessible through search engines, websites, blogs, and other digital platforms. Additional details on the Budapest Open Access Initiative and their guidelines are available at https://www.budapestopenaccessinitiative.org/

Open Access Statement

The journal is an open access journal and all content is freely available without charge to the user or his/her institution. Except for commercial purposes, users are allowed to read, download, copy, print, search, or link to the full texts of the articles in this journal without asking prior permission from the publisher or the author. This is in accordance with the BOAI definition of open access. The open access articles in the journal are licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) license.

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Publication Charges

The Journal of Thoracic-Cardiovascular Anesthesia and Intensive Care Society assesses no submission fees, publication fees, or page charges.

ETHICAL POLICY

It is targeted that all parties participating in the creation of a scientific study (author, editor, reviewer, publisher and reader) contribute to the proper progress of science. Compliance with scientific ethical principles is important in the scientific studies prepared in accordance with this target. Kare Media adopted the ethical principles based on the directive prepared by the Committee on Publication Ethics (COPE) and recommended its adoption by all individuals contributing in the creation of a scientific work. Some items of this directive are mentioned below.

Ethical Responsibilities of the Authors

In accordance with the journal's policy, an approval of research protocols by an ethics committee in accordance with international agreements "WMA Declaration of Helsinki - Ethical Principles for Medical Research Involving Human Subjects (last updated: October 2013, Fortaleza, Brazil)", "Guide for the care and use of laboratory animals (8^{th} edition, 2011)" and/or "International Guiding Principles for Biomedical Research Involving Animals (2012)" is required for all research studies. If the submitted manuscript does not include ethics committee approval, it will be reviewed according to COPE's guideline (Guidance for Editors: Research, Audit and Service Evaluations). If the study should have ethical approval, authors will be asked to provide ethical approval in order to proceed the review process. If they cannot provide ethical approval, their manuscript will be rejected and also their institutions and when needed, the related bodies in their country will be informed that such studies must have ethics committee approval. If they provide approval, review of the manuscript will continue.

If the study does not need ethics committee approval after the editorial board's review, the authors will be asked to provide an ethics committee approval or a document given by a related independent committee that indicates the study does not need ethics committee approval according to the research integrity rules in their country. If the authors provide either an approval or a document showing that ethics approval is not needed, the review process can be continued. If the authors cannot provide either documents, the manuscript may be rejected.

For articles concerning experimental research on humans, a statement should be included that shows informed consent of patients and volunteers was obtained following a detailed explanation of the procedures that they may undergo. The journal may request a copy of the Ethics Committee Approval received from the relevant authority. Informed consent must also be obtained for case reports and clinical images.

Studies using human or animal subjects should be approved by the appropriate institutional and local Ministry of Health ethics committees. Ethics approval of research protocols in accordance with international agreements is required for experimental, clinical, and drug studies, as well as for some case reports. Ethics committee reports or an equivalent official document may be requested from the authors. For manuscripts involving experimental research on humans, a statement should be included that shows that written, informed consent of patients and volunteers was obtained. For studies carried out on animals, the measures taken to prevent pain and suffering of the animals should be stated clearly. A statement regarding patient consent, and the name of the ethics committee, the ethics committee approval date, and number should be stated in the Materials and Methods section of the manuscript. It is the authors' responsibility to carefully protect patients' anonymity.

Research Ethics for Vulnerable Populations

At the Journal of Thoracic-Cardiovascular Anesthesia and Intensive Care Society, we are committed to upholding the highest ethical standards in all research involving human participants, especially vulnerable populations such as children. In line with our dedication to responsible and respectful research practices, we have established the following guidelines to ensure the protection and ethical treatment of these groups:

Consent Requirements for Children

Parental/Guardian Consent: For all research involving children under the age of 18, written informed consent must be obtained from a parent or legal guardian. This consent must be informed, voluntary, and documented.

Assent from Children: In addition to parental consent, researchers are required to obtain assent from children who are capable of forming an opinion and making a decision regarding their participation in the study. This process must be age-appropriate and must respect the child's level of understanding and autonomy.

Privacy and Confidentiality: Extra precautions will be taken to protect the privacy and confidentiality of child participants. This includes using pseudonyms, removing identifiable details from published data, and securely storing data.

Ethical Review: All studies involving children must undergo a rigorous ethical review process to ensure that the research is justified, and the potential benefits outweigh any risks. The ethical review will also ensure that the study adheres to the principles of beneficence, non-maleficence, and justice.

Oversight and Monitoring

To ensure adherence to these ethical guidelines, the Journal of Cardiovascular Thoracic Anesthesia and Intensive Care Society requires that all studies involving vulnerable populations be reviewed and monitored by an Institutional Review Board (IRB) or an equivalent ethical oversight committee. This committee will oversee the study from its inception to its completion, ensuring continuous protection of the participants' rights and well-being.

For more details on our research ethics policies and procedures, or to report any concerns regarding the ethical conduct of a study published in our journal, please contact our ethics committee at kare@karepb.com.

Ethical Duties and Responsibilities of the Editors

Acting in a balanced, objective and fair manner while performing their duties without any discrimination based on gender, religious or political beliefs, ethnic or geographical origin of the authors.

To evaluate the work submitted to the journal according to its content without showing any privilege to any author.

To take necessary measures to prevent potential conflicts of interest and to evaluate existing statements, if any.

To deal with sponsored works or special studies in the same way as other studies,

In case of complaints related to violation of ethics, to enforce necessary procedures by adhering to the policies and procedures of the journal. To give the authors an opportunity to respond to the complaint, and without refraining from imposing the necessary sanctions, regardless of the identity of the owner of the work To reject the study if it does not meet the purpose and scope of the journal.

Ethical Responsibilities of the Reviewers

In order to contribute to the editor's decision-making process, the manuscript should be scrutinized in a timely fashion and reviews should only accept the critical evaluation of the study of his/her expertise.

The assessment should be done in an objective manner only in relation to the content of the study. The study should be evaluated without considering religious, political and economic interests.

To make suggestions to help improve the quality of the article to be published and to critically review the study. To communicate his/her comments to the author in a constructive and gentle language.

To protect the confidentiality of the information provided by the editor and the author, to destroy the work after the evaluation process in accordance with the principle of confidentiality, to report to the editor if there is anything contrary to the blind review process and not to evaluate this study.

To be cognizant of potential conflicts of interest (financial, institutional, collaborative, or other relationships between the author and the author), and, if necessary, to alert the editor to withdraw his or her assistance for this article.

Ethical Responsibilities of the Publisher

Among the parties involved in a creation of a scientific study, the publisher should act within all these ethical principles.

In addition to these, the publisher is obliged to use its communication power without any individual interest and to direct the target audience correctly.

It protects the ownership and copyright of each work published in its journals/books and undertakes the task of archiving every published work.

People should not hesitate to get contact with the publisher when they encounter an unethical situation.

Some of the actions considered to be against scientific research and publication ethics

Plagiarism: To adopt the original ideas, methods, data or works of others partially or wholly without referencing them in compliance with scientific rules,

Fraud: to use data that is not actually present or falsified in scientific research

Distortion: Distorting the research records or data obtained, demonstrating unused devices or materials as if they were used in the research, and distorting or shaping the results of research in the interests of the people and organizations that sponsored the study;

Republication: To present duplicates as separate publications in academic appointments and elevations

Slicing: To present the results of a research as separate publications in academic appointments and upgrades by disseminating and publishing the results of a research in a way that disrupts the integrity of the research and submit them as separate publications more than once;

Unfair authorship: to include people who are not active contributors or not to include those who are contributing to the study, to change the

ranking of the authors inappropriately without any justification and, to remove the names of those who offered their active contributions in t the previous editions, to include their names among the writers by using their influence even though they did not actively contributed to the work.

Not specifying the people, institutions or organizations that support the publications realized as a result of the researches carried out with their support, and contributions,

To use the thesis or studies which have not been submitted yet or have not been accepted as a source without the permission of the owner,

Failure to comply with ethical rules in human and animal researches, not to respect patient rights in its publications, to harm animal health and ecological balance, to refrain from obtaining necessary permissions,

To misuse resources, places, facilities and devices provided for scientific research,

To make false or misleading statements regarding scientific research and publications in academic appointments and elevations.

Artificial Intelligence (AI)-Assisted Technology

At submission, the journal should require authors to disclose whether they used artificial intelligence (AI)-assisted technologies (such as Large Language Models [LLMs], chatbots, or image creators) in the production of submitted work. Authors who use such technology should describe, in both the cover letter and the submitted work, how they used it.

Chatbots (such as ChatGPT) should not be listed as authors because they cannot be responsible for the accuracy, integrity, and originality of the work, and these responsibilities are required for authorship. Therefore, humans are responsible for any submitted material that included the use of AI-assisted technologies. Authors should carefully review and edit the result because AI can generate authoritative-sounding output that can be incorrect, incomplete, or biased. Authors should not list AI and Alassisted technologies as an author or co-author, nor cite AI as an author. Authors should be able to assert that there is no plagiarism in their paper, including in text and images produced by the AI.

Humans must ensure there is appropriate attribution of all quoted material, including full citations.

PLAGIARISM POLICY

Plagiarism (cheating) is a violation of ethics, regardless of whether it is intentional or not. It is a crime and an unacceptable code of conduct as it is unethical to submit, and publish manuscripts imitating other sources, without citing references,. For this reason, due to publication policies Kare Publishing, for all studies to be published in all of its periodicals, necessitates use of a plagiarism checker.

All studies submitted to our periodicals and passed the evaluation of the reviewers blinded to the studies, are evaluated by us using Turnitin or iThenticate software programs.

In our study, our criterion is not a percentage of matching. An auditng is carried out by a specialized team excluding percentages of matching but considering the parameters, such as identification of matching paragraphs, whether or not citations and references are properly written in accordance with the writing rules of the journal, the places of the matching sentences/ paragraphs in the article, and the sources with which they are matched. The prepared plagiarism report is sent to the relevant editor of the study. In consideration of the report, the editorial board may request from the author correction of the errors in the manuscript and sent it again or accept or reject it. The acceptance of the study is on the initiative of the editor.

The Editorial Board may act in accordance with the COPE rules against allegations, and suspicions related to plagiarism, citation manipulation and fraudulent misrepresentation of the works submitted to the journal.

COPYRIGHT TRANSFER

CONFLICT ON INTEREST

Conditions which provide financial or personal benefit bring about a conflict of interest. The reliability of the scientific process and the published articles is directly related to the objective consideration of conflicts of interest during the planning, implementation, writing, evaluation, editing and publication of scientific studies.

Financial relations are the most easily identified conflicts of interest and it is inevitable that they will undermine the credibility of the journal, the authors and the science. These conflicts can be caused by individual relations, academic competition or intellectual approaches. The authors should refrain as much as possible from making agreements with sponsors in the opinion of gaining profit or any other advantage that restrict their ability to access to all data of the study or analyze, interpret, prepare, and publish their articles In order to prevent conflicts of interest, editors should refrain from bringing together those who may have any relationship between them during the evaluation of the studies. The editors, who make the final decision about the articles, should not have any personal, professional or financial ties with any of the issues they are going to decide. Authors should inform the editorial board concerning potential conflicts of interest to ensure that their articles will be evaluated within the framework of ethical principles through an independent assessment process.

Our publication team works devotedly to ensure that the evaluation process is conducted in an impartial manner, taking all these situations into consideration.

You can review the conflict of interest form and the related link to get more detailed information and to declare an conflict of interest.

WRITING GUIDE

Double-Blind Review And Evaluation Process

The decision to publish all articles submitted to the journal belongs to the editor in chief. However, editors shape these decisions in line with the reviewers' recommendations.

The double blind review process is the process of evaluating the work completely anonymously. In this system, only the editor knows each stage. In this system authors do not know who the reviewer is, and the reviewers do not know whose work they are evaluating. Thus, biased evaluation of the work by the reviewers is prevented. In addition, since the author does not know the reviewers, he/she can not possibly get contact with the reviewer, and influence him/her through 'special routes'. From this point of view, the double- blind review process is thought to provide objective evaluation and increase the equal opportunity.

For these reasons, all studies submitted to GKDAYB Journal are subject to double-blind review. At least two reviewers expert in their fields, will evaluate each submitted work. Every effort is spent by the editors for quick evaluation of the articles. The editor is the final decision-making authority in the evaluation processes of all articles.

First Evaluation

The relevant editor or journal secretary examines the work regarding the purpose and scope of the journal, its conformity to the rules of writing, and its English and Turkish language proficiency. As a result of this assessment, the manuscripts which do not comply with the publication rules and the publication policy of the journal are returned to the responsible author.

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Preliminary Evaluation Process

In the pre-evaluation process; the study that left a positive impression on the editor is directed to the field editors. Field editors examine summary, introduction, material / method, discussion and conclusion sections of the manuscript as well as its scientific, and formal conformity to the writing rules of the journal. As a result of this review, manuscripts which are found suitable are taken into the process of reviewers' evaluation.

Reviewers' Evaluation Process

According to the content of the manuscript, at least two expert reviewers who had current studies in the relevant field are determined. Suggestions of the field editor regarding the selection of reviewers are appraised by the chief editor, and reviewers are assigned for the assessments of the manuscripts. The reviewers evaluate the study and prepare a report.

Reports of the Reviewers

The reviewers evaluate the objective, material / method, results and discussion sections of the study, and its conformity to scientific principles. The work may be accepted directly, its revision may be requested or rejected. If correction in the manuscript is required, the suggestions coming from the reviewers are communicated to the authors and the authors are asked to revise their work.The results of correction coming from the authors are reexamined by the reviewers and their decisions are reported to the editor. In case of disagreement between the assigned reviewers, the manuscript is sent to a designated third reviewer.

Statistical Analysis

Manuscripts deemed appropriate for publication by the reviewers are sent to the statistical editor. Articles that are approved by the statistical editor are accepted for publication.

Publication Printing Process

Clinical studies or experimental research articles accepted for publication are usually included in the first issue to be published. Case presentations can wait 6-9 months according to the intensity.

CHECKLIST FOR AUTHORS

- Make sure that name of the author (s), information about the institution thank you letter about ethics committee etc. are not included in the study. This issue is important according to the 'double- blind review principle' concerning the evaluation process of your work so that it can be dealt with impartially.
- You should not forget that your study will be subject to plagiarism audit if it is deemed to be adequate and appropriate in terms of the subject and you should avoid making quotations that will be covered by plagiarism when preparing the work
- If your article is derived from a study, a thesis, abstract of a case report, poster, etc. be sure to cite it in a footnote and specify its date.
- Please fill out the form and upload it to the system, as you cannot proceed to the next step without uploading the copyright transfer form to your system. It is sufficient to communicate it in the online system, you do not need to communicate this information in printed form.
- If your work has been returned to you for revision, and you have made a change in the title and summary of your work, please update it during preparation of the article
- There cannot be any changes in your article once its published. Therefore we advise you strongly to examine your article carefully when last check e-mail sent to you and if there is any neccesary revisions you have to make please send them to us before the journal is published.

MANUSCRIPT PREPARATION

Manuscripts should preferably be written using the Microsoft Word program. The manuscripts should be typed in 12 point Times New Roman characters. Manuscripts should be written double- spaced on one side of the A4 (21x29.7 cm) white paper and throughout the entire manuscript (including headings, abstracts in Turkish and English, main text, references, tables and subtitles) and justified leaving 3-cm margin from both sides. They should be written in accordance with word processor's page layout settings.

Journal Agent Online Article Collection and Evaluation System is being uploaded online, Article and Abstract Information, Information about Institute, Author Information, Responsible Author Information, Article Title, Article Turkish and English Summaries of the Article, Turkish and English Key Words, NoteEdit, File Upload (Full Text - References – Table(s) - Pictures - Graphics – Notes to the Editor) are recorded separately step by step in the system.

The authors are kindly requested to submit their ORCID numbers obtained the website from www.orcid.org and indicate them in the relevant area at this stage. Abstract and full text should not containinformation about the individuals and institutions participating in the study.

The files must be loaded in the following order.

- The electronic article file (Full Text) should be named with the title of the article in capital letters. They should only include "Title (Turkish-English) - Short Title (Turkish-English)", "**Introduction**", "**Materials and Methods**", "**Results**", "**Discussion**", "**Acknowledgement** (if) - **Conflict of Interest**". Each of the sections should be presented on separate pages. The titles of the text sections should appear at the left of the page with capital letters. All pages should be numbered sequentially from the bottom right corner.
- The file "**References**" should be recorded separately
- **Tables** should be prepared and written double-spaced on a separate sheet, and the number and title of each table must be written on top of the table. If abbreviations are given in the table, these abbreviations should be written in alphabetical order as subheadigs. . When previously printed or electronically published tables are used, written permission must be obtained from both the author and the publisher, and it must be sent by fax or mail to the editor of the journal.
- F**igures, graphics, illustrations, photos** and **legends** should be written double-spaced on a separate sheet. If the abbreviations are given in figures, graphics and illustrations, the expansions of these abbreviations should be written under the subtitle and in alphabetical order. When previously printed or electronically published figures, graphics and images are used, written permission must be obtained from both the author and the publisher, and this must be sent by fax or mail to the editor of the journal.
- **Copyright transfer form**

Authors must declare that all or part of the material in the manuscript has not been published and is not currently being evaluated elsewhere for publication. Each author must declare that he/she participated in the investigation enough to share the responsibility of its content.

This participation may involve the following issues:

- Creation of concepts and designs of experiments,
- Collection, analysis or expression of the data;
- The preparation of the draft of the mauscript or the review of the scientific content
- Approval of the final format of the manuscript ready for publication
- Ethics committee approval letter
- Original articles and review articles should not exceed 10, case reports 4, letters to editors 1 page (excluding references, tables and graphics).

In the manuscript, the sections and contents of the manuscript should be presented as follows.

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Anaesthesia and Intensive Care Society

Title: A short title should be used whenever possible. The title of the research, and review articles should not exceed 95 characters (each letter, space, and punctuation marks are considered as one character), in case of case reports, letters and presentations of surgical techniques it should not contain more than 80 characters. Abbreviations should not be used in the title. The title should be written in Turkish and English. A short title should be added as a subtitle which should not exceed 40 characters.

Funds and organizations supporting the research should be mentioned here, If the study is planned to be presented in any congress or if it has been presented before, the name, place, and date (day-month-year) of the congress should be written.

The abstracts should not exceed 250 words in the research papers Headings should not be used in summaries (the English translation of the title should be written on the title page). Abstract in Turkish should consist of four subheadings as While abstract in English should include subheadings of Aim, Material and Method, Results, and Conclusion) In case reports and review articles donot contain these sections, and abstracts should not exceed 100 words. English title, and abstract should be. English title and abstract should be word by word translation of the Turksih abstract. Letters to editor, and Editorials do not require abstracts.

Use of abbreviations should be avoided as much as possible in summaries. If absolutely required, abbreviation should be used after its definition is provided in parenthesis at the first mention of the term. Reference should not be used in the abstract.

Key words: In accordance with "Index Medicus Medical Subject Headings (MeSH)" there should be no more than five key words under the summary written both in Turkish and English. Available terms can be used if there is no appropriate term for the "Index Medicus" medical subject headings for the newly entered terms.

Introduction: The general conditions of the study settings, the structure and significance of the problem, the specific objective of the study or research tested in the study or observation should be clearly indicated. The primary and secondary objectives of the work should be clearly stated and the predefined subgroup analyzes should be transferred. Only references related to the topic should be used and the data or results of the presented work should not be included in these references.

Material and Method: The informed consent of the patient and the approval of the ethics committee should be acknowledged. A statement must be added that the informed consent was obtained from each participant in clinical trials. It should be noted in experimental studies that all animals were subjected to a humane treatment in accordance with the Guide for the Care and Use of Laboratory Animals (www.nap.edu/catalog/5140.html).

Definition of optimal working conditions, exclusion criteria and referenced population; the participants in the observational or experimental study must be clearly indicated. Since the relevance of the variables such as age and gender for the purpose of the research is not always obvious, the authors should explain the purpose of using these variables in a research article. The main principles that determine how and why the study is performed using such a method should be clear. References should be shown for established methods, brief descriptions should be given for new methods.

The methods, tools (manufacturer's name and address are written in parentheses) and the operations performed should be described in detail to the extent of interpretation of the results. The initials of the drug names should be in lower case, the pharmacological names of the drugs should be used and at their first mention in the text they should be written in brackets in the following order"Generic name, trade name, and Manufacturing firm ". Example: "midazolam (Dormicum, Roche)". The terms should be written in their explicit forms at their first mention in the text, and then their abbreviations (if any) should be enclosed in parentheses. Frequently used abbreviations should be used as accustomed (iv, im, po and sc). Units must be used in compliance with the International system of units (SIU (Le Système international d'unités),Examples: mg / kg, mL / kg, mL / kg / min, mL / kg.

Statistical methods should be provided in sufficient detail so that the readers can reach the original data and evaluate the reported results. Findings should be measured as much as possible and the appropriate margin of error and uncertainty (such as confidence intervals) should be indicated. It is important to avoid relying only on the p-values of statistical hypothesis measures that are insufficient to convey important information about the dimensions of the effects. P values must be given explicitly. Statistical terms, abbreviations and symbols should be defined. In the last paragraph of this section, statistical analyses used, and the values given by the (±) sign after the arithmetic mean or proportion should be indicated.

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RESEARCH ARTICLE

Effect of Preoperative Oral Magnesium on Postoperative Arrhythmias After Coronary Artery Bypass Grafting: A Retrospective Study

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ABSTRACT

Objectives: Magnesium plays an essential role in numerous cellular functions, including energy metabolism and enzyme regulation. We evaluated the impact of preoperative oral magnesium supplementation on the development of intraoperative ventricular fibrillation (VF) after aortic cross-clamp removal, postoperative atrial fibrillation (POAF), and renal function parameters in patients undergoing coronary artery bypass grafting (CABG).

Methods: Ninety patients who underwent isolated CABG were included and divided into magnesium and non-magnesium groups. Demographic, perioperative, and postoperative variables were compared. Multivariate logistic regression analysis was performed to identify independent predictors of POAF.

Results: The incidence rates of POAF and VF after cross-clamp removal did not differ between the groups. In multivariate analysis, preoperative magnesium supplementation was not an independent predictor of POAF (OR: 1.35, 95% CI: 0.42–4.36, p=0.615), whereas age was an independent risk factor (OR: 1.10, 95% CI: 1.02–1.19, p=0.016). Magnesium supplementation had no significant impact on postoperative urea or creatinine levels.

Conclusion: Preoperative oral magnesium administration did not reduce the incidence of POAF or VF after CABG surgery. Further large-scale, prospective, randomized studies are needed to clarify the potential benefits of magnesium supplementation in this patient population.

Keywords: Atrial fibrillation, CABG, magnesium, ventricular fibrillation

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Introduction

Both postoperative arrhythmias and hypomagnesemia are common after CABG. Magnesium (Mg) is an essential mineral that plays a crucial role in numerous physiological functions, including enzyme activation, energy production, and cellular respiration.[1] In addition to its fundamental cellular functions, magnesium has been suggested to have a protective effect against cardiac arrhythmias, particularly atrial fibrillation (AF) and ventricular fibrillation (VF).[2] Despite its potential benefits, the impact of preoperative magnesium supplementation on the incidence of AF and VF in patients undergoing CABG remains unclear. Magnesium plays an important role in renal handling, and its homeostasis is closely linked to kidney function. Both hypomagnesemia and magnesium supplementation can influence tubular reabsorption and urinary excretion, particularly in patients undergoing cardiac surgery. Considering this physiological relationship, serum urea and creatinine levels were evaluated in addition to arrhythmic outcomes to assess the potential renal effects of preoperative oral magnesium supplementation.

This study aimed to evaluate whether preoperative oral magnesium administration can reduce the incidence of postoperative atrial or ventricular fibrillation following cross-clamp removal in patients undergoing CABG surgery

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by comparing outcomes between patients who received magnesium supplementation and those who did not.

Methods

This study was approved by the Ordu University ethics committee (approval number: 218; date: 01.09.2023) and was conducted in accordance with the Declaration of Helsinki. Informed consent forms were obtained from all patients. This single-center, retrospective study was performed at a cardiovascular surgery center between June 2023 and December 2023.

Patients over 18 years of age who were scheduled for elective, on-pump CABG were included in the study. The exclusion criteria were urgent or redo surgery, chronic AF, renal insufficiency, and the presence of a permanent preoperative pacemaker.

Participants were divided into two groups:

Group 1: Patients who received 365 mg of oral magnesium daily for 15 days before surgery.

Group 2: Patients who did not receive magnesium supplementation before surgery.

All patients underwent standard preoperative, intraoperative, and postoperative care according to hospital protocols. The type and number of grafts, cross-clamp time, and cardiopulmonary bypass (CPB) duration were recorded for each patient. Demographic data (age, sex, and comorbidities), operative details (number of grafts, cross-clamp and CPB times, and EuroSCORE), and postoperative outcomes were collected from hospital records.

The setup of the EuroSCORE project, as well as how the data were collected, entered, and checked for quality, has been described previously.[3] EuroSCORE was calculated using www.EuroSCORE.org. The primary outcome was the incidence of POAF or intraoperative VF, while secondary outcomes included time to extubation, urea and creatinine levels, and length of stay in the critical care unit and hospital. POAF was defined as any episode of atrial fibrillation lasting longer than 30 seconds, detected by continuous electrocardiographic monitoring or standard 12-lead electrocardiography during the postoperative period. The postoperative period was defined as the time from arrival in the intensive care unit until hospital discharge. Intraoperative ventricular fibrillation (VF) was defined as ventricular fibrillation occurring immediately after aortic cross-clamp removal during cardiopulmonary bypass. VF episodes were identified by intraoperative electrocardiographic monitoring and managed according to standard defibrillation protocols. Postoperative urea and creatinine measurements were based on values obtained on the second postoperative day.

Laboratory tests, including serum urea and creatinine measurements, were performed preoperatively, on postoperative days 1 and 2, and before discharge.

Statistical Analysis

All statistical analyses were performed using SPSS for Windows version 22.0. Descriptive statistics (number, percentage, mean, and standard deviation) were used to summarize the data. Categorical variables were compared using the chi-square and Fisher's exact tests. Continuous variables were compared using the independent samples t-test. For repeated measures and the evaluation of changes over time, the general linear model (GLM) was used. A p value of <0.05 was considered statistically significant. The normality of continuous variables was assessed using the Shapiro–Wilk test. Normally distributed variables were expressed as mean±standard deviation and compared using the independent samples t-test, while non-normally distributed variables were presented as median (interquartile range) and compared using the Mann–Whitney U test. To determine the independent predictors of POAF, univariate analyses were first performed. Variables with $p<0.10$ in univariate comparisons were entered into a multivariate logistic regression model. Magnesium supplementation (yes/no), age, sex, left ventricular ejection fraction, EuroSCORE, cardiopulmonary bypass time, and preoperative creatinine were included in the regression model based on clinical relevance and data availability.

Results

A total of 90 patients who underwent elective on-pump CABG surgery were included. Fifty patients received 365 mg/day oral magnesium for 15 days before surgery (Group 1), while 40 did not (Group 2). Among comorbid conditions, chronic obstructive pulmonary disease was present in 5 patients (10.0%) in the magnesium group and 3 patients (7.5%) in the non-magnesium group, while hypertension was present in 34 patients (68.0%) and 27 patients (67.5%), respectively.

The incidence of arrhythmia (POAF and/or VF) did not differ significantly between the two groups. POAF occurred in 28.0% (n=14) of Group 1 and 20.0% (n=8) of Group 2 ($\chi^2=0.770$, $p=0.265$). Similarly, intraoperative arrhythmia rates were not significantly different between the groups. Intraoperative VF occurred in 58.0% (n=29) of Group 1 and 45.0% (n=18) of Group 2 ($\chi^2=1.505$, $p=0.155$). (Table 1) VF episodes were managed with defibrillation according to the standard protocol; spontaneous reversal was not recorded in this dataset. There were no reported deaths in either group. Data on myocardial biomarkers (CK-MB and troponin) were not available.

Table 1. Distribution according to magnesium usage status

	Group 1		Group 2		p
	n	%	n	%	
Gender					
Male	38	76.0	35	87.5	X^2=1.918
Female	12	24.0	5	12.5	p=0.132[b]
Postoperative arrhythmia					
No	36	72.0	32	80.0	X^2=0.770
Yes	14	28.0	8	20.0	p=0.265[b]
Intraoperative arrhythmia					
No	21	42.0	22	55.0	X^2=1.505
Yes	29	58.0	18	45.0	p=0.155[b]

[a]: Chi-square analysis; [b]: Fisher exact.

The distribution of graft numbers between the groups is presented in Table 2. There was no statistically significant difference between the two groups regarding the number of grafts. In Table 3, the baseline demographic and perioperative characteristics known to be associated with the development of postoperative atrial fibrillation are compared according to magnesium supplementation status. There were no significant differences between the groups in terms of ICU stay, hospital stay, or cross-clamp time. The mean CPB duration was significantly longer in Group 1 (84.02±24.64 minutes) compared with Group 2 (74.10±21.66 minutes) (t=2.001, p=0.048). The mean EuroSCORE was 3.82±1.61 in Group 1 and 4.53±2.15 in Group 2, with no statistically significant difference (t=-1.778, p=0.089).

In the analysis evaluating differences in pre- and postoperative urea levels between individuals who received magnesium supplementation and those who did not, the effect of time was statistically significant (F=22.683, p<0.001, η^2=0.205). This finding indicates that urea levels changed significantly from the preoperative to postoperative period. However, the group effect was not significant (F=1.708, p=0.195, η^2=0.019), indicating that there was no significant difference in overall urea levels between the magnesium and non-magnesium groups. In addition, the group-by-time interaction was not significant (F=2.023, p=0.158, η^2=0.022), indicating that the changes observed over time did not differ according to magnesium use. Although an increase in urea levels was observed in both groups, this increase did not differ significantly between the groups (Table 4).

Similarly, in the analysis of creatinine levels, the effect of time was significant (F=16.117, p<0.001, η^2=0.155), demonstrating that creatinine levels changed significantly from the preoperative to postoperative period across all participants. However, the group effect was not significant (F=2.571, p=0.112, η^2=0.028), indicating that there was no significant difference in overall creatinine levels between the magnesium and non-magnesium groups. Furthermore, the group-by-time interaction was not significant (F=3.124, p=0.081, η^2=0.034), revealing that the pattern of change in creatinine levels over time did not differ based on magnesium supplementation status. Although both groups exhibited an increase in creatinine levels postoperatively, this increase was not significantly different between the groups (Table 5).

In the multivariate logistic regression analysis, preoperative magnesium supplementation was not identified as an independent predictor of POAF (OR: 1.35, 95% CI: 0.42–4.36, p=0.615). Age was found to be an independent predictor of POAF (OR: 1.10 per year, 95% CI: 1.02–1.19, p=0.016). Other variables, including ejection fraction, EuroSCORE, cardiopulmonary bypass time, and preoperative creatinine, were not independently associated with POAF.

Discussion

POAF is a well-documented complication following CABG surgery. Magnesium has been widely studied for its potential protective role against arrhythmias, given its influence on cardiac ion channels and cellular stability.

Table 2. Independent groups T-test

Groups	Group 1 (n=50)		Group 2 (n=40)		t	SD	p
	Avg	SD	Avg	SD			
ICU stay (day)	3.140	2.339	3.380	2.415	-0.467	88	0.642
Hospital stay (day)	8.780	4.37	10.070	5.521	-1.222	88	0.225
Cross clamp time (min)	68.140	22.061	61.200	23.543	1.439	88	0.154
CPB time (min)	84.020	24.640	74.100	21.661	2.001	88	**0.048**
EF (%)	52.520	8.481	51.850	8.851	0.365	88	0.716
EuroSCORE	3.820	1.612	4.530	2.148	-1.778	88	0.089

CPB: Cardiopulmonary bypass; EF: Ejection fraction; ICU: Intensive care unit; min: Minute.

Table 3. Independent groups T-test. Number of grafts

Number of grafts	Group 1 (n=50)	Group 2 (n=40)
CABG ×1	0	1
CABG ×2	7	6
CABG ×3	24	17
CABG ×4	15	15
CABG ×5	4	1

CABG: Coronary artery bypass grefting

Table 4. Urea measurements according to magnesium usage status anova test

Time	Group 1 (mean±SD)	Group 2 (mean±SD)
Preoperative urea(mg/dL)	34.98±14.05	43.11±33.78
Postoperative urea (mg/dL)	45.47±15.35	48.78±22.88
Group	F=1.708, p=0.195, η^2=0.019	
Time	F=22.683, p=0.000, η^2=0.205	
Group*Time	F=2.023, p=0.158, η^2=0.022	

SD: Standard deviation.

Table 5. Creatine measurements according to magnesium usage status anova test

Time	Group 1 (mean±SD)	Group 2 (mean±SD)
Preoperative creatinine (mg/dL)	0.831±0.152	1.239±0.170
Postoperative creatinine (mg/dL)	1.114±0.122	1.349±0.136
Group	F=2.571, p=0.112, η^2=0.028	
Time	F=16.117, p=0.000, η^2=0.155	
Group*Time	F=3.124, p=0.081, η^2=0.034	

Although hypomagnesemia is common after cardiac surgery and has been implicated in arrhythmogenesis, our findings suggest that preoperative oral magnesium supplementation did not significantly reduce the incidence of POAF or intraoperative VF. This is consistent with previous studies indicating that the timing, dosage, and route of magnesium administration are critical variables influencing outcomes. Importantly, VF following cross-clamp removal is a multifactorial phenomenon often related to myocardial protection strategies rather than preoperative electrolyte status alone. Our study also observed increased urea and creatinine levels postoperatively, likely reflecting transient renal impairment due to CPB rather than a direct effect of magnesium. Notably, magnesium levels were not measured in this study, which represents a significant limitation. Without baseline and postoperative serum magnesium values, it remains unclear whether the administered dose effectively altered systemic magnesium levels. Furthermore, the retrospective nature of the study, modest sample size, and lack of biomarker data, such as CK-MB or troponin, restrict the depth of mechanistic insights. Nevertheless, these findings contribute to the growing body of evidence suggesting that routine oral magnesium loading before CABG may not provide substantial antiarrhythmic benefit.

With the rise in functional medicine practices, the number of patients using daily magnesium supplements has increased significantly. Mg is a vital cation in the body, ranking fourth overall and second intracellularly after potassium. It plays a fundamental role as a cofactor in more than 300 enzymatic reactions, including those involved in energy metabolism and nucleic acid synthesis. Mg is involved in various physiological processes, such as hormone receptor binding, calcium channel gating, transmembrane ion flux, muscle contraction, neuronal activity, cardiac excitability, and neurotransmitter release. It is distributed mainly in bone, muscle, and soft tissues, with less than 1% found in serum and red blood cells.[1,2]

There is an inverse relationship between magnesium intake or serum magnesium levels and cardiovascular conditions such as hypertension, coronary artery calcification, stroke, ischemic heart disease, atrial fibrillation, heart failure, and cardiac mortality. One study noted that mild or moderate magnesium deficiency can lead to physiological and metabolic changes that increase cardiovascular risk through mechanisms such as inflammatory stress, oxidative stress, and endothelial dysfunction. Despite previous beliefs that magnesium deficiency was rare, recent studies have shown that inadequate magnesium intake is common, especially in populations that do not consume enough whole grains, pulses, and green vegetables.[4]

Hypomagnesemia is a significant electrolyte imbalance observed in patients after CABG, with an incidence of 8% to 19.5%. It can occur due to various factors, including decreased intake, preoperative diuresis, low magnesium levels in cardioplegia, increased utilization due to diuretics, increased myocardial calcium ATPase activity, ischemia-induced lipolysis, and postoperative free radicals. The optimal method, duration, and dose of magnesium supplementation for preventing AF have also been discussed in several studies.[5]

For example, Khan et al.[6] found that individuals with the lowest serum magnesium levels were approximately 50% more likely to develop AF compared with those with the highest levels. Since hypomagnesemia is common in the general population, this finding has important clinical implications. This suggests that monitoring and managing magnesium levels could help reduce the risk of AF in the general population. Gu et al.[7] conducted a meta-analysis

of seven double-blind, placebo-controlled, randomized clinical trials and found that intravenous magnesium significantly reduced the incidence of POAF, suggesting it as a promising alternative for prevention. However, the benefit of oral supplementation remains controversial. Klinger et al.[8] reported that high-dose intraoperative magnesium administration did not significantly reduce the incidence of new-onset POAF after cardiac surgery. The incidence of POAF was 42.5% in the Mg group compared with 37.9% in the placebo group, with no significant difference in the time to onset of POAF or in logistic regression analysis after adjustment for AF risk. Similarly, Zangrillo et al.[9] found no significant difference in the incidence of POAF between the magnesium and placebo groups.

A systematic review and meta-analysis by Chaudhary et al.,[10] which included 20 randomized controlled trials with 2,430 participants, found no statistically significant reduction in POAF with magnesium supplementation overall. However, when magnesium was administered specifically in the postoperative period, a significant reduction in POAF was observed. No significant benefit was seen with intraoperative or combined intraoperative and postoperative magnesium administration. Another meta-analysis by Miller et al.[11] also highlighted the importance of timing, suggesting that preoperative administration may be most beneficial.

Some studies have demonstrated positive effects of preoperative oral magnesium loading. Tohme et al.[12] found that preoperative oral magnesium loading significantly reduced the incidence of POAF in patients undergoing CABG, as demonstrated in a randomized controlled trial. Beşoğul and colleagues compared preoperative oral magnesium administration for 10 days with intraoperative flush infusion and found that magnesium levels play a crucial role in reducing morbidity associated with heart surgery, particularly in preventing cardiac arrhythmias and VF.[13]

Kohno et al.[14] reported that magnesium administration significantly reduced the incidence of AF from 35% in untreated patients to 16% in those treated with magnesium, although magnesium alone was insufficient for AF prophylaxis in older patients or those with reduced cardiac function. Another study indicated that magnesium administration after cardiac surgery appears to reduce AF without significant adverse events, although there is limited evidence regarding its effectiveness in preventing other arrhythmias. The study found no effect on mortality and no significant increase in adverse events.[15]

Karim et al.[16] found that intravenous magnesium administration significantly reduced the incidence of ventricular arrhythmias after cardiopulmonary bypass in open-heart surgery, supporting its routine use for arrhythmia prevention in this setting.

The discrepancy in findings across studies may be attributed to differences in magnesium dosing regimens, timing (preoperative, intraoperative, or postoperative), routes of administration, and patient populations. While intravenous magnesium appears more effective in acute settings, the bioavailability and efficacy of oral magnesium, especially in the context of short-term preoperative loading, remain uncertain. Additionally, the baseline magnesium status of patients, dietary intake, and concomitant use of diuretics or other medications affecting magnesium homeostasis may influence outcomes. Many studies suggest that the timing of magnesium supplementation is critical. Preoperative oral supplementation alone may not achieve sufficient serum magnesium levels at the time of greatest arrhythmic risk. The dose and form of magnesium used can affect its efficacy. Oral magnesium has variable absorption and bioavailability, and 365 mg daily may not have been sufficient to raise serum magnesium to therapeutic levels, especially during the stress of surgery. If patients did not have hypomagnesemia before surgery, the benefit of supplementation may be limited. Magnesium prophylaxis is often most effective in patients with low baseline magnesium levels. The development of AF and VF is multifactorial. Factors such as age, comorbidities, surgical technique, and concomitant medications can influence arrhythmia risk and may have masked any modest effect of magnesium.

Our study also observed a significant increase in urea and creatinine levels postoperatively in both groups, reflecting the expected renal response to cardiac surgery. However, these changes were not significantly different between the groups, suggesting that preoperative oral magnesium supplementation did not adversely affect renal function in this cohort. This is notable, as some recent evidence has suggested that higher postoperative serum magnesium levels may be associated with an increased risk of acute kidney injury (AKI), underscoring the need for careful monitoring.[17]

It is important to acknowledge certain limitations of our study. The retrospective design and relatively small sample size may limit the generalizability of our findings. Additionally, serum magnesium levels were not routinely measured, precluding the assessment of magnesium status before and after supplementation. The study also did not account for potential confounders, such as dietary intake, concomitant medications, or genetic predisposition to arrhythmias. Another limitation of the present study is

the absence of data regarding left atrial diameter, which is an established predictor of postoperative atrial fibrillation. Due to the retrospective nature of the study, this variable could not be retrieved from patient files and, therefore, was not included in the analysis. Despite these limitations, our findings contribute to the growing body of evidence suggesting that routine preoperative oral magnesium supplementation may not provide significant protection against postoperative arrhythmias in patients undergoing CABG. Given the heterogeneity in existing studies, further large-scale, prospective, randomized controlled trials are warranted to clarify the optimal dose, timing, and route of magnesium administration and to identify patient subgroups that may benefit most from supplementation.

Conclusion

In conclusion, while magnesium remains an essential element in cardiac physiology and its deficiency is a recognized risk factor for arrhythmias, our study did not demonstrate a significant benefit of preoperative oral magnesium supplementation in reducing POAF or VF after CABG surgery. Future research should focus on individualized magnesium management strategies, incorporating baseline magnesium status and perioperative risk factors, to optimize arrhythmia prevention in cardiac surgical patients.

Disclosures

Ethics Committee Approval: The study was approved by the Ordu University Ethics Committee (no: 218, date: 01/09/2023).

Informed Consent: Informed consent forms were obtained from all patients.

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RESEARCH ARTICLE

Analytical Agreement Between ABL90 FLEX and GEM Premier 5000 Blood Gas Analyzers in Arterial Whole Blood Samples

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ABSTRACT

Objectives: Point-of-care blood gas analyzers are essential in acute care settings because of their rapid turnaround time and integrated quality control. However, analytical variability between platforms may influence clinical interpretation. This study aimed to evaluate the analytical agreement between the ABL90 FLEX and GEM Premier 5000 blood gas analyzers in arterial whole blood samples.

Methods: A total of 433 arterial samples were collected at Zonguldak Bulent Ecevit University Hospital; 406 samples met the inclusion criteria and were analyzed consecutively on the ABL90 FLEX and GEM Premier 5000 within 2 minutes. Parameters included blood gases, electrolytes, co-oximetry fractions, metabolic analytes, and calculated values. Statistical analysis was performed using Pearson correlation, Passing–Bablok regression, and Bland–Altman analysis.

Results: pH and pCO_2 showed strong agreement (r=0.880 and 0.957, respectively), with minimal bias (−0.003 and −1.34, respectively) and no significant difference ($p>0.05$). No significant differences were observed for ionized calcium, chloride, methemoglobin, total bilirubin, or lactate ($p>0.05$). Significant differences were detected for pO_2, SO_2, sodium, potassium, glucose, bicarbonate, osmolality, and co-oximetry parameters ($p<0.05$). Bland–Altman analysis showed narrow limits of agreement for acid–base parameters but wider bias for pO_2 (1.63) and SO_2 (1.24). Passing–Bablok regression demonstrated proportional bias for oxygenation indices, sodium, and O_2Hb, with significant deviation from linearity in several parameters, indicating limited interchangeability between analyzers for oxygenation and derived measurements.

Conclusion: The ABL90 FLEX and GEM Premier 5000 provide comparable results for key acid–base and selected metabolic parameters, whereas oxygenation indices, sodium, and some co-oximetry fractions require cautious interpretation and consistent platform use for serial monitoring.

Keywords: ABL90 FLEX, GEM Premier 5000, pCO_2, pH, pO_2

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Introduction

Point-of-care (POC) blood gas analyzers are indispensable tools in acute care medicine, enabling the rapid evaluation of acid–base balance, oxygenation, electrolyte status, and key metabolic parameters. Their clinical relevance is particularly pronounced in emergency departments, intensive care units, operating rooms, and neonatal care settings, where therapeutic interventions frequently rely on immediate and reliable laboratory results. In this context, cartridge-based systems such as the ABL90 FLEX and GEM Premier 5000 have become widely adopted owing to their short turnaround time, reduced preanalytical handling, and integrated internal quality control features. Nevertheless, analytical variability between devices may still occur as a result of differences in sensor technologies, calibration approaches, and underlying measurement principles, potentially influencing clinical interpretation and patient management.

In recent years, several method-comparison studies have addressed the analytical performance of POC blood gas analyzers and have consistently demonstrated that agreement may vary substantially across analytes. Kim et al.,[1] in a comprehensive evaluation of six POC platforms,

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reported that acid–base parameters generally exhibit high comparability, whereas agreement for electrolytes and selected metabolites may be less consistent across systems. Similarly, Larcher et al.[2] showed that cartridge-based blood gas analyzers can achieve acceptable analytical performance in critically ill patients; however, they emphasized that inter-device comparison remains essential for parameters susceptible to systematic bias. Indrasari et al.[3] further reported that lactate and blood gas measurements may differ between POC systems in intensive care populations, supporting the need for local verification before routine parallel use. More recently, Yang et al.[4] validated the clinical performance of an integrated bedside blood gas analyzer and highlighted that, despite overall reliability, analyte-specific differences may persist under acute care conditions.

Importantly, comparative evidence specifically addressing commonly implemented analyzers remains limited. Katar et al.[5] compared GEM Premier 5000 and Radiometer ABL 800 series analyzers in routine clinical practice and demonstrated that agreement is strongly parameter-dependent, underscoring the importance of institution-specific validation before adopting interchangeable workflows. Furthermore, Marija et al.[6] emphasized that even when analytical agreement appears satisfactory, clinically meaningful discrepancies may still arise in critically ill patients due to both methodological and physiological factors. Collectively, these findings reinforce the need for ongoing comparative evaluations to determine whether results generated by different POC blood gas analyzers can be used interchangeably in routine and critical clinical decision-making. Therefore, this study aimed to evaluate the analytical agreement between the ABL90 FLEX and GEM Premier 5000 blood gas analyzers in arterial whole blood samples and to interpret the findings in the context of recent literature.

Methods

This study was designed as a prospective observational method-comparison study conducted at Zonguldak Bulent Ecevit University Hospital between January 2025 and March 2026. Arterial whole blood samples were collected from patients requiring blood gas analysis as part of routine clinical care in the emergency department, intensive care units, and inpatient wards. The inclusion criterion was the requirement for arterial blood gas analysis as part of routine clinical care. The exclusion criteria were as follows: (1) delayed initiation of testing (>2 min after sample collection), (2) sample contamination (e.g., air bubbles, clot formation, or dilution), (3) insufficient sample volume (<0.5 mL), (4) visible hemolysis or clotting in the syringe, (5) improper anticoagulant use or incorrect heparin concentration, and (6) incomplete paired measurements (samples not successfully analyzed on both devices).

A total of 433 samples were collected, of which 406 were eligible and included in the analysis. Approval was granted by the Medical Ethics Committee of Zonguldak Bulent Ecevit University (Ethics Approval No: 2026/03). The study was conducted in accordance with the Declaration of Helsinki. Due to the observational nature of the study and the use of routine clinical samples, informed consent was waived.

Study measurements were performed using the ABL90 FLEX (Radiometer, Copenhagen, Denmark) blood gas analyzer, which was newly introduced in our laboratory. Reference measurements were performed using the GEM Premier 5000 (Instrumentation Laboratory, Bedford, MA, USA) blood gas analyzer and its corresponding reagent kits, which are routinely used in our department. Detailed characteristics and comparative results are presented in Table 1.

Arterial blood samples were collected into 2-mL blood gas syringes containing 70 IU lithium heparin (Ayset Medical Products, Seyhan, Adana, Türkiye). Samples collected from the same patient at different time points were considered independent measurements. Each sample was analyzed consecutively using the ABL90 FLEX followed by the GEM Premier 5000. All analyses were initiated within 2 minutes of collection at room temperature. The evaluated parameters included pH, partial pressure of carbon dioxide (pCO_2), partial pressure of oxygen (pO_2), oxygen saturation (SO_2), ionized calcium (iCa^{2+}), sodium (Na^+), potassium (K^+), chloride (Cl^-), hemoglobin (Hb), O_2Hb, COHb, MetHb, HHb, glucose, total bilirubin, lactate, bicarbonate (HCO_3^-), and osmolality.

Statistical Analysis

All statistical analyses were performed using SPSS Statistics Version 19.0 (IBM Corporation, Armonk, NY, USA) and MedCalc Statistical Software Version 23.1.3 (MedCalc Software Ltd, Ostend, Belgium). Descriptive statistics were used to summarize the characteristics of the study population. Continuous variables were expressed as mean±standard deviation, and categorical variables were reported as n (%). Differences between paired measurements obtained from the two analyzers were assessed using appropriate significance tests. Method comparison was performed using Pearson correlation, Passing–Bablok regression, and Bland–Altman analysis. Associations between paired categorical variables were evaluated using cross-tabulations and the McNemar test. A p value of <0.05 was considered statistically significant for all analyses.

Table 1. Comparison of technical characteristics between ABL90 FLEX and GEM Premier 5000

Characteristic	ABL90 FLEX	GEM premier 5000
Device type	Cartridge-based blood gas analyzer	Cartridge-based blood gas analyzer
Size(Width×Depth×Height)	250 mm×290 mm×470 mm	330mm×420mm×470mm
Sample volume	65 µL	150 µL
Analysis time	35 second	45 second
Calibration method	Automatic/Manual	Automatic
Quality management	Automatic Quality Management (AQM)	Intelligent Quality Management (iQM2)
Potentiometry (Reportable Range)		
pH	6.3–8.0	6.00 to 8.50
pCO_2	5–250 mmHg	0–239 mmHg
K^+	0.5–25 mmol/L	0–27.5 mmol/L
Na^+	7–350 mmol/L	55–220 mmol/L
$iCa2^+$	0.1–10 mmol/L	0–5.50 mmol/L
Cl^-	7–350 mmol/L	30–200 mmol/L
Amperometry (Reportable Range)		
Glucose	0–1080 mg/dL	0–1998 mg/dL
Lactate	0.1–31.0 mmol/L	0–50 mmol/L
pO_2	–	0–948 mmHg
Optical measurement (Reportable Range)		
pO_2	0-800 mmHg	–
Spectrophotometry (Reportable Range)		
tHb	-0.48–27.7 g/L	-50 to 300 g/L
COHb	-2–103 %	-10 to 110.0 %
MetHb	-2–103 %	-10 to 110.0 %

pCO_2: Partial pressure of carbon dioxide; pO_2: Partial pressure of oxygen; iCa: Ionized calcium; Na: Sodium; K: Potassium; Cl: Chloride; tHb: Total hemoglobin; COHb: Carboxyhemoglobin; MetHb: Methemoglobin.

Results

A total of 232 specimens were obtained from male patients and 174 from female patients, with a mean age of 61.9±20.9 years. Samples were collected from inpatient wards (n=184), the emergency department (n=25), and intensive care units (n=197). Baseline descriptive characteristics and overall comparisons of measured parameters between the two analyzers are presented in Table 2, while agreement and correlation analyses are summarized in Table 3.

No statistically significant differences were observed between the two analyzers for pH (7.41±0.08 vs. 7.42±0.09, p=0.144), ionized calcium (4.49±0.43 vs. 4.50±0.45, p=0.268), chloride (103.1±6.77 vs. 102.9±5.94, p=0.080), methemoglobin (0.88±0.60 vs. 0.87±0.61, p=0.408), total bilirubin (1.45±2.32 vs. 1.47±2.29, p=0.139), and lactate (1.94±2.04 vs. 1.89±2.05, p=0.071), as detailed in Table 2. In contrast, statistically significant differences were identified for pCO_2 (42.38±11.3 vs. 41.01±11.4, p<0.05), pO_2 (96.35±59.0 vs. 98.01±55.34, p<0.05), SO_2 (89.98±14.65 vs. 91.17±14.16, p<0.05), sodium (138.36±4.22 vs. 136.05±4.83, p<0.05), potassium (3.86±0.71 vs. 3.98±0.78, p<0.05), glucose (161.5±74.2 vs. 157.7±77.1, p<0.05),

Table 2. Comparison of measured and calculated parameters between the ABL90 FLEX and GEM Premier 5000 blood gas analyzers

Parameters	Abl 90 FLEX	GEM PREMIER 5000	p
pH	7.41±0.08	7.42±0.09	0.144
PCO_2	42.38±11.3	41.01±11.4	<0.05
PO_2	96.35±59.0	98.01±55.34	<0.05
SO_2	89.98±14.65	91.17±14.16	<0.05
İCa	4.49±0.43	4.50±0.45	0.268
Na	138.36±4.22	136.05±4.83	<0.05
K	3.86±0.71	3.98±0.78	<0.05
Cl	103.1±6.77	102.9±5.94	0.080
THb	11.15±2.88	11.28±2.82	<0.05
O2Hb	88.19±14.50	89.49±13.58	<0.05
COHb	1.49±0.71	1.56±0.75	<0.05
MetHb	0.88±0.60	0.87±0.61	0.408
HHb	14.1±0.70	13.2±0.68	<0.05
Glucose	161.5±74.2	157.7±77.1	<0.05
Total Bilirubin	1.45±2.32	1.47±2.29	0.139
Lactate	1.94±2.04	1.89±2.05	0.071
HCO_3	26.58±6.72	25.59±7.38	<0.05
Osmolality	286.2±10.2	284.9±10.0	<0.05

SO_2: Oxygen saturation; O_2Hb: Oxyhemoglobin; HHb: Deoxyhemoglobin; HCO_3^-: Bicarbonate.

Table 3. Results of agreement and correlation analyses between the ABL90 FLEX and GEM Premier 5000 blood gas analyzers

Parameters	Passing-Bablok regression					Bland-Altman analysis		
	Slope (95% CI)	Intercept (95% CI)	Residual standard deviation (95% CI)	Linear model validity	r	Bias (95% CI)	Lower limit of agreement (95% CI)	Upper limit of agreement (95% CI)
pH	1.0000 0.9231 to 1.0000	3.3218E-13 0.0000 to 0.5738	0.02615 -0.05125 to 0.05125	No significant deviation from linearity (p=0.68)	0.880	-0.003154 -0.006817 to 0.0005092	-0.07527 -0.08154 to -0.06900	0.06896 0.06270 to 0.07523
PCO_2	1.0000 1.0000 to 1.0000	2.0000 2.0000 to 2.0000	2.1007 -4.1174 to 4.1174	No significant deviation from linearity (p=0.46)	0.957	-1.3446 -1.6327 to -1.0565	-7.0161 -7.5088 to -6.5233	4.3268 3.8341 to 4.8196
PO_2	1.0539 1.0435 to 1.0645	-7.7665 -8.6935 to -6.8696	3.4337 -6.7301 to 6.7301	Significant deviation from linearity (p=0.05)	0.995	1.6333 1.0311 to 2.2355	-10.2222 -11.2523 to -9.1922	13.4889 12.4589 to 14.5190
SO_2	1.1300 1.0997 to 1.1678	-13.3002 -16.9785 to -10.3759	1.6228 -3.1808 to 3.1808	Significant deviation from linearity (p<0.01)	0.932	1.2449 1.0482 to 1.4415	-2.6272 -2.9636 to -2.2908	5.1169 4.7805 to 5.4533
iCa	0.9937 (0.9787 to 1.0000)	0.01635 (-0.01000 to 0.08298)	0.08655 (-0.1696 to 0.1696)	No significant deviation from linearity (p=0.52)	0.968	0.006051 (-0.006128 to 0.01823)	-0.2337 (-0.2546 to -0.2129)	0.2458 (0.2250 to 0.2667)
Na	0.8750 0.8000 to 1.0000	19.8750 3.0000 to 30.0000	2.4186 -4.7404 to 4.7404	Significant deviation from linearity (p=0.05)	0.669	-2.3923 -2.7361 to -2.0485	-9.1608 -9.7489 to -8.5727	4.3762 3.7881 to 4.9643
K	0.8889 (0.8750 to 0.9000)	0.3111 (0.2700 to 0.3750)	0.1669 (-0.3271 to 0.3271)	No significant deviation from linearity (p=0.07)	0.941	0.1180 (0.09328 to 0.1427)	-0.3680 (-0.4103 to -0.3257)	0.6040 (0.5617 to 0.6463)
Cl	1.1481 (1.1000 to 1.2000)	-15.0185 (-20.3000 to -10.0000)	1.7291 (-3.3891 to 3.3891)	No significant deviation from linearity (p=0.06)	0.887	-0.2128 (-0.4707 to 0.04502)	-5.2891 (-5.7301 to -4.8481)	4.8635 (4.4224 to 5.3045)
Hb	1.0000 1.0000 to 1.0196	-0.1000 -0.3716 to -0.1000	0.5496 -1.0772 to 1.0772	No significant deviation from linearity (p=0.14)	0.971	0.1344 0.05716 to 0.2116	-1.3855 -1.5176 to -1.2535	1.6543 1.5222 to 1.7863
O2Hb	1.1510 1.1250 to 1.1827	-14.9934 -17.9769 to -12.5375	2.8727 -5.6305 to 5.6305	Significant deviation from linearity (p<0.01)	0.906	1.3077 0.9026 to 1.7128	-6.6677 -7.3606 to -5.9748	9.2831 8.5901 to 9.9760
COHb	1.0000 (1.0000 to 1.0000)	-0.10000 (-0.10000 to -0.10000)	0.1554 (-0.3046 to 0.3046)	No significant deviation from linearity (p=0.39)	0.930	0.07231 (0.05063 to 0.09398)	-0.3544 (-0.3915 to -0.3174)	0.4991 (0.4620 to 0.5361)
MetHb	1.0000 (1.0000 to 1.0000)	0.0000 (0.0000 to 0.0000)	0.09032 (-0.1770 to 0.1770)	No significant deviation from linearity (p=0.09)	0.930	-0.005385 (-0.01807 to 0.007304)	-0.2552 (-0.2769 to -0.2335)	0.2444 (0.2227 to 0.2661)
HHb	1.0000 (1.0000 to 1.0030)	0.0000 (-0.001339 to 0.0000)	0.6590 (-1.2916 to 1.2916)	No significant deviation from linearity (p=0.06)	0.999	-0.2315 (-0.3195 to -0.1436)	-1.9984 (-2.1489 to -1.8480)	1.5354 (1.3850 to 1.6858)
Glucose	0.9830 (0.9677 to 1.0000)	6.1307 (4.0000 to 8.1129)	9.1575 (-17.9487 to 17.9487)	No significant deviation from linearity (p=0.30)	0.989	-3.8454 (-5.1590 to -2.5318)	-29.6397 (-31.8866 to -27.3928)	21.9490 (19.7021 to 24.1959)
Total Bilirubin	1.0000 1.0000 to 1.0000	0.0000 0.0000 to 0.0000	0.2210 -0.4332 to 0.4332	Significant deviation from linearity (p=0.04)	0.985	0.02371 -0.007360 to 0.05478	-0.5864 -0.6396 to -0.5333	0.6338 0.5807 to 0.6870
Lactate	1.0435 (1.0000 to 1.0714)	0.02609 (-0.02143 to 0.10000)	0.4307 (-0.8441 to 0.8441)	Significant deviation from linearity (p=0.01)	0.959	-0.05231 (-0.1119 to 0.007241)	-1.2247 (-1.3265 to -1.1228)	1.1200 (1.0182 to 1.2219)
HCO_3	0.9421 0.9281 to 0.9570	2.6066 2.2457 to 2.9478	1.9030 -3.7299 to 3.7299	No significant deviation from linearity (p=0.31)	0.949	-1.0402 -1.3148 to -0.7655	-6.4468 -6.9165 to -5.9770	4.3665 3.8967 to 4.8362
Osmolality	1.0000 (1.0000 to 1.0741)	2.0000 (-19.7407 to 2.0000)	2.0673 (-4.0520 to 4.0520)	Significant deviation from linearity (p=0.03)	0.942	-1.3059 (-1.5886 to -1.0232)	-6.8644 (-7.3480 to -6.3809)	4.2526 (3.7690 to 4.7362)

pCO_2: Partial pressure of carbon dioxide; pO_2: Partial pressure of oxygen; SO_2: Oxygen saturation; iCa: Ionized calcium; Na: Sodium; K: Potassium; Cl: Chloride; Hb: Total hemoglobin; O_2Hb: Oxyhemoglobin; COHb: Carboxyhemoglobin; MetHb: Methemoglobin; HHb: Deoxyhemoglobin; HCO_3^-: Bicarbonate; r: Pearson correlation coefficient.

bicarbonate (26.58±6.72 vs. 25.59±7.38, p<0.05), and osmolality (286.2±10.2 vs. 284.9±10.0, p<0.05), also summarized in Table 2.

Bland–Altman analysis (Fig. 1, Table 3) demonstrated minimal bias for pH (−0.003; 95% limits of agreement [LOA]: −0.075 to 0.069) and pCO_2 (−1.34; LOA: −7.02 to 4.33), with relatively narrow agreement intervals, as shown in Figure 1. Ionized calcium also showed low bias (0.006; LOA: −0.23 to 0.25). In contrast, wider limits of agreement and clinically relevant bias were observed for pO_2 (1.63; LOA: −10.22 to 13.49) and SO_2 (1.24; LOA: −2.63 to 5.12), as illustrated in Figure 1. Sodium demonstrated a negative bias (−2.39; LOA: −9.16 to 4.38), indicating reduced agreement between analyzers, consistent with the findings in both Table 3 and Figure 1. O_2Hb also showed proportional bias (1.31; LOA: −6.67 to 9.28), supporting the presence of systematic differences (Figs. 1, 2).

Pearson correlation analysis (Table 3) demonstrated strong agreement for pH (r=0.880), pCO_2 (r=0.957), ionized calcium (r=0.968), potassium (r=0.941), chloride (r=0.887), hemoglobin (r=0.971), glucose (r=0.989), and lactate (r=0.959). In contrast, sodium showed a weaker correlation (r=0.669), indicating reduced concordance between analyzers. Oxygenation-related parameters such as pO_2 (r=0.995) and SO_2 (r=0.932) also demonstrated high correlation coefficients; however, as illustrated in Figure 2, correlation alone did not fully reflect analytical agreement.

Passing–Bablok regression analysis (Fig. 2, Table 3) revealed no significant deviation from linearity for pH (p=0.68), pCO_2 (p=0.46), ionized calcium (p=0.52), potassium (p=0.07), chloride (p=0.06), hemoglobin (p=0.14), glucose (p=0.30), and bicarbonate (p=0.31). However, significant deviation from linearity was observed for pO_2 (p=0.05), SO_2 (p<0.01), sodium (p=0.05), O_2Hb (p<0.01), total bilirubin (p=0.04), lactate (p=0.01), and osmolality (p=0.03), indicating proportional or systematic differences between methods for these analytes (Table 3, Fig. 2).

Overall, as summarized across Table 2, Table 3, Figure 1, and Figure 2, acid–base parameters exhibited strong agreement and minimal bias, whereas oxygenation parameters, sodium, and several derived measurements showed greater variability, proportional bias, and limited interchangeability between analyzers.

Discussion

In this study, the ABL90 FLEX and GEM Premier 5000 demonstrated strong analytical agreement for pH and pCO_2, supporting the interchangeability of these core acid–base parameters in routine acute-care decision-making. For pH, Passing–Bablok regression showed a slope of 1.0 and a near-zero intercept, indicating minimal systematic or proportional bias between the analyzers. The linear model was consistent with the expected stability of potentiometric pH measurements across modern cartridge-based systems. Bland–Altman analysis further supported this finding, demonstrating a very small mean bias and relatively narrow limits of agreement, suggesting that differences were unlikely to be clinically meaningful in most ICU or emergency department contexts. Importantly, this strong agreement aligns with the literature showing that pH generally exhibits the most consistent cross-platform performance among blood gas analytes, including multi-device comparisons and evaluations of newer cartridge-based analyzers.[1–4]

Similarly, pCO_2 exhibited excellent analytical concordance, with Passing–Bablok regression showing a slope of 1.0 and a fixed intercept, again with no significant deviation from linearity. Although Bland–Altman analysis identified a small systematic bias, the overall agreement remained strong, with limits of agreement comparable to those reported in recent ICU method-comparison studies. These findings are consistent with contemporary evaluations demonstrating that pCO_2 is generally robust across point-of-care blood gas platforms, particularly when strict preanalytical handling is maintained and devices use standardized electrochemical measurement principles.[1–3] In addition, recent validation of integrated cartridge-based bedside blood gas analyzers in acute care has confirmed that pH and pCO_2 typically meet clinical performance expectations and show high agreement with established reference systems, reinforcing the reliability of these parameters for rapid bedside interpretation.[4] Overall, our data indicate that pH and pCO_2 can be considered analytically stable between the ABL90 FLEX and GEM Premier 5000, in contrast to pO_2, which demonstrated proportional bias and wider limits of agreement. However, as no central laboratory reference method was included, the present study evaluates analytical agreement and potential interchangeability between platforms rather than analytical accuracy or trueness. Accordingly, agreement was interpreted primarily using Passing–Bablok regression and Bland–Altman analysis rather than correlation coefficients alone.

pO_2 measurements exhibited significant proportional bias and wider Bland–Altman limits, reinforcing a well-recognized limitation in blood gas analyzer comparability: pO_2 is often the most method-dependent analyte and commonly demonstrates broader variability than pH or pCO_2, even when other parameters show excellent agreement.[3,6,7] This variability is largely attributable to the high preanalytical sensitivity of oxygen tension measurements, including susceptibility

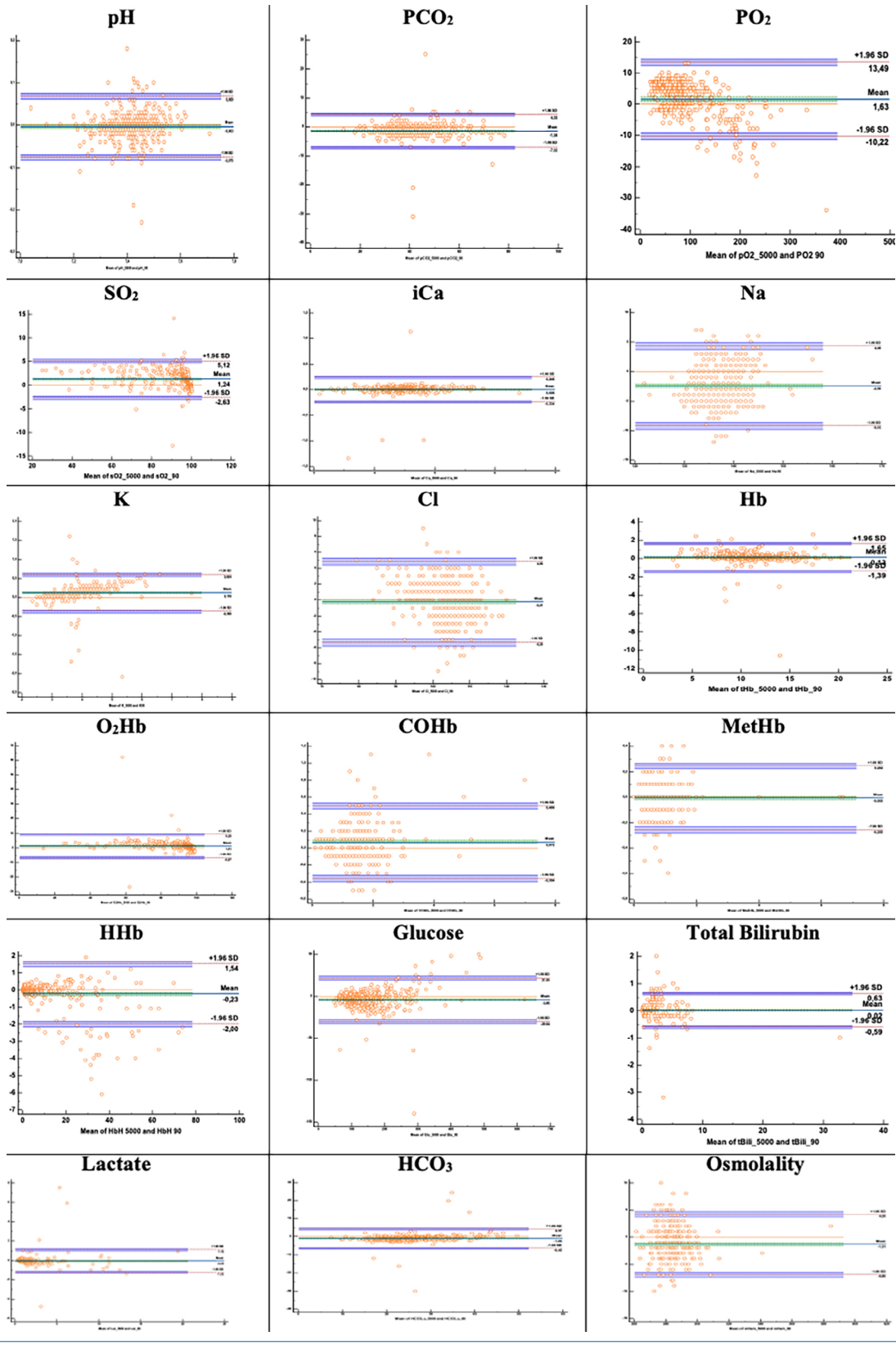

Figure 1. Bland-Altman Plots Demonstrating Agreement between the ABL90 Flex and GEM Premier 5000.

The x-axis represents the mean value of paired measurements obtained from both analyzers, and the y-axis represents the difference between paired measurements (ABL90 FLEX – GEM Premier 5000). The solid central line indicates the mean bias, while the upper and lower dashed lines represent the 95% limits of agreement (mean bias±1.96 SD). Narrower limits indicate better agreement between analyzers. pCO_2: Partial pressure of carbon dioxide; pO_2: Partial pressure of oxygen; SO_2: Oxygen saturation; iCa: Ionized calcium; Na: Sodium; K: Potassium; Cl: Chloride; Hb: Total hemoglobin; O_2Hb: Oxyhemoglobin; COHb: Carboxyhemoglobin; MetHb: Methemoglobin; HHb: Deoxyhemoglobin; HCO_3^-: Bicarbonate.

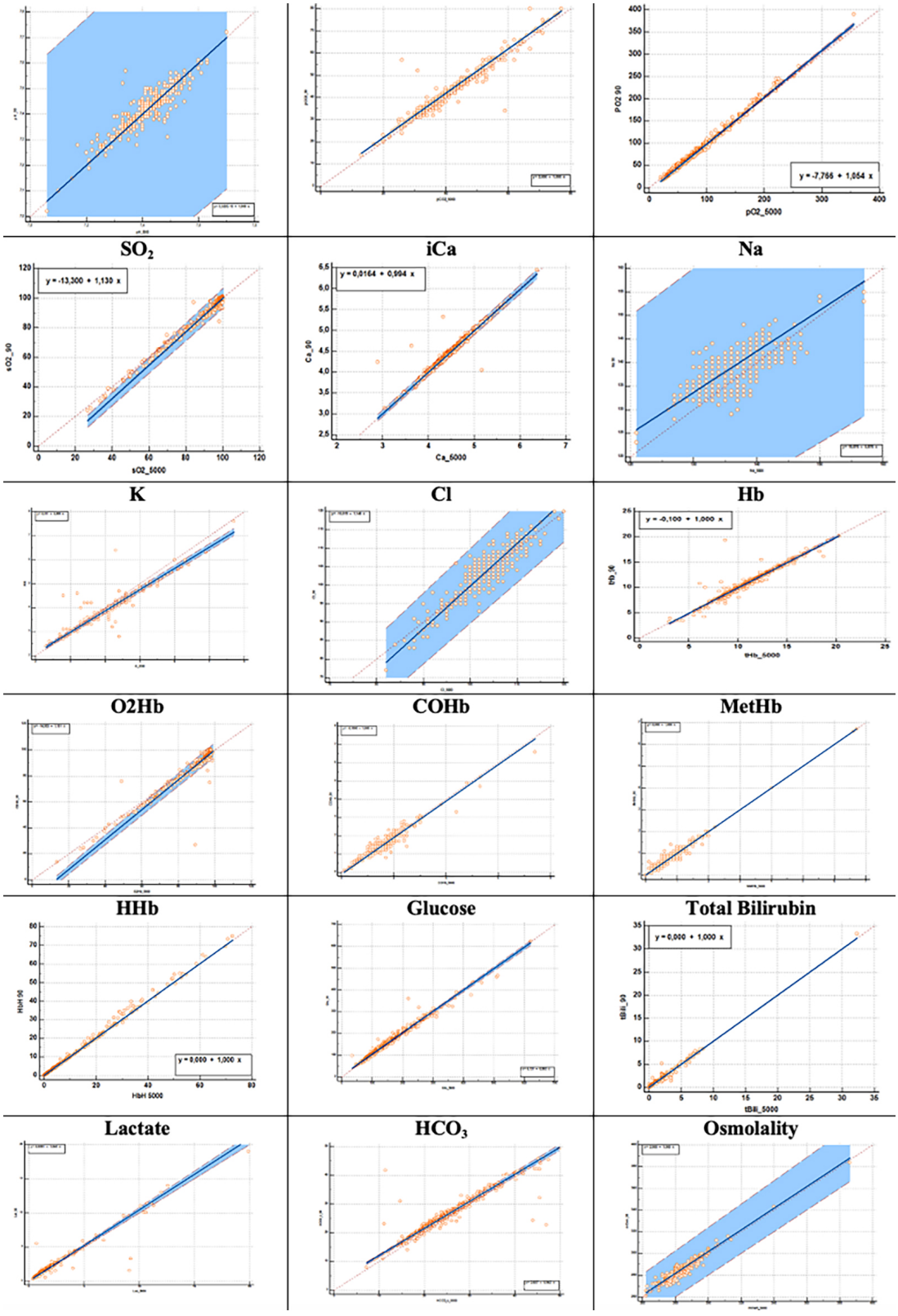

Figure 2. Passing-Bablok Regression Analysis for the Agreement Between ABL90 Flex and GEM Premier 5000.

The x-axis represents measurements obtained from the GEM Premier 5000 analyzer, while the y-axis represents measurements obtained from the ABL90 FLEX analyzer. The solid regression line represents the Passing–Bablok fit, and the dashed line represents the line of identity (y=x). Regression equations and confidence intervals are shown within each panel. Deviation from the identity line indicates proportional or systematic differences between analyzers. pCO_2: Partial pressure of carbon dioxide; pO_2: Partial pressure of oxygen; SO_2: Oxygen saturation; iCa: Ionized calcium; Na: Sodium; K: Potassium; Cl: Chloride; Hb: Total hemoglobin; O_2Hb: Oxyhemoglobin; COHb: Carboxyhemoglobin; MetHb: Methemoglobin; HHb: Deoxyhemoglobin HCO_3^-: Bicarbonate.

to air contamination, delayed analysis, temperature effects, inadequate mixing, diffusion-related factors, and device-specific differences in sensor membrane characteristics and calibration algorithms.[3,6] In addition, unmeasured clinical variables such as FiO_2 level and patient oxygenation status may also have contributed to the observed variability. Previous ICU and method-comparison studies similarly reported clinically relevant disagreement for pO_2 between POC analyzers and reference systems, particularly at higher oxygen tensions.[3,6,7] Therefore, although pH and pCO_2 demonstrated close alignment, the broader variability observed for pO_2 suggests that oxygenation-related measurements should be interpreted cautiously across different analytical platforms, especially during longitudinal monitoring or when strict ventilatory thresholds are applied. Despite this statistical bias, the clinical relevance of the observed differences should be interpreted in relation to clinically acceptable limits for oxygenation management, as these differences may not consistently alter clinical decision-making in all clinical contexts.

Electrolyte analysis demonstrated that iCa^{2+} and K^+ results were broadly comparable between the ABL90 FLEX and GEM Premier 5000, supporting their routine use for rapid bedside decision-making. This finding is clinically important because both ionized calcium and potassium are frequently used in urgent scenarios such as arrhythmia risk assessment, massive transfusion protocols, and critically ill patient monitoring, where analytical stability across point-of-care platforms is essential. In contrast, Na^+ showed weaker agreement, and the relationship between the two analyzers suggested that sodium values may not be fully interchangeable across platforms. Similar discrepancies have been consistently described in method-comparison studies evaluating electrolyte performance among blood gas analyzers, particularly when results are contrasted with other POC devices or central laboratory systems.[5–8] A key explanation is that sodium measurement is especially sensitive to methodological differences between direct and indirect ion-selective electrode (ISE) approaches, as well as to sample matrix effects in critically ill populations.[8] Although both analyzers rely on direct ISE principles for whole blood, sodium is more vulnerable than potassium to shifts caused by changes in plasma water fraction, protein concentration, and other ICU-related factors, which may amplify device-to-device differences even when both instruments are technically compliant. This phenomenon has been highlighted in critical care literature, where sodium discrepancies have been attributed not only to analytical technique but also to clinical sample characteristics that affect electrode response and calibration behavior.[6,8] Moreover, international recommendations emphasize that electrolyte interpretation in whole blood requires careful attention to preanalytical handling and method standardization, particularly when results are used for high-impact therapeutic decisions such as hypernatremia correction or fluid management.[9] Overall, these findings indicate that iCa^{2+} and K^+ can be interpreted with greater confidence across the ABL90 FLEX and GEM Premier 5000, whereas sodium results should be interpreted cautiously, especially when monitoring trends over time or when clinical decisions depend on strict numerical thresholds. Where possible, serial sodium measurements should ideally be performed using the same analytical platform. Although statistically significant differences were observed for sodium, the clinical impact of this bias should be interpreted in the context of clinically acceptable limits, as it may not necessarily lead to changes in therapeutic decisions unless values approach critical decision thresholds.

Co-oximetry parameters demonstrated heterogeneous performance between the ABL90 FLEX and GEM Premier 5000. Total hemoglobin, COHb, and MetHb showed generally good agreement, supporting their clinical use for rapid bedside assessment in most routine critical care scenarios. In contrast, O_2Hb and SO_2 exhibited clinically relevant bias and reduced interchangeability, indicating that oxygenation-related co-oximetry fractions may vary more substantially between platforms. This pattern is consistent with previous reports showing that co-oximetry agreement is strongly analyte-dependent, with hemoglobin species such as COHb and MetHb often demonstrating more stable cross-device performance than oxygen saturation metrics.[2] A plausible explanation is that O_2Hb and SO_2 are highly influenced by device-specific optical algorithms, wavelength selection, and calibration models, and even subtle differences in signal processing can lead to systematic shifts between analyzers. Additionally, oxygenation fractions are more vulnerable to sample-related factors common in critically ill populations, such as dyshemoglobinemia, altered perfusion, anemia, and complex spectral interference, which may amplify discrepancies across different co-oximetry systems.[10] Recent evaluations of modern point-of-care blood gas platforms have similarly emphasized that while co-oximetry provides valuable bedside information, oxygen saturation outputs derived from co-oximetry should be interpreted with caution when comparing results across different devices, particularly for longitudinal monitoring or when clinical decisions rely on strict cut-offs.[10] Overall, these findings suggest that hemoglobin concentration and dyshemoglobin

fractions are more consistently comparable between the ABL90 FLEX and GEM Premier 5000, whereas O_2Hb and SO_2 should preferably be monitored using the same analytical platform, particularly during longitudinal follow-up or when clinical decisions depend on strict oxygenation thresholds. In this context, evaluation of agreement within clinically acceptable limits is essential to determine the true clinical impact of these observed analytical differences.

Metabolite measurements demonstrated generally strong comparability between the ABL90 FLEX and GEM Premier 5000, supporting the use of both devices for metabolic monitoring in acute care. Glucose and lactate showed high concordance overall, consistent with the literature indicating that these analytes tend to perform reliably across modern point-of-care blood gas platforms in emergency and intensive care settings.[3,7] Clinically, this is particularly relevant because glucose and lactate are frequently used for rapid risk stratification, shock monitoring, and therapy guidance, where timely bedside availability often outweighs small analytical differences.[11] Nevertheless, lactate showed evidence of method-dependent variability, a finding also described in prior POC comparisons, emphasizing that even when overall agreement is strong, systematic differences may occur due to differences in enzymatic sensor chemistry, cartridge design, and calibration models between manufacturers.[3,7] Total bilirubin demonstrated overall agreement but with indications of nonlinearity, suggesting that performance may be less consistent across the full concentration range and potentially more vulnerable to analytical or optical interference, which is in line with the known complexity of bilirubin measurement in POC systems. In contrast, calculated parameters such as bicarbonate (HCO_3^-) and osmolality demonstrated greater variability between instruments, a pattern repeatedly highlighted in the literature because derived outputs are inherently dependent on the accuracy and stability of underlying measured variables (e.g., pH, pCO_2, electrolytes), as well as on device-specific calculation formulas.[12,13] Even small systematic shifts in primary measurements can propagate into larger differences in calculated values, reducing cross-device interchangeability despite acceptable agreement for the directly measured analytes. Prior studies comparing calculated versus measured bicarbonate have further emphasized that such differences may become clinically relevant in acid–base interpretation and critically ill patient management, reinforcing the importance of consistent platform use for longitudinal monitoring and threshold-based decision-making.[13] Overall, these findings support the routine use of both the ABL90 FLEX and GEM Premier 5000 for key metabolic analytes such as glucose and lactate, while suggesting that calculated parameters should be interpreted more cautiously across different analytical platforms, particularly when clinical decisions rely on strict thresholds or longitudinal trend monitoring.

Overall, the findings of this study are consistent with recent literature indicating that while modern point-of-care blood gas analyzers provide reliable results for most core parameters, certain analytes—particularly pO_2, Na^+, and oxygenation indices—exhibit limited interchangeability across platforms.[6,10,14,15] Method-comparison studies in critically ill populations have repeatedly shown that oxygen-related parameters are among the most vulnerable to device-specific differences, largely due to the combined influence of preanalytical sensitivity, electrode or optical design, and platform-dependent calibration strategies, which may produce clinically relevant shifts even when overall analytical performance is acceptable.[6,10,14,15] Similarly, sodium is well recognized as a challenging analyte for cross-platform harmonization, as results can be influenced by sample matrix effects and ISE-related methodological differences that are amplified in ICU settings, where protein concentration and plasma water fraction may be abnormal.[6] In addition, manufacturer and independent evaluation reports have emphasized that even within high-performing blood gas systems, some parameters may show broader variability and require cautious interpretation when comparing results between different analyzers, particularly for longitudinal monitoring and strict threshold-based clinical decisions.[14,15] Taken together, these observations reinforce that although point-of-care blood gas analyzers are highly valuable for rapid bedside assessment, analyte-specific limitations should be recognized to avoid inappropriate assumptions of full interchangeability, particularly for oxygenation- and sodium-related measurements. Overall, the interpretation of analytical differences should consider clinically acceptable limits and decision-making thresholds, rather than statistical significance alone, to better reflect the potential impact on patient management.

This study has several limitations. First, it was conducted in a single center, which may limit generalizability to other clinical settings and patient populations. Second, preanalytical variables such as sample transport time, air exposure, and heparin type were not analyzed separately, although these factors are known to influence blood gas results, particularly pO_2 and lactate.[7,12] Furthermore, clinical variables, including FiO_2 level and patient oxygenation status, were not analyzed separately and may have influenced pO_2 variability between analyzers.

Third, the comparison was limited to two POC analyzers without inclusion of a central laboratory reference method; therefore, trueness could not be fully assessed.[4,12] Finally, clinical impact analyses, such as error grid analysis, were not performed, which could further clarify the clinical relevance of the observed biases.[6]

Conclusion

The ABL90 FLEX and GEM Premier 5000 blood gas analyzers demonstrated high analytical agreement for several key parameters, including pH, pCO_2, iCa^{2+}, glucose, and lactate, supporting acceptable analytical agreement for acute care applications. However, reduced agreement and clinically relevant variability were observed for pO_2, Na^+, and selected co-oximetry parameters, limiting full interchangeability between platforms. These findings suggest that consistent use of the same analyzer may be preferable for serial monitoring and critical clinical decision-making, particularly when interpretation depends on strict numerical thresholds or longitudinal trend assessment. In addition, device-specific analytical characteristics should be considered when interpreting oxygenation- and sodium-related measurements. Future multicenter studies incorporating reference methods and clinical impact analyses are warranted to further define analyte-specific interchangeability and support the optimal clinical use of point-of-care blood gas analyzers in acute patient management.

Disclosures

Ethics Committee Approval: The study was approved by the Zonguldak Bulent Ecevit University Ethics Committee (no: 2026/03, date: 04/02/2026).

Informed Consent: Due to the observational nature of the study and the use of routine clinical samples, informed consent was waived.

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RESEARCH ARTICLE

Association of HbA1c and TyG Index with Major Adverse Events After Coronary Artery Bypass

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ABSTRACT

Objectives: Major adverse events (MAEs) following coronary artery bypass grafting (CABG) represent important clinical outcomes affecting early postoperative morbidity and mortality. This study aimed to evaluate the association of preoperative glycated hemoglobin (HbA1c) and the triglyceride–glucose (TyG) index with the development of postoperative MAEs in patients undergoing elective CABG.

Methods: In this retrospective cohort study, data from 500 patients who underwent elective on-pump CABG between January 1, 2022, and December 31, 2023, were analyzed. Demographic characteristics, comorbidities, EuroSCORE II, and preoperative laboratory parameters were recorded. The TyG index was calculated using fasting triglyceride and glucose levels. The primary outcome was MAE, defined as the occurrence of at least one of the following: mortality, stroke, sepsis, or acute kidney injury. Logistic regression analyses were performed to identify predictors associated with MAE.

Results: MAE occurred in 110 patients (22%). Patients who developed MAE were older and had a higher prevalence of hypertension ($p<0.001$). However, no significant differences were observed between the groups in terms of HbA1c, fasting glucose, triglyceride levels, or the TyG index ($p>0.05$). In the multivariable analysis, age (OR: 1.03, 95% CI: 1.00–1.06; $p=0.034$) and hypertension (OR: 2.63, 95% CI: 1.58–4.36; $p<0.001$) were identified as independent predictors of MAE.

Conclusion: Preoperative HbA1c and the TyG index were not independent predictors of early postoperative MAE in patients undergoing elective CABG. In contrast, advanced age and the presence of hypertension were independently associated with an increased risk of MAE.

Keywords: Coronary artery bypass, glycated hemoglobin, insulin resistance, postoperative complications, triglycerides

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Introduction

Coronary artery bypass grafting (CABG) is one of the principal surgical treatments for advanced coronary artery disease and can improve survival and provide symptomatic relief. Early postoperative complications following CABG have a significant impact on morbidity, mortality, length of intensive care unit stay, and duration of hospitalization. Therefore, efforts to establish optimal risk stratification using easily accessible and low-cost biomarkers in the preoperative period remain an important and current area of investigation.[1]

Insulin resistance and disturbances in glucose metabolism are closely associated with the development of cardiovascular diseases and adverse clinical outcomes. Glycated hemoglobin (HbA1c) is widely used as an indicator of long-term metabolic burden, particularly in patients with diabetes mellitus.[2] In the cardiac surgery literature, elevated preoperative HbA1c levels have been reported to be associated with postoperative complications; however, the evidence regarding the strength and independence of this association remains inconsistent.[3]

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The triglyceride–glucose (TyG) index, proposed as a practical indicator of insulin resistance, is an easily applicable and low-cost parameter calculated from fasting triglyceride and glucose levels. The TyG index has been shown to be associated with adverse cardiovascular outcomes in patients with coronary artery disease, while its prognostic role in patients undergoing CABG has only recently begun to be investigated.[4] However, existing studies have evaluated the association of the TyG index with different clinical outcomes in cardiac surgery populations, and the results appear to vary depending on the specific endpoints examined.[5,6] Therefore, it remains uncertain whether the TyG index provides additional prognostic value beyond established clinical risk scores.

Accordingly, evaluating the association of preoperative HbA1c and the TyG index with postoperative mortality and morbidity in patients undergoing CABG and determining whether these metabolic markers provide additional prognostic value beyond traditional clinical risk factors are of particular importance. In this study, we aimed to investigate the relationship between preoperative HbA1c and the TyG index and postoperative major adverse events, as well as early clinical outcomes, in patients undergoing CABG.

Methods

This retrospective cohort study was conducted through a review of the medical records of patients who underwent elective on-pump CABG at our institution between January 1, 2022, and December 31, 2023. Ethical approval was obtained from the University of Health Sciences, Bursa Yüksek İhtisas Training and Research Hospital ethics committee (approval date: 15.05.2024, no: 2024-TBEK 2024/05-10), and all data were retrieved from the hospital information management system and patient medical records. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

Patients aged 18–90 years who underwent elective CABG were included in the study. Patients who underwent emergency surgery, those who underwent concomitant surgical procedures in addition to CABG, and patients with a limited life expectancy due to terminal illness were excluded.

The recorded demographic and clinical variables included age, sex, diabetes mellitus, hypertension, hyperlipidemia, coronary artery disease, chronic kidney disease, the presence of asthma/chronic obstructive pulmonary disease, ejection fraction, and EuroSCORE II values. Preoperative laboratory parameters, including HbA1c, fasting glucose, and triglyceride levels, were obtained from the same blood panels. In addition, cross-clamp time, cardiopulmonary bypass duration, mechanical ventilation time, length of intensive care unit stay, and total hospital length of stay were recorded as part of the perioperative clinical data.

The triglyceride–glucose (TyG) index was calculated using the following formula as an indirect indicator of insulin resistance.[1]

$$\text{TyG index} = \ln(\text{triglyceride [mg/dL]} \times \text{glucose [mg/dL]} / 2).$$

The primary outcome of the study was the development of major adverse events (MAE). MAE was defined as the occurrence of at least one of the following: mortality, stroke, sepsis, or acute kidney injury. Acute kidney injury was assessed according to the Kidney Disease: Improving Global Outcomes (KDIGO) criteria.[7]

Secondary outcomes included duration of mechanical ventilation, prolonged mechanical ventilation, length of intensive care unit stay, and total hospital length of stay.

Statistical Analysis

Statistical analysis was performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Kolmogorov–Smirnov test and visual inspection methods. Continuous variables were examined for distribution, and those that were not normally distributed were presented as median and interquartile range (IQR).

Continuous variables between two independent groups were compared using Student's t-test when normally distributed and the Mann–Whitney U test when not normally distributed. Categorical variables were presented as counts and percentages (%). Comparisons of categorical variables were performed using the Pearson chi-square test, and Fisher's exact test was applied when expected cell counts were low.

Logistic regression analysis was performed to identify potential predictors associated with the development of postoperative major adverse events (MAE). Initially, univariable logistic regression analysis was conducted, and variables with $p<0.10$ were included in the multivariable logistic regression model. Results were reported as odds ratios (ORs) with 95% confidence intervals (CIs). Model fit was assessed using the Hosmer–Lemeshow test.

All statistical analyses were performed as two-tailed tests, and a p-value<0.05 was considered statistically significant.

Results

Between January 1, 2022, and December 31, 2023, a total of 500 patients who underwent elective CABG were included in the study. Postoperative major adverse events (MAE) occurred in 110 patients (22.0%), while 390 patients (78.0%) experienced no MAE.

Table 1. Baseline and preoperative characteristics according to MAE

Variable	Overall (n=500)	MAE (–) (n= 390)	MAE (+) (n= 110)	p
Age (years), median (IQR)	62 (55–69)	61 (55–68)	65 (59–71.5)	**<0.001**
Male, n (%)	398 (79.6)	315 (79.1)	83 (75.5)	0.222
Diabetes mellitus, n (%)	242 (48.4)	181 (46.4)	61 (55.5)	0.094
Hypertension, n (%)	294 (58.8)	209 (53.6)	85 (77.3)	**<0.001**
Hyperlipidemia, n (%)	121 (24.2)	96 (24.6)	25 (22.7)	0.683
Prior coronary artery disease, n (%)	128 (25.6)	106 (27.2)	22 (20.0)	0.128
Chronic renal failure, n (%)	9 (1.8)	5 (1.3)	4 (3.6)	0.112
Asthma/COPD, n (%)	40 (8.0)	27 (6.9)	13 (11.8)	0.095
EuroSCORE II, median (IQR)	3 (1–5)	3 (1–4)	4 (2–5.5)	**<0.001**
Ejection fraction (%), median (IQR)	55 (46.5–60)	55 (48.5–60)	55 (45–60)	0.126
HbA1c (%), median (IQR)	6.4 (5.7–8)	6.3 (5.7–7.8)	6.7 (5.8–8.1)	0.349
Glucose (mg/dL), median (IQR)	123 (99–188)	122.5 (98–181.5)	126 (100–197.5)	0.464
Triglycerides (mg/dL), median (IQR)	151 (111.5–213.2)	151.5 (113.8–216)	146 (101.2–198)	0.124
TyG index, median (IQR)	9.2 (8.7–9.6)	9.2 (8.7–9.6)	9.2 (9.2–9.6)	0.715

Data are presented as median (interquartile range), or number (percentage). COPD: Chronic obstructive pulmonary disease; EuroSCORE II: European System for Cardiac Operative Risk Evaluation II; HbA1c: Glycated hemoglobin; IQR: Interquartile range; MAE: Major adverse events; MAE (–): No major adverse events; MAE (+):, Presence of major adverse events; TyG: Triglyceride–glucose index.

Table 2. Operative variables and postoperative course according to MAE

Variable	MAE (–) (n=390)	MAE (+) (n=110)	p
Cross-clamp time (min), median (IQR)	76 (72–85)	76.5 (72.75–85)	0.745
Cardiopulmonary bypass time (min), median (IQR)	99 (95–106)	99 (94–105)	0.720
Mechanical ventilation duration (hours), median (IQR)	7 (6–8)	8 (8–28)	**<0.001**
Prolonged mechanical ventilation (>24 h), n (%)	9 (2.3)	27 (24.5)	**<0.001**
ICU length of stay (days), median (IQR)	2 (2–3)	4 (3–8)	**<0.001**
Prolonged ICU stay (>3 days), n (%)	76 (19.5)	72 (65.5)	**<0.001**
Hospital length of stay (days), median (IQR)	7 (6–8)	10 (7–15)	**<0.001**

Continuous variables are presented as median (interquartile range) and compared using the Mann–Whitney U test. Categorical variables are presented as number (percentage) and compared using the chi-square test. ICU: Intensive care unit; IQR: Interquartile range; MAE: Major adverse events; MAE (–): No major adverse events; MAE (+): Presence of major adverse events.

Among patients who developed MAE, the most common complication was acute kidney injury, observed in 63 patients (57.3%). This was followed by sepsis in 44 patients (40.0%), mortality in 20 patients (18.2%), and stroke in 9 patients (8.2%). In addition, reoperation was performed in 6 patients (1.2%) in the overall cohort. As some patients experienced more than one complication, the total percentages exceeded 100%.

The demographic and preoperative characteristics of the study population according to the development of MAE are presented in Table 1. Patients who developed MAE were significantly older than those who did not (median age 65 [IQR 59–71.5] vs. 61 [IQR 55–68] years, p<0.001). The prevalence of hypertension was also significantly higher in the MAE group (77.3% vs. 53.6%, p<0.001). Similarly, EuroSCORE II values were higher among patients who developed MAE (4 [IQR 2–5.5] vs. 3 [IQR 1–4], p<0.001). In contrast, no significant differences were observed between the two groups in terms of sex, diabetes mellitus, hyperlipidemia, coronary artery disease, chronic kidney disease, the presence of asthma/COPD, or ejection fraction (all p>0.05).

When evaluated in terms of metabolic markers, no statistically significant differences were observed between patients with and without MAE with respect to HbA1c, fasting glucose, triglyceride levels, or the TyG index (all p>0.05).

Operative and postoperative clinical outcomes are presented in Table 2. No significant differences were found between patients with and without MAE in terms of cross-clamp time or cardiopulmonary bypass duration (p=0.745 and p=0.720).

In contrast, marked differences were observed between the two groups in terms of the postoperative clinical course. The duration of mechanical ventilation was

Table 3. Univariable logistic regression analysis for predictors of MAE

Variable	OR	95% CI	p
Age	1.05	1.02–1.08	<0.001
Hypertension	2.94	1.81–4.80	<0.001
EuroSCORE II	1.20	1.10–1.32	<0.001
Ejection fraction	0.99	0.97–1.01	0.319
HbA1c	1.05	0.94–1.17	0.320
TyG index	0.90	0.66–1.21	0.475

Odds ratios (OR) with 95% confidence intervals (CI) were calculated using univariable logistic regression analysis. Continuous variables were entered into the model as continuous predictors. CI: Confidence interval; HbA1c: Glycated hemoglobin; EuroSCORE II: European System for Cardiac Operative Risk Evaluation II; MAE: Major adverse events; OR: Odds ratio; TyG: Triglyceride–glucose index.

significantly longer in patients who developed MAE (median 8 hours [IQR 8–28] vs. 7 hours [IQR 6–8], p<0.001). Similarly, the rate of prolonged mechanical ventilation (>24 hours) was significantly higher in the MAE group (24.5% vs. 2.3%, p<0.001).

The length of intensive care unit stay was also significantly longer among patients who developed MAE (4 days [IQR 3–8] vs. 2 days [IQR 2–3], p<0.001). In addition, the proportion of patients with prolonged ICU stay (>3 days) was significantly higher in the MAE group (65.5% vs. 19.5%, p<0.001). Total hospital length of stay was likewise significantly longer in patients with MAE (10 days [IQR 7–15] vs. 7 days [IQR 6–8], p<0.001).

Univariable logistic regression analysis was performed to evaluate potential predictors associated with the development of postoperative MAE (Table 3). In this analysis, age (OR: 1.05, 95% CI: 1.02–1.08, p<0.001), the presence of hypertension (OR: 2.94, 95% CI: 1.81–4.80, p<0.001), and EuroSCORE II (OR: 1.20, 95% CI: 1.10–1.32, p<0.001) were significantly associated with the development of MAE. In contrast, no statistically significant associations were observed between MAE and ejection fraction, HbA1c level, or the TyG index (all p>0.05).

Variables with p<0.10 in the univariable analysis were included in the multivariable logistic regression model. In the multivariable analysis, age (OR: 1.03, 95% CI: 1.00–1.06, p=0.034) and the presence of hypertension (OR: 2.63, 95% CI: 1.58–4.36, p<0.001) were identified as independent predictors of MAE (Table 4). In contrast, EuroSCORE II did not retain statistical significance in the multivariable model (p=0.130).

The overall significance of the model was evaluated using the Omnibus test, which showed that the model was statistically significant (p<0.001). Model fit was assessed using the Hosmer–Lemeshow test, indicating good agreement between the model and the observed data (p=0.646).

Table 4. Multivariable logistic regression analysis for predictors of MAE

Variable	Adjusted OR	95% CI	p
Age	1.03	1.00–1.06	**0.034**
Hypertension	2.63	1.58–4.36	**<0.001**
EuroSCORE II	1.09	0.98–1.22	0.130

Adjusted odds ratios (OR) with 95% confidence intervals (CI) were calculated using multivariable logistic regression analysis. Variables with p<0.10 in univariable analysis were included in the multivariable model. Omnibus test p<0.001; Hosmer–Lemeshow test p=0.646; Nagelkerke R^2=0.108. CI: Confidence interval; MAE: Major adverse events; OR: Odds ratio.

Discussion

In this retrospective cohort study, preoperative HbA1c and the TyG index were not found to be independently associated with the development of postoperative MAE in patients undergoing elective CABG. In contrast, advanced age and the presence of hypertension were identified as independent predictors of MAE. In addition, patients who developed MAE had a significantly longer duration of mechanical ventilation, longer intensive care unit stays, and prolonged hospital length of stay.

In our study, patients who developed MAE were older and had a higher prevalence of hypertension. Advanced age has long been recognized as an important risk factor for postoperative complications following cardiac surgery.[8] With increasing age, the growing burden of comorbidities, reduced physiological reserve, and decline in organ function may decrease tolerance to factors such as cardiopulmonary bypass and surgical stress, thereby increasing the risk of postoperative complications.[9] Studies conducted in large cardiac surgery cohorts have also demonstrated that advanced age is independently associated with increased mortality and major postoperative complications.[9–11] Similarly, the presence of hypertension has been identified as an important comorbidity in the cardiac surgery population and is associated with increased cardiovascular risk and endothelial dysfunction, potentially contributing to the development of postoperative complications.[12]

In our study, EuroSCORE II values were higher in patients who developed MAE; however, this association did not remain significant as an independent predictor in the multivariable analysis. EuroSCORE II was primarily developed to predict mortality risk after cardiac surgery, and its performance in predicting heterogeneous complications that constitute postoperative morbidity may therefore be more limited.[13] Previous studies have shown that EuroSCORE II is a strong predictor of mortality; however, its ability to predict early organ-specific complications or composite morbidity outcomes may be more limited.[13,14]

The association between preoperative HbA1c levels and clinical outcomes after cardiac surgery has been extensively investigated in the literature. Studies have suggested that elevated HbA1c levels may be associated with complications such as infections and acute kidney injury following both cardiac and non-cardiac surgery.[15,16] However, other studies have reported no significant association between HbA1c levels and early postoperative complications.[17] In our study, no independent association was found between preoperative HbA1c levels and the development of early postoperative MAE. This finding suggests that the relationship between HbA1c and clinical outcomes after cardiac surgery may not be consistent across different patient populations.

The triglyceride–glucose (TyG) index has increasingly been used as a practical indicator of insulin resistance in cardiovascular risk assessment. Several studies have demonstrated that the TyG index is associated with coronary artery disease, major adverse cardiovascular events, and mortality.[18,19] In studies conducted in cardiac surgery populations, a higher TyG index has been reported to be associated particularly with acute kidney injury and postoperative delirium.[20,21] However, most existing studies have been conducted in different patient populations or have focused on specific clinical endpoints. In our study, no independent association was identified between the TyG index and the development of early postoperative MAE. Furthermore, exploratory analyses evaluating individual complications separately and subgroup analyses according to the presence of diabetes mellitus also revealed no significant association. These findings suggest that the TyG index may have limited prognostic value in predicting early postoperative complications in the cardiac surgery population.

In our study, patients who developed MAE had a significantly longer duration of mechanical ventilation, longer intensive care unit stays, and prolonged hospital length of stay. This finding is expected and is consistent with the existing cardiac surgery literature.[22] The development of postoperative complications is generally associated with a greater need for prolonged mechanical ventilation, extended intensive care monitoring, and increased length of hospital stay. Indeed, previous studies have demonstrated that major complications following cardiac surgery are strongly associated with prolonged mechanical ventilation and longer ICU stays.[23,24]

In the multivariable analysis, advanced age and the presence of hypertension were identified as independent predictors of MAE. In contrast, EuroSCORE II did not retain statistical significance in the multivariable model. This may be attributed to the fact that EuroSCORE II was primarily developed to predict surgical mortality and may have a more limited ability to reflect early composite morbidity outcomes.[13,14] Furthermore, the limited explanatory power of the model suggests that the development of complications after cardiac surgery is a multifactorial process and that clinical or metabolic markers alone may be insufficient to fully explain the overall risk.

The findings of this study suggest that preoperative metabolic markers may have limited value in predicting early postoperative complications in patients undergoing CABG. In particular, HbA1c and the TyG index did not appear to provide additional prognostic value beyond traditional clinical risk factors. Therefore, clinical variables such as age and overall comorbidity burden may remain more influential in risk assessment within the cardiac surgery population, and metabolic markers alone may be insufficient to predict early postoperative complications.

This study has several limitations. First, the retrospective and single-center design may limit the ability to establish causal relationships. Second, metabolic markers were evaluated based on a single preoperative measurement, and perioperative metabolic changes were not analyzed. In addition, the study focused on early postoperative outcomes, and long-term clinical outcomes were not assessed. Therefore, the findings should be confirmed in larger populations and through prospective studies.

Conclusion

In conclusion, preoperative HbA1c and the TyG index were not identified as independent predictors of early major adverse events in patients undergoing elective CABG. In contrast, advanced age and the presence of hypertension were independently associated with the development of postoperative MAE. These findings suggest that clinical risk factors, rather than metabolic markers, may play a more prominent role in predicting the risk of early postoperative complications in patients undergoing cardiac surgery.

Disclosures

Ethics Committee Approval: The study was approved by the University of Health Sciences, Bursa Yüksek İhtisas Training and Research Hospital Ethics Committee (no: 2024-TBEK 2024/05-10, date: 15/05/2024).

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RESEARCH ARTICLE

Anesthetic Experience and Short-Term Outcomes in Our First 29 Pulmonary Endarterectomy Cases

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ABSTRACT

Objectives: Chronic thromboembolic pulmonary hypertension (CTEPH) is a potentially curable form of pulmonary hypertension caused by organized thromboembolic obstruction of the pulmonary arteries. Advances in surgical and anesthetic techniques have improved outcomes, highlighting the importance of evaluating institutional experience. This study presents our anesthetic management and short-term outcomes in the first 29 patients who underwent pulmonary endarterectomy (PEA) for CTEPH.

Methods: This retrospective, single-center study included 29 patients with CTEPH who underwent PEA between November 2018 and July 2024 at Baskent University Ankara Hospital, Türkiye. Demographic, preoperative, and intraoperative anesthetic data and postoperative outcomes were analyzed. Outcomes included duration of mechanical ventilation, intensive care unit (ICU) and hospital lengths of stay, early and 6-month echocardiographic findings, and mortality. Preoperative and follow-up data were compared, and univariate logistic regression was performed to assess risk factors for in-hospital mortality.

Results: The mean patient age was 55.1±18 years, and 44.8% were male. Preoperative echocardiography revealed a mean EF of 53±12%, mPAP of 85±29.2 mmHg, and TAPSE of 17±4.7 mm. Mean CPB, aortic cross-clamp, and total circulatory arrest durations were 232±64.8, 84±29.7, and 34±15.5 minutes, respectively. Early postoperative echocardiography showed a substantial reduction in mPAP to 45.6±22.9 mmHg, which remained stable at 6 months (44.4±27.9 mmHg). The 6-month mortality rate was 21.5%, with no perioperative variables independently associated with mortality.

Conclusion: PEA resulted in significant early improvement in pulmonary hemodynamics. Although mortality was higher than that reported by high-volume centers, this likely reflects advanced disease and early institutional experience, consistent with the learning-curve effect described in the literature.

Keywords: Anesthetic management, cardiopulmonary bypass, chronic thromboembolic pulmonary hypertension, pulmonary endarterectomy, right ventricular dysfunction

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Introduction

Chronic thromboembolic pulmonary hypertension (CTEPH) is a life-threatening yet potentially curable form of pulmonary hypertension characterized by persistent obstruction of the pulmonary arterial bed by organized thromboembolic material and secondary small-vessel arteriopathy. These pathophysiological changes result in elevated pulmonary vascular resistance (PVR), increased mean pulmonary arterial pressure (mPAP), and, if left untreated, progressive right ventricular failure.[1] The 2-year cumulative incidence of CTEPH following an episode of acute pulmonary embolism has been reported to be approximately 2.3%.[2]

Surgical pulmonary endarterectomy (PEA) remains the gold-standard curative therapy for eligible patients with CTEPH.[3] Delcroix et al.[4] demonstrated a significantly

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higher 3-year survival rate of 89% in patients undergoing PEA compared with 70% in those managed non-surgically.

From an anesthetic perspective, PEA represents a major perioperative challenge. The procedure requires not only cardiopulmonary bypass (CPB) but also deep hypothermic total circulatory arrest (TCA) to provide a bloodless surgical field, along with meticulous perioperative management to prevent right ventricular dysfunction, reperfusion lung injury, and pulmonary hemorrhage.[2,5] Recent reviews emphasize the critical role of targeted anesthetic strategies, advanced intraoperative monitoring—such as transesophageal echocardiography (TEE) and near-infrared spectroscopy (NIRS)—and individualized fluid and vasoactive management in optimizing perioperative outcomes.[6–8]

Başkent University Ankara Hospital initiated its PEA program in November 2018. This study summarizes our anesthetic experience in the first 29 patients and reports the intraoperative and postoperative outcomes of patients who underwent PEA at our center between November 2018 and July 2024.

Methods

This retrospective observational study was approved by the Baskent University Institutional Review Board and Ethics Committee (Project No: KA23/84). All consecutive patients who underwent pulmonary endarterectomy (PEA) for chronic thromboembolic pulmonary hypertension (CTEPH) at Baskent University Ankara Hospital between November 2018 and July 2024 were included (n=29). Inclusion criteria were a confirmed diagnosis of CTEPH, scheduled PEA, availability of complete intraoperative monitoring data, and a minimum follow-up of 6 months. The study and manuscript preparation were conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained as part of the surgical consent form before the subjects were included in the study.

Preoperative assessment included transthoracic echocardiography, right heart catheterization when indicated, and coronary angiography. All patients were evaluated and optimized by a dedicated multidisciplinary CTEPH team. Functional status was classified according to the New York Heart Association (NYHA) system. Baseline echocardiographic and hemodynamic variables, including LVEF, PAP, and TAPSE, were recorded.

Standard intraoperative monitoring included invasive arterial pressure, five-lead electrocardiography, pulse oximetry, central venous and pulmonary artery catheterization, and transesophageal echocardiography when available. Cardiopulmonary bypass (CPB) was established following systemic heparinization (3 mg/kg) and achievement of an activated clotting time >400 seconds. Patients were cooled to 20–25°C, and total circulatory arrest (TCA) was instituted after cardiac arrest. Pulmonary endarterectomy was performed sequentially on both pulmonary arteries. Cerebral protection strategies included pharmacological neuroprotection and near-infrared spectroscopy monitoring.

All patients were transferred intubated to the intensive care unit. A negative fluid balance strategy was employed using fluid restriction and intermittent diuretic therapy. The patients were kept sedated for the first 24 hours postoperatively, with extubation targeted on postoperative day 1 in those who were hemodynamically stable, had normal arterial blood gas values, and showed no evidence of reperfusion lung injury or persistent right ventricular dysfunction. Residual pulmonary hypertension was managed according to institutional intensive care unit protocols. Residual pulmonary hypertension was defined as a mean pulmonary arterial pressure >25 mmHg measured by postoperative echocardiography or right heart catheterization.

Clinical outcomes included in-hospital mortality, 6-month mortality, neurological complications, intensive care unit length of stay, hospital length of stay, and echocardiographic parameters (LVEF, TAPSE, and PAP) assessed early postoperatively and at 6-month follow-up.

Statistical Analysis

Statistical analyses were performed using SPSS version 15.0 (SPSS Inc., Chicago, IL, USA). Continuous variables are presented as mean±standard deviation or median (range), and categorical variables are presented as numbers (percentages). Preoperative and follow-up variables were compared using paired-sample t-tests or Wilcoxon signed-rank tests, as appropriate. Univariate logistic regression analysis was performed to identify predictors of in-hospital mortality. A p-value <0.05 was considered statistically significant.

Results

A total of 29 patients were included in the study. The mean age was 55.1±18 years; 13 patients (44.8%) were male and 16 (55.2%) were female. Preoperatively, 4 patients (13.8%) were in New York Heart Association (NYHA) functional class II, 9 (31.0%) were in class III, and 16 (55.2%) were in class IV. The mean left ventricular ejection fraction (LVEF) was 53±12%, mean pulmonary arterial pressure (PAP) was 85±29.2 mmHg, and mean tricuspid annular plane systolic excursion (TAPSE) was 17±4.7 mm (Table 1).

Table 1. Patient demographics (n [%], mean±SD)

Demographics	n	%	Mean±SD
Age (year)			55.1±18
Sex			
Male	13		
Female	16		
NYHA			
II	4	13.8	
III	9	31	
IV	16	55.2	
EF (%)			53±12
PAP (mmHg)			85±29.2
TAPSE (mm)			17±4.7
Preop. SpO_2 (%)			89±7.6

SD: Standard deviation; NYHA: New York Heart Association; EF: Ejection fraction; PAP: Pulmonary artery pressure; TAPSE: Tricuspid annular plane systolic excursion.

Table 2. Patients comorbidities (n [%])

Comorbidities	n	%
None	10	34.5
HT	8	27.6
DM	2	7
Hypothyroidism	0	0
COPD	1	3.5
HT+DM	2	7
Asthma	1	3.5
HT+CHF	3	10.3
HT+Hypothyroidi	1	3.5
HT+DM+COPD	1	3.5

HT: Hypertension; DM: Diabetes mellitus; COPD: Chronic obstructive pulmonary disease; CHF: Congestive heart failure.

Thirteen patients (44.8%) had at least one comorbidity. Hypertension was present in 8 patients (27.6%), diabetes mellitus in 2 (7.0%), chronic obstructive pulmonary disease in 1 (3.5%), asthma in 1 (3.5%), and combined hypertension and congestive heart failure in 3 patients (10.3%), as detailed in Table 2.

The mean cardiopulmonary bypass duration was 232±64.8 minutes, with a mean aortic cross-clamp time of 84±29.7 minutes. Total circulatory arrest duration averaged 34±15.5 minutes, with a mean of 2±0.5 arrest periods per patient. Intraoperative parameters are summarized in Table 3. Mean anesthesia and operative times were 417±79.3 and 355±86.8 minutes, respectively.

Postoperatively, the mean intensive care unit length of stay was 15±16.5 days, and the mean hospital length of stay was 22.9±17.8 days. No neurological complications were observed in any of the patients throughout their intensive

Table 3. Intraoperative values (minimum, maximum, mean±SD)

Intraoperative values	Mean±SD	Min	Max
Length of CPB (min)	232±64.8	122	457
Lenght of XC (min)	84±29.7	22	165
Lenght of TCA (min)	34±15.5	2	63
Count of TCA	2±0.5	1	2
Duration of anesthesia (min)	417±79.3	270	600
Duration of surgery (min)	355±86.8	210	540

SD: Standard deviation; Min: Minimum; Max: Maximum; CPB: Cardiopulmonary bypass; XC: Cross-clamp; TCA: Total circulatory arrest.

Table 4. Postoperative findings

Postoperative findings	Mean±SD
Postop. SpO_2	86.2±24.6
Postop. ICU stay (day)	15±16.5
Postop. EF (%)	52.8±15.8
Postop. TAPSE (mm)	12.1±4.5
Postop. PAP (mmHg)	45.6±22.9
Hospital Stay (day)	22.9±17.8
Postop. 6 months EF (%)	47.5±21.6
Postop. 6 months TAPSE (mm)	13.6±5.5
Postop. 6 months PAP (mmHg)	44.4±27.9

SD: Standard deviation; SpO_2: Peripheral oxygen saturation; ICU: Intensive care unit; EF: Ejection fraction, TAPSE: Tricuspid annular plane systolic excursion; PAP: Pulmonary artery pressure.

Table 5. Postoperative mortality (n [%])

Postoperative mortality	n	%
Exitus	7	21.5
Alive	22	78.5

care unit stay. Echocardiographic follow-up was performed in the early postoperative period and at 6 months. Early postoperative echocardiography demonstrated a mean LVEF of 52.8±15.8%, TAPSE of 12.1±4.5 mm, and PAP of 45.6±22.9 mmHg. At the 6-month follow-up, the mean LVEF was 47.5±21.6%, TAPSE was 13.6±5.5 mm, and PAP was 44.4±27.9 mmHg (Table 4). The 6-month mortality rate was 21.5% (Table 5).

Discussion

Chronic thromboembolic pulmonary hypertension (CTEPH) is increasingly recognized as a potentially curable cause of pulmonary hypertension when managed with timely intervention.[5] Although the reported incidence following acute pulmonary embolism varies widely (0.5%–9%), a recent meta-analysis estimated the true incidence to be approximately 2.3%.[2] A 2022 systematic review of

pulmonary endarterectomy (PEA) outcomes reported a 30-day mortality rate of 8.4% (95% CI, 7.2%–9.6%) and residual pulmonary hypertension in 8.2%–44.5% of cases. High-volume centers consistently demonstrate superior outcomes, highlighting a clear volume–outcome relationship.[3] Recent registry data further indicate 3-year survival rates of approximately 94% for PEA and 92% for balloon pulmonary angioplasty, compared with 71% in patients managed without mechanical intervention.[7]

The 6-month mortality rate of 21.5% observed in our cohort was higher than that reported by established expert centers (approximately 5%–10%).[9–13] This difference likely reflects the high proportion of patients presenting with advanced disease, as evidenced by the predominance of NYHA functional class IV (55.2%) and severe baseline hemodynamic burden (mean mPAP of 85 mmHg), in addition to our center's early experience with the PEA program.

Intraoperative parameters in our series (mean CPB time of 232 minutes, cross-clamp time of 84 minutes, and total circulatory arrest time of 34 minutes) were broadly comparable with those reported in the literature. A previous Turkish series described mean CPB, cross-clamp, and TCA times of approximately 207, 39, and 23 minutes, respectively.[12] In contrast, a European center reported a CPB time of 215 minutes, cross-clamp time of 11.3 minutes, and TCA time of 42.8 minutes. Variations in cross-clamp and circulatory arrest durations likely reflect differences in surgical techniques, anesthetic management, and cardiopulmonary bypass protocols.

Advanced intraoperative monitoring strategies, including near-infrared spectroscopy (NIRS) for cerebral oximetry, may help mitigate the neurological risks associated with hypothermic circulatory arrest. Recent reviews emphasize the importance of coordinated perfusion and anesthetic management in improving perioperative safety during PEA.[2]

The mean hospital length of stay in our cohort (22 days, including a 15-day ICU stay) exceeded that reported by high-volume centers (e.g., Spain: hospital stay of 14 days and ICU stay of 6 days; India: hospital stay of 11 days and ICU stay of 4 days).[9,14] This prolonged hospitalization likely reflects higher baseline patient risk, greater comorbidity burden, and the influence of the surgical and anesthetic learning curve. Reducing length of stay remains an important goal, given its implications for healthcare costs, morbidity, and mortality.[15]

Mean pulmonary arterial pressure decreased substantially from 85 mmHg preoperatively to approximately 45–46 mmHg both in the early postoperative period and at the 6-month follow-up. Although residual pulmonary hypertension, defined as mPAP >25 mmHg, remains a concern and has been reported in 5%–35% of patients, with an associated 3.66-fold increase in mortality, the hemodynamic improvement observed in our cohort is clinically meaningful.[16] Residual pulmonary hypertension may result from distal small-vessel disease not amenable to endarterectomy, delayed referral, suboptimal anticoagulation, or persistent microvascular remodeling.[17]

This study has several limitations, including its retrospective, single-center design, relatively small sample size, and absence of a control group. In addition, the heterogeneity of patient characteristics and the learning curve inherent to a newly established PEA program may have influenced perioperative outcomes. Despite these limitations, this study offers valuable real-world data and provides important insights into the early anesthetic and intensive care management of patients undergoing pulmonary endarterectomy at a developing center. These findings may serve as a practical reference for other institutions in the initial phases of implementing a PEA program and contribute to the growing body of evidence in this field.

Conclusion

The present study describes our initial institutional anesthetic and perioperative experience with pulmonary endarterectomy for CTEPH. Although 6-month mortality was higher than that reported by established high-volume centers, the observed improvements in pulmonary hemodynamics and functional status are encouraging. These findings underscore the importance of early referral, standardized anesthetic and cardiopulmonary bypass protocols, multidisciplinary coordination, and accumulation of institutional experience to optimize outcomes in emerging PEA programs.

Disclosures

Ethics Committee Approval: The study was approved by the Baskent University Ethics Committee (no: KA23/84, date: 18/04/2023).

Informed Consent: Written informed consent was obtained as part of the surgical consent form before the subjects were included in the study.

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RESEARCH ARTICLE

Impact of Genetic Anomalies on Postoperative Hemodynamics and Clinical Outcomes After Congenital Heart Surgery

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ABSTRACT

Objectives: Genetic anomalies are frequently associated with congenital heart disease and may influence postoperative outcomes after pediatric cardiac surgery. However, their relationship with postoperative hemodynamic severity remains incompletely characterized. This study aimed to evaluate postoperative clinical burden and hemodynamic severity in pediatric patients with congenital heart disease and genetic anomalies who underwent cardiac surgery.

Methods: This retrospective, single-center cohort study included pediatric patients who underwent surgery for congenital heart disease during a two-year study period. Patients were classified according to the presence or absence of documented genetic anomalies. Demographic, operative, and postoperative variables, including the vasoactive–inotropic score (VIS), cross-clamp duration, mechanical ventilation duration, intensive care unit (ICU) length of stay, hospital length of stay, extracorporeal membrane oxygenation (ECMO) requirement, dialysis requirement, delayed sternal closure, reintubation, and in-hospital mortality, were analyzed.

Results: A total of 1,456 pediatric patients were included, including 86 patients with documented genetic anomalies. Patients with genetic anomalies demonstrated significantly greater postoperative hemodynamic severity and resource utilization. Median VIS values were significantly higher in the genetic anomaly group (17.0 [12.0–22.0] vs. 13.0 [8.0–17.0], p=0.003). Cross-clamp duration (p=0.027), mechanical ventilation duration (p=0.007), ICU length of stay (p=0.007), and hospital length of stay (p=0.002) were significantly prolonged. Mortality was numerically higher among patients with genetic anomalies, although statistical significance was not reached.

Conclusions: Pediatric patients with congenital heart disease and genetic anomalies who undergo cardiac surgery represent a clinically vulnerable subgroup characterized by greater postoperative hemodynamic severity and increased healthcare resource utilization. Recognition of this phenotype may facilitate intensified perioperative monitoring and earlier supportive interventions.

Keywords: Congenital heart surgery, genetic anomalies, pediatric cardiac intensive care, postoperative outcomes, vasoactive–inotropic score

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Introduction

Congenital heart disease is frequently associated with underlying genetic and chromosomal abnormalities, and these patients often represent a clinically complex subgroup in pediatric cardiac surgery.[1,2] Genetic anomalies may influence perioperative physiology, immune regulation, airway anatomy, myocardial performance, and postoperative recovery, thereby increasing the need for prolonged intensive care support and contributing to adverse postoperative outcomes.

Advances in neonatal and pediatric cardiac surgery have substantially improved survival over recent decades; however, postoperative morbidity remains considerable, particularly among patients with increased surgical

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complexity and perioperative hemodynamic instability.[3,4] Previous studies have demonstrated that genetically vulnerable pediatric cardiac patients may experience prolonged mechanical ventilation, increased intensive care unit stays, greater healthcare resource utilization, and a higher postoperative complication burden following congenital heart surgery.[2,5] Underlying genetic disorders may additionally impair myocardial reserve, vascular tone regulation, inflammatory response, and perioperative physiologic adaptation, potentially contributing to increased postoperative hemodynamic instability.

The vasoactive–inotropic score (VIS) has emerged as a practical bedside marker of postoperative cardiovascular support intensity and illness severity after congenital heart surgery and has consistently been associated with increased postoperative morbidity and adverse short-term outcomes.[6,7] Similarly, prolonged mechanical ventilation duration, intensive care unit length of stay, and extracorporeal membrane oxygenation requirement are widely recognized indicators of increased postoperative clinical burden in pediatric cardiac intensive care populations.

Despite increasing recognition of the clinical importance of genetic anomalies in congenital cardiac populations, their relationship with postoperative hemodynamic severity and resource utilization remains incompletely characterized. Therefore, the present study aimed to evaluate the impact of genetic anomalies on postoperative hemodynamic severity and clinical outcomes following pediatric congenital heart surgery.

Methods

This retrospective, single-center cohort study included pediatric patients who underwent congenital heart surgery over a two-year study period at a tertiary pediatric cardiac surgery center. The study was approved by the Dr. Siyami Ersek Thoracic and Cardiovascular Surgery Training and Research Hospital ethics committee (Approval No.: E-28001928-604.01-315162585; Date: May 18, 2026). The requirement for informed consent was waived because of the retrospective design of the study. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and its subsequent amendments.

Patients were classified according to the presence or absence of a documented genetic anomaly based on institutional medical records and genetic evaluations. Genetic anomalies included syndromic and chromosomal disorders identified during routine clinical evaluation. Demographic, operative, and postoperative variables were extracted from institutional electronic medical records. The collected variables included age, sex, body weight, Society of Thoracic Surgeons (STAT) mortality category, cardiopulmonary bypass duration, aortic cross-clamp duration, vasoactive–inotropic score (VIS), mechanical ventilation duration, intensive care unit (ICU) length of stay, hospital length of stay, extracorporeal membrane oxygenation (ECMO) requirement, dialysis requirement, delayed sternal closure, reintubation, and in-hospital mortality. VIS was defined as the highest vasoactive–inotropic score recorded during the first 24 postoperative hours in the intensive care unit and was calculated according to the previously validated formula described by Gaies et al.[6] VIS was calculated as dopamine dose (μg/kg/min)+dobutamine dose (μg/kg/min)+100×epinephrine dose (μg/kg/min)+10×milrinone dose (μg/kg/min)+10,000×vasopressin dose (U/kg/min)+100×norepinephrine dose (μg/kg/min).

Statistical Analysis

Continuous variables were expressed as median and interquartile range (IQR), whereas categorical variables were expressed as frequency and percentage. Continuous variables were compared using the Mann–Whitney U test. Categorical variables were compared using chi-square or Fisher's exact tests, as appropriate. A p value of <0.05 was considered statistically significant.

Results

A total of 1,456 pediatric patients who underwent congenital heart surgery were included in the analysis, including 86 patients with documented genetic anomalies. Among the 86 patients with documented genetic anomalies, Down syndrome/trisomy 21 was the most frequent diagnosis, observed in 73 patients (84.9%), followed by DiGeorge syndrome/22q11.2 deletion in 9 patients (10.5%). The remaining 4 patients (4.6%) had other genetic anomalies.

Baseline demographic and operative characteristics are summarized in Table 1. No statistically significant differences were observed in age, body weight, sex distribution, STAT mortality category, or cardiopulmonary bypass duration between the groups. However, patients with genetic anomalies demonstrated significantly prolonged aortic cross-clamp duration (p=0.027).

Postoperative outcomes are summarized in Table 2. Patients with genetic anomalies demonstrated significantly greater postoperative hemodynamic severity and resource utilization compared with patients without genetic anomalies.

Median vasoactive–inotropic score (VIS) values were significantly higher among patients with genetic anomalies (p=0.003), suggesting increased postoperative cardiovascular instability and greater vasoactive support requirements.

Table 1. Baseline demographic and operative characteristics according to presence of genetic anomalies

Variable	No genetic anomaly (n=1370)	Genetic anomaly (n=86)	p
Age (months)	11.0 (1.3–48.0)	9.0 (5.0–30.0)	0.481
Weight (kg)	7.0 (3.6–14.0)	5.0 (4.2–8.6)	0.323
Male sex	806/1370 (58.8%)	43/86 (50.0%)	0.105
STAT mortality category	3.0 (2.0–4.0)	3.0 (2.0–4.0)	0.430
Cross-clamp duration (min)	75.0 (40.2–115.0)	98.0 (70.5–131)	0.027
Cardiopulmonary bypass duration (min)	134.0 (92.0–181.0)	144.0 (102.5–190.5)	0.404

Continuous variables are presented as median (interquartile range [IQR]). Categorical variables are presented as number (%). STAT: Society of thoracic surgeons.

Table 2. Postoperative outcomes

Variable	No genetic anomaly (n=1370)	Genetic anomaly (n=86)	p
VIS	13.0 (8.0–17.0)	17.0 (12.0–22.0)	0.003
ECMO requirement	100/1370 (7.3%)	6/86 (7.0%)	0.899
Dialysis requirement	142/1370 (10.4%)	9/86 (10.5%)	0.874
Reintubation	214/1370 (15.6%)	17/86 (19.8%)	0.330
Delayed sternal closure	212/1370 (15.5%)	12/86 (14.0%)	0.697
Mechanical ventilation duration (days)	1.0 (0.0–5.0)	3.0 (0.0–7.0)	0.007
ICU length of stay (days)	4.0 (2.0–8.0)	6.0 (3.2–13.8)	0.007
Hospital length of stay (days)	9.0 (6.0–17.0)	12.0 (8.0–25.0)	0.002
CPR	39/1370 (2.8%)	3/86 (3.5%)	0.733
In-hospital mortality	97/1370 (7.1%)	8/86 (9.3%)	0.420

Continuous variables are presented as median (interquartile range [IQR]). Categorical variables are presented as number (%). VIS: vasoactive–inotropic score; ICU: intensive care unit; ECMO: extracorporeal membrane oxygenation.

Postoperative recovery was substantially prolonged among patients with genetic anomalies. Mechanical ventilation duration was significantly longer in the genetic anomaly group (p=0.007). Similarly, intensive care unit length of stay (p=0.007) and total hospital length of stay (p=0.002) were significantly increased.

Although mortality was numerically higher among patients with genetic anomalies, statistical significance was not reached, likely because of the relatively limited size of the genetic anomaly subgroup. No statistically significant differences were observed in ECMO requirement, dialysis requirement, delayed sternal closure, or reintubation.

Discussion

The present study demonstrates that pediatric patients with genetic anomalies undergoing congenital heart surgery represent a clinically vulnerable postoperative subgroup characterized by greater postoperative hemodynamic severity and increased healthcare resource utilization.

One of the most important findings of this study was the significantly higher vasoactive–inotropic score (VIS) observed among patients with genetic anomalies. VIS has been validated as a practical marker of postoperative cardiovascular support intensity and has consistently been associated with morbidity and adverse short-term outcomes after pediatric cardiac surgery.[6,8] Therefore, the higher VIS values identified in the genetic anomaly group suggest greater postoperative circulatory instability and an increased need for vasoactive and inotropic support. Since VIS reflects the intensity of pharmacologic cardiovascular support required to maintain postoperative hemodynamic stability, these findings may additionally indicate reduced physiologic reserve and increased susceptibility to postoperative circulatory dysfunction in patients with genetic anomalies.

In addition to increased hemodynamic severity, patients with genetic anomalies demonstrated significantly prolonged mechanical ventilation duration, intensive care unit (ICU) length of stay, and total hospital length of stay. These findings are consistent with previous reports demonstrating that genetically vulnerable pediatric cardiac patients may experience more complex postoperative recovery and greater healthcare resource utilization following congenital heart surgery.[2,5,9–11] Several mechanisms may contribute to this increased postoperative burden, including altered cardiopulmonary physiology, airway abnormalities, impaired myocardial

reserve, feeding difficulties, immune dysregulation, and increased susceptibility to postoperative complications.

The significantly prolonged aortic cross-clamp duration observed in the genetic anomaly group may additionally reflect increased operative complexity. However, no statistically significant difference was identified in STAT mortality category distribution between groups, suggesting that the increased postoperative burden may not be explained solely by procedural complexity. Surgical complexity remains one of the strongest determinants of postoperative morbidity and mortality in congenital heart surgery, and established risk stratification models, such as the Society of Thoracic Surgeons Congenital Heart Surgery Database, emphasize the importance of procedural complexity in postoperative outcome prediction.[3,4]

Although mortality was numerically higher in patients with genetic anomalies, statistical significance was not reached, likely because of the limited subgroup size and heterogeneity of the underlying syndromes. Nevertheless, the consistent increase in VIS, mechanical ventilation duration, ICU stay, and hospital length of stay suggests substantially increased postoperative morbidity despite the absence of a statistically significant mortality difference.

Another important finding of the present study is that postoperative vulnerability in patients with genetic anomalies appears to extend beyond isolated surgical risk alone. Rather than representing only a categorical comorbidity, genetic anomalies may define a broader postoperative phenotype characterized by increased physiologic fragility, prolonged recovery, and greater intensive care requirements. Recognition of this phenotype may facilitate earlier supportive interventions, intensified perioperative surveillance, and more individualized postoperative management strategies in pediatric cardiac intensive care practice.

Several limitations should be acknowledged. First, the retrospective, single-center design may introduce selection bias and limit the external validity and generalizability of the findings to other pediatric cardiac surgery centers and patient populations. Second, the genetic anomaly subgroup was relatively small, reducing the statistical power for low-frequency outcomes such as mortality. Third, genetic anomalies included heterogeneous syndromic and non-syndromic conditions with potentially different physiologic and postoperative implications. Finally, residual confounding related to operative complexity and baseline patient severity may still be present. In addition, outcomes were not analyzed according to specific genetic syndromes, and individual genetic disorders may carry distinct physiologic and postoperative risk profiles.

Conclusion

Pediatric patients with genetic anomalies undergoing congenital heart surgery exhibit greater postoperative hemodynamic severity and increased healthcare resource utilization compared with patients without genetic anomalies. Higher vasoactive support requirements and prolonged recovery suggest increased postoperative vulnerability in this population. Recognition of these patients as a high-risk subgroup may facilitate intensified perioperative monitoring and individualized postoperative management strategies.

Disclosures

Ethics Committee Approval: The study was approved by the Dr. Siyami Ersek Thoracic and Cardiovascular Surgery Training and Research Hospital Ethics Committee (no: E-28001928-604.01-315162585, date: 18/05/2026).

Informed Consent: The requirement for informed consent was waived because of the retrospective design of the study.

Conflict of Interest Statement: The authors declare that there is no conflict of interest.

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RESEARCH ARTICLE

Lung Ultrasound Detection of Perioperative Atelectasis in Orthopaedic Surgery: A Comparative Study of Regional versus General Anaesthesia

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ABSTRACT

Objectives: To compare perioperative lung aeration loss after elective lower extremity orthopaedic surgery under regional versus general anaesthesia using a standardised 12-zone lung ultrasound (LUS) score and to evaluate its relationship with spirometry and arterial blood gas (ABG) outcomes.

Methods: In this prospective, single-centre observational study conducted at a tertiary care university hospital, 60 adults (ASA I–III) without pulmonary disease undergoing elective lower extremity orthopaedic surgery were allocated by clinical decision to receive combined spinal–epidural anaesthesia (n=30) or general anaesthesia (n=30). LUS, spirometry, and ABG on room air were performed preoperatively and within 2 hours postoperatively.

Results: Baseline characteristics and preoperative LUS scores were comparable between the groups (13.03±3.60 vs. 12.70±3.29). Postoperative aeration loss was significantly greater after general anaesthesia (ΔLUS 6.53±2.90) than after regional anaesthesia (ΔLUS 1.90±3.26), with a mean difference of 4.63 (95% CI 3.03–6.24; p<0.001; Cohen's d=1.50). Clinically significant atelectasis (ΔLUS≥4) occurred more frequently in the general anaesthesia group (76.7% vs. 36.7%; absolute risk reduction, 40.0%; NNT, 2.5). Adjusted analysis confirmed an independent group effect (β=4.79; p<0.001; R^2=0.513). Oxygenation did not differ between the groups and showed no correlation with ΔLUS. Small airway function declined more after general anaesthesia.

Conclusions: These findings suggest that regional anaesthesia may be associated with reduced perioperative lung aeration loss and support the potential role of LUS in perioperative monitoring. Further randomised controlled trials are warranted.

Keywords: Atelectasis, general anesthesia, postoperative complications, regional anesthesia, ultrasonography.

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Introduction

Postoperative pulmonary complications (PPCs) are clinically relevant even in non-cardiac surgery, including orthopaedic procedures, as they adversely affect recovery, prolong hospital stay, increase healthcare costs, and may be associated with serious morbidity and mortality; therefore, their recognition is essential for prevention, timely management, and improved postoperative outcomes.[1–3]

Atelectasis is a major contributor to postoperative pulmonary morbidity after general anaesthesia and results from reduced functional residual capacity, airway closure, and the effects of mechanical ventilation. This loss of lung aeration impairs gas exchange, increases the risk of hypoxaemia and infection, and may prolong postoperative recovery.[3,4]

Conventional imaging modalities, such as chest radiography and standard CT scans, have limited sensitivity

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for detecting early perioperative pulmonary changes, as practical challenges, including patient positioning, surgical dressings, and clinical instability, can affect imaging quality.[5] Moreover, these techniques provide primarily structural information and do not allow functional assessment of lung aeration or ventilation abnormalities, while concerns regarding radiation exposure restrict their repeated use. These limitations highlight the need for advanced imaging and clinical assessment methods.[6]

Lung ultrasonography has become vital in anaesthesiology because of its noninvasive, bedside, radiation-free, real-time imaging capabilities, enabling the rapid diagnosis of pulmonary conditions such as pneumothorax, pleural effusion, and atelectasis, thereby enhancing patient safety in critical and emergency care.[7] It aids procedural guidance and has been increasingly integrated into anaesthesiology practice as part of point-of-care ultrasound.[7–9] Lung ultrasound (LUS) is increasingly used to detect perioperative atelectasis, but evidence comparing atelectasis after regional versus general anaesthesia in orthopaedic surgery remains limited. General anaesthesia promotes alveolar collapse, whereas regional anaesthesia may preserve spontaneous breathing and reduce the risk of atelectasis. However, this potential advantage has not been systematically evaluated using standardised LUS assessments in orthopaedic procedures.[10]

The primary objective of this study was to compare perioperative lung aeration loss and atelectasis between patients who underwent general anaesthesia and regional anaesthesia for orthopaedic surgery, as quantified by a standardised LUS score. Although LUS has been established as a reliable method for identifying structural lung changes, current research has mainly focused on groups undergoing general anaesthesia without direct comparison with regional anaesthesia techniques. This gap in the literature raises questions regarding the impact of anaesthesia type on postoperative lung aeration patterns. The secondary objectives were to evaluate the associations between LUS-derived aeration scores and postoperative respiratory outcomes, such as spirometric parameters and arterial blood gas measurements, and to assess the feasibility of LUS as an early detection tool in the orthopaedic perioperative setting. This study aimed to provide comparative data to inform the anaesthetic strategy for minimising perioperative pulmonary complications in patients undergoing orthopaedic surgery.

Methods

This prospective observational study was conducted in a single-centre setting at a tertiary care university hospital in Istanbul, Türkiye, between October 2017 and February 2018. Approval was obtained from the Marmara University ethics committee (approval number: 09.2017.133), and informed consent was obtained from all participants. The study was conducted in accordance with the Declaration of Helsinki. The study was not prospectively registered, as it was designed as a prospective observational study without investigator-assigned intervention.

Sixty patients aged ≥18 years, classified as American Society of Anesthesiologists (ASA) physical status I–III, and scheduled for elective lower extremity orthopaedic surgery were enrolled. The exclusion criteria included emergency cases, refusal to participate, pre-existing pulmonary disease, and inability to cooperate with spirometry or lung ultrasound. Patients were allocated to the regional anaesthesia (Group I, n=30) or general anaesthesia (Group II, n=30) group. Allocation was determined by the attending anaesthesiologist based on clinical considerations, resulting in non-randomised assignment. The sample size of this pilot study was based on previous studies investigating perioperative lung ultrasound and atelectasis, and recruitment ceased upon reaching the predetermined group numbers. No formal a priori power calculation was performed.

Regional Anaesthesia Protocol: Combined spinal–epidural anaesthesia was administered using the needle-through-needle technique. This involved the intrathecal injection of 2.5–3 mL of 0.5% hyperbaric bupivacaine for spinal anaesthesia. Following catheter placement, an epidural mixture of fentanyl, bupivacaine, and saline was administered to enhance the anaesthetic effect. During surgery, patients received oxygen at 3 L/min via a facemask. Postoperative analgesia was managed with patient-controlled analgesia delivering 0.125% bupivacaine combined with 3 mcg/mL fentanyl, set at a 4 mL/h basal rate, with 5 mL bolus doses and a 30-minute lockout interval.

General Anaesthesia Protocol: Patients underwent preoxygenation with 80% oxygen for 3 minutes before induction. Anaesthesia induction was performed using midazolam, propofol, and remifentanil, with rocuronium for tracheal intubation. Patients were positioned supine or prone based on the surgical approach. Anaesthesia was maintained using desflurane inhalation with continuous remifentanil infusion and intermittent rocuronium. Ventilation used volume-controlled settings at 6–8 mL/kg predicted body weight, FiO_2 30%–40%, respiratory rate 12–15 breaths/min, end-tidal CO_2 30–35 mmHg, inspiratory-to-expiratory ratio 1:2, and positive end-expiratory pressure 5–6 cmH_2O. Postoperative analgesia included paracetamol and morphine HCl (0.1 mg/kg) as required.

Perioperative care was conducted according to institutional protocols. Although efforts were made to maintain consistency in patient positioning, monitoring, and general perioperative management, inherent differences between regional and general anaesthesia, such as airway management, ventilation strategies, oxygen administration, and analgesic techniques, were unavoidable. These differences reflect real-world clinical practice and may have contributed to the observed outcomes.

Lung ultrasound, spirometry, and arterial blood gas (ABG) analysis under spontaneous breathing in room air were performed twice: during the preoperative period and within 2 hours after arrival at the postanaesthetic care unit. Postoperative assessments were performed after regression of the sensory block below the T10 dermatome and adequate pain control (visual analogue scale score <4). Measurements were conducted within a predefined and consistent time window for all patients to ensure comparability between the groups. Spirometry measurements were performed 3 times per period, and the best values were recorded.

Lung ultrasonography examinations were performed by an anaesthesiologist using a Philips Sparq ultrasound system with a 4–12 MHz high-frequency linear probe. A standardised 12-zone LUS protocol, as described by Bouhemad et al.,[11] was applied. Each hemithorax was divided into 6 zones: anterior (zones 1 and 2, above the anterior axillary line), lateral (zones 3 and 4, between the anterior and posterior axillary lines), and posterior (zones 5 and 6, below the posterior axillary line) regions, each further subdivided into superior (odd-numbered zones) and inferior (even-numbered zones) segments (Fig. 1). The worst aeration pattern in each zone was recorded. Ultrasound images were analysed by 2 independent physicians blinded to the anaesthesia type. Each zone was scored from 0 to 3 based on a modified LUS scoring system. The total LUS score ranged from 0, indicating normal aeration, to 36, representing complete loss of aeration.[8]

Pulmonary function tests (PFTs) were performed using a MiniSpir Light device (MIR, Rome, Italy). The assessed parameters included forced expiratory volume in 1 second (FEV_1), percentage of predicted FEV_1 (FEV_1% predicted), forced vital capacity (FVC), percentage of predicted FVC (FVC% predicted), FEV_1/FVC ratio, percentage of predicted FEV_1/FVC ratio (FEV_1/FVC% predicted), forced expiratory flow at 25%–75% of pulmonary volume (FEF_{25-75}), and percentage of predicted FEF_{25-75} (FEF_{25-75}% predicted). PFT could not be completed in 1 patient from each group because of cognitive impairment. Haemodynamic parameters, including blood pressure, heart rate, and peripheral oxygen saturation, were recorded every 15 minutes during surgery. In the general anaesthesia group, end-tidal CO_2 levels were continuously monitored. The duration of anaesthesia and surgery was documented. ABG analysis, which measured pH, $PaCO_2$, PaO_2, SaO_2, and the PaO_2/FiO_2 ratio, was performed using an ABL800 Flex analyser (Radiometer, Copenhagen, Denmark). The images were analysed using a blinded assessment, with evaluators unaware of the patient information.

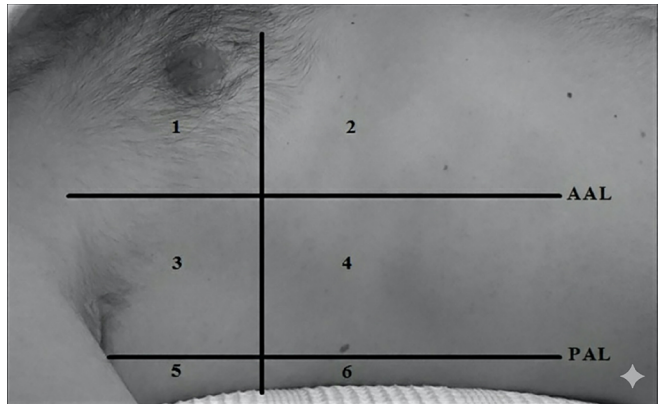

Figure 1. Standardised 12-zone lung ultrasound scanning zones.

Each hemithorax was divided into six regions according to a modified lung ultrasound (LUS) scoring framework: anterior (zones 1–2), lateral (zones 3–4), and posterior (zones 5–6), based on the anterior and posterior axillary lines. Each region was further subdivided into superior (odd-numbered) and inferior (even-numbered) zones. The image is provided for illustrative purposes to demonstrate lung ultrasound scanning zones and anatomical landmarks.

The primary outcome of this study was the change in the total LUS score between the preoperative and postoperative assessments, which served as the principal pulmonary function measure. Secondary outcomes included alterations in pulmonary function test (PFT) parameters, specifically forced expiratory volume in 1 second (FEV_1), forced vital capacity (FVC), and forced expiratory flow at 25%–75% of pulmonary volume (FEF_{25-75}). In addition, arterial blood gas (ABG) variables, including the partial pressures of oxygen (PaO_2) and carbon dioxide ($PaCO_2$), were analysed to assess respiratory gas exchange efficiency. It should be noted that spirometry data from 1 patient in each group were excluded due to cognitive impairment, and the missing data points were appropriately documented to ensure the integrity of the dataset.

Statistical Analysis

Statistical analyses were performed using Python version 3.12 with the SciPy (version 1.11), Statsmodels (version 0.14), and Pandas (version 2.0) libraries. The normality of continuous variables was assessed using the Shapiro-Wilk test. Variables following a normal distribution are presented as mean±standard deviation and were compared using

Table 1. Baseline demographic and clinical characteristics

Variable	Regional (n=30)	General (n=30)	p
Age (years)	45.6±15.3	41.3±14.9	0.283
BMI (kg/m^2)	27.6±5.0	27.9±4.5	0.824
ASA I / II / III, n	7 / 18 / 5	11 / 16 / 3	0.425
Surgery duration (min)	95.5±28.5	89.7±30.2	0.446
Anaesthesia duration (min)	123.8±32.1	118.2±33.5	0.514
Baseline LUS score	13.03±3.60	12.70±3.29	0.717

Data are presented as mean±SD or n. P values from independent t-test or chi-square test. SD: Standard deviation; BMI: Body mass index; ASA: American Society of Anesthesiologists physical status classification; LUS: Lung ultrasound.

Table 2. Primary outcome: Change in lung ultrasound score

Parameter	Regional (n=30)	General (n=30)	Difference	p
Preoperative LUS	13.03±3.60	12.70±3.29	0.33	0.717
Postoperative LUS	14.93±3.77	19.23±3.08	-4.30	<0.001
ΔLUS (Post–Pre)	1.90±3.26	6.53±2.90	-4.63	<0.001
Cohen's d	–	–	1.50	–
NNT (95% CI)	–	–	2.5 (1.6–5.7)	–

Data are presented as mean±SD. Effect size: Cohen's d>0.8 indicates large effect. SD: Standard deviation; LUS: Lung ultrasound score (range 0–36); ΔLUS: change in LUS; NNT: Number needed to treat; CI: Confidence interval.

the independent samples t-test for between-group comparisons and the paired samples t-test for within-group preoperative-to-postoperative comparisons. Variables that did not follow a normal distribution are presented as medians (interquartile range) and were compared using the Mann-Whitney U test for between-group comparisons and the Wilcoxon signed-rank test for within-group comparisons. Categorical variables were analysed using the chi-square test or Fisher's exact test, as appropriate. Effect sizes for continuous outcomes were calculated using Cohen's d, with 95% confidence intervals derived from 10,000 bootstrap resampling. Effect sizes were interpreted as small (d=0.2), medium (d=0.5), or large (d≥0.8). Analysis of covariance (ANCOVA) was performed to evaluate between-group differences in postoperative LUS scores after adjusting for potential confounders, including age, body mass index, ASA physical status, duration of surgery, and baseline LUS score. The number needed to treat (NNT) was calculated for clinically significant atelectasis (ΔLUS≥4 cm). All tests were two-tailed, and statistical significance was set at $p<0.05$.

Results

A total of 68 patients were assessed for eligibility, of whom 60 met the inclusion criteria and were allocated to receive either regional (n=30) or general anaesthesia (n=30). All included patients completed the study protocol, and there were no crossovers between the groups. Data from all 60 patients were included in this analysis.

Baseline demographic characteristics and surgical variables were well balanced between the 2 groups (Table 1). Importantly, preoperative total LUS scores were comparable between the groups (regional: 13.03±3.60 vs. general: 12.70±3.29; p=0.717), indicating baseline comparability with respect to pulmonary status.

The primary outcome, change in the total LUS score from preoperative to postoperative assessment (ΔLUS), is summarized in Table 2. Individual patient trajectories of LUS scores from baseline to postoperative measurements are illustrated in Figure 2.

Patients in the regional anaesthesia group demonstrated significantly smaller increases in LUS scores than those in the general anaesthesia group. The mean ΔLUS was 1.90±3.26 points in the regional anaesthesia group versus 6.53±2.90 points in the general anaesthesia group, representing a mean difference of 4.63 points (95% confidence interval [CI]: 3.03–6.24; $p<0.001$). The effect size was very large (Cohen's d=1.50), indicating a clinically meaningful difference between the anaesthetic techniques.

Analysis of individual lung zones revealed that general anaesthesia was associated with greater aeration loss across all examined regions (Table 3, Fig. 3). The anatomical heatmap (Fig. 3) shows the distribution of ΔLUS values across all 12 lung zones in both groups, demonstrating uniformly greater aeration loss in the general anaesthesia group.

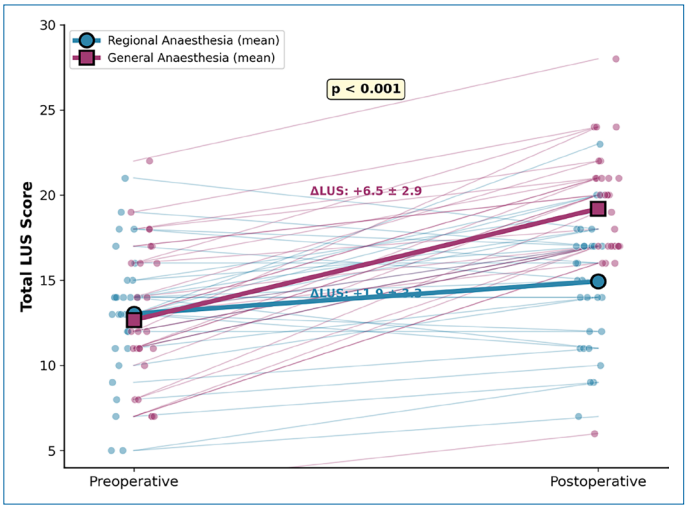

Figure 2. Individual patient trajectories of lung ultrasound scores.

Spaghetti plot demonstrating individual patient changes in total LUS score from preoperative to postoperative measurements. Each thin line represents a single patient trajectory, with blue lines indicating regional anaesthesia (n=30) and magenta lines indicating general anaesthesia (n=30). Bold lines with markers represent group means±standard error of the mean (SEM). Individual data points are shown at each timepoint with slight horizontal jitter for visibility. The regional anaesthesia group demonstrated minimal change (ΔLUS: +1.9±3.3), whilst the general anaesthesia group showed substantial increases (ΔLUS: +6.5±2.9). Between-group difference was statistically significant (p<0.001). Note the consistent upward trajectory in the general anaesthesia group contrasted with the heterogeneous responses in the regional group, where several patients showed no change or slight improvement.

The right lung demonstrated a ΔLUS of 1.17±1.78 in the regional anaesthesia group compared with 3.73±1.48 in the general anaesthesia group (p<0.001). Similarly, the left lung ΔLUS was significantly lower in the regional anaesthesia group (0.73±1.98 vs. 2.80±2.37; p=0.001). When stratified by anatomical position relative to the axillary lines, all regions showed significantly greater aeration loss in the general anaesthesia group: anterior (0.80±1.49 vs. 2.20±1.95; p=0.004), lateral (0.47±1.41 vs. 2.37±1.40; p<0.001), and posterior zones (0.63±1.87 vs. 1.97±1.47; p=0.007). The lateral lung zones demonstrated the most pronounced between-group differences (Cohen's d=1.35).

Using a predefined threshold of ΔLUS≥4 points to indicate clinically significant atelectasis, 11 of 30 patients (36.7%) in the regional anaesthesia group met this criterion, compared with 23 of 30 patients (76.7%) in the general anaesthesia group (Fig. 2). This yielded an absolute risk reduction of 40.0% (95% CI: 17.4%–62.6%), a relative risk of 2.09, and a number needed to treat of 2.5, indicating that for every 2–3 patients managed with regional rather than general anaesthesia, 1 case of clinically significant perioperative atelectasis would be avoided.

To assess whether the observed difference in ΔLUS remained significant after adjusting for potential confounders, an analysis of covariance (ANCOVA) was performed (Table 4). After adjusting for age, BMI, baseline LUS score, and surgery duration, the group effect remained highly significant (β=4.79; 95% CI: 3.24–6.33; p<0.001). The model explained 51.3% of the variance in ΔLUS (R^2=0.513). Baseline LUS score was a significant predictor (β=−0.30; p=0.013), indicating that patients with higher preoperative scores tended to show smaller increases. Neither age, BMI, nor surgery duration significantly influenced the primary outcome.

The secondary outcome measures, including arterial blood gas parameters and pulmonary function tests, are listed in Table 5. The intraoperative haemodynamic profiles, including SpO_2 and mean arterial pressure (MAP) over time, are illustrated in Figure 4. The postoperative PaO_2/FiO_2 (P/F) ratio did not differ between the groups (regional: 431.4±96.4 vs. general: 468.7±92.6; p=0.167). The change in the P/F ratio from baseline to postoperative measurement did not differ between the groups (regional: −2.9±79.3 vs. general: −25.7±93.3; p=0.460), with no correlation between ΔLUS and the postoperative P/F ratio (Spearman ρ=−0.158; p=0.227). Hypoxaemia (P/F ratio <300 mmHg) occurred in 1 patient (3.3%) in the regional anaesthesia group and in no patients in the general anaesthesia group (p=1.000). Both groups showed postoperative declines in spirometric parameters. FEV_1 decreased by 0.27±0.38 L (−10.0%) in the regional anaesthesia group and by 0.28±0.33 L (−11.7%) in the general anaesthesia group, with no significant between-group difference (p=0.834). FVC declined comparably in

Table 3. Regional analysis of lung ultrasound score changes by anatomical zone

Region	Regional Δ	General Δ	Diff	Cohen's d	p
Right lung (zones 1–6)	1.17±1.78	3.73±1.48	-2.57	1.57	<0.001
Left lung (zones 1–6)	0.73±1.98	2.80±2.37	-2.07	0.95	0.001
Anterior (zones 1–2)	0.80±1.49	2.20±1.95	-1.40	0.81	0.004
Lateral (zones 3–4)	0.47±1.41	2.37±1.40	-1.90	1.35	<0.001
Posterior (zones 5–6)	0.63±1.87	1.97±1.47	-1.33	0.79	0.007

Data are presented as mean ΔLUS±SD. ΔLUS=change in lung ultrasound score (postoperative – preoperative). Zones are defined relative to axillary lines: anterior (zones 1–2)=above the anterior axillary line; lateral (zones 3–4)=between anterior and posterior axillary lines; posterior (zones 5–6)=below the posterior axillary line. Within each region, odd-numbered zones represent the superior and even-numbered zones represent the inferior hemithorax. P values from independent t-test.

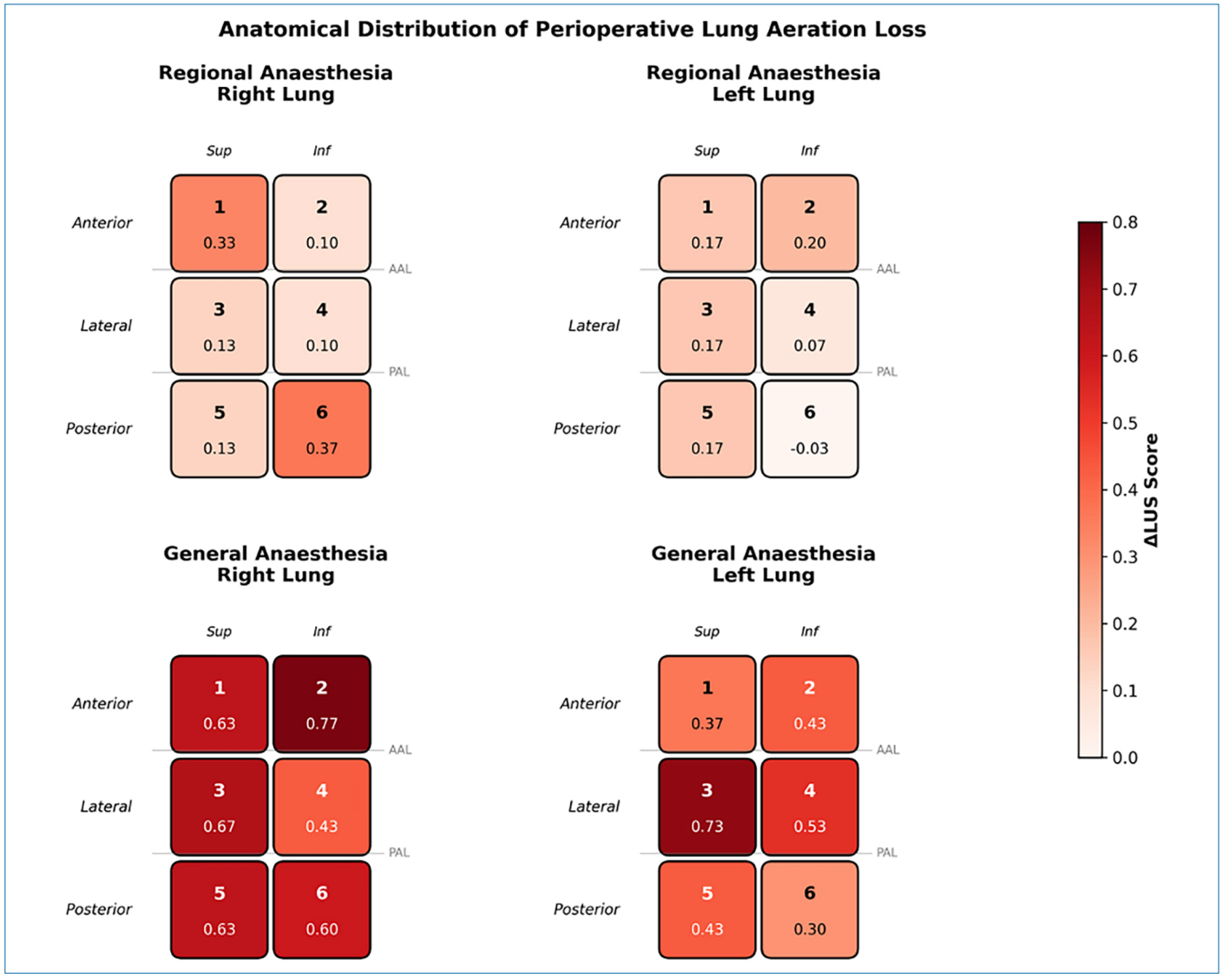

Figure 3. Anatomical distribution of perioperative lung aeration loss.

Heatmap representation of the mean change in lung ultrasound (LUS) scores (ΔLUS=postoperative − preoperative) across six anatomical zones for each lung. Zones are displayed according to the standardised 12-zone LUS framework illustrated in Figure 1, with rows representing anterior, lateral, and posterior regions and columns representing superior and inferior divisions. Colour intensity indicates magnitude of aeration loss, with darker red representing greater ΔLUS values. The colour scale (0–0.8) is consistent across all panels. Note the uniformly greater aeration loss across all zones in the general anaesthesia group compared with the regional anaesthesia group, with the highest values observed in the right lung anterior-inferior zone (R2: 0.77) and left lung lateral-superior zone (L3: 0.73) in the general anaesthesia group.

both groups (p=0.780). The general anaesthesia group showed a greater decline in $FEF_{25–75}$ compared with the regional anaesthesia group (−19.0±22.1% vs. −5.5±14.9%; p=0.008), suggesting preferential impairment of small airway function after general anaesthesia. Blood gas analysis showed comparable postoperative pH values between the groups (regional: 7.40±0.04 vs. general: 7.38±0.04; p=0.073). The general anaesthesia group had higher $PaCO_2$ (39.6±5.2 vs. 36.7±4.6 mmHg; p=0.030) and lower bicarbonate levels (22.5±2.2 vs. 23.9±2.4 mEq/L; p=0.023), consistent with mild respiratory acidosis. Intraoperative monitoring showed that patients who received regional anaesthesia maintained a higher MAP throughout surgery than those who received general anaesthesia, despite the latter group receiving supplemental oxygen (FiO_2 0.4–0.5) versus room air. SpO_2 levels remained within acceptable limits in both groups.

No serious adverse events were observed in either group. Transient intraoperative hypotension (MAP <65 mmHg) requiring vasopressor support occurred in 3 patients (10%) in the general anaesthesia group and 1 patient (3.3%) in the regional anaesthesia group. Postoperative nausea and vomiting occurred in 7 patients (23.3%) who received general anaesthesia compared with 2 patients (6.7%) in the regional anaesthesia group (p=0.145). No patient required unplanned intensive care admission or experienced respiratory failure.

Table 4. ANCOVA Results for ΔLUS

Variable	β	SE	95% CI	t	p
Intercept	5.30	2.88	-0.48, 11.09	1.84	0.071
Group (General vs Regional)	4.79	0.77	3.24, 6.33	6.22	<0.001
Age (years)	-0.01	0.02	-0.06, 0.04	-0.42	0.679
BMI (kg/m^2)	-0.02	0.07	-0.15, 0.11	-0.31	0.756
Baseline LUS	-0.30	0.12	-0.53, –0.07	-2.57	0.013
Surgery duration (min)	0.01	0.01	-0.01, 0.03	0.82	0.414

Model R^2: 0.513. ANCOVA: Analysis of covariance; β: Unstandardised coefficient; SE: Standard error; CI: Confidence interval; BMI: Body mass index; LUS: Lung ultrasound.

Table 5. Secondary outcomes: Arterial blood gas and pulmonary function

Parameter	Regional Pre	Regional Post	General Pre	General Post	p (Post)	p (Δ)
pH	7.41±0.03	7.40±0.04	7.40±0.04	7.38±0.04	0.073	0.126
$PaCO_2$ (mmHg)	36.5±4.4	36.7±4.6	37.2±4.8	39.6±5.2	0.030	0.040
HCO_3^- (mEq/L)	24.1±2.3	23.9±2.4	23.8±2.1	22.5±2.2	0.023	0.046
P/F ratio	434.2±70.6	431.4±96.4	494.3±66.7	468.7±92.6	0.167	0.460
FEV_1 (L)	2.69±0.72	2.42±0.66	2.45±0.64	2.17±0.62	0.143	0.834
FVC (L)	3.29±0.85	2.88±0.78	3.07±0.81	2.63±0.74	0.214	0.780
$FEF_{25–75}$ (% pred)	79.2±24.1	73.7±22.8	76.8±22.5	57.8±20.3	0.007	0.008

Data are presented as mean±SD. P/F ratio: PaO_2/FiO_2 ratio; FEV_1: Forced expiratory volume in one second; FVC: Forced vital capacity; $FEF_{25–75}$: Forced expiratory flow at 25–75% of FVC. p (Post) = between-group comparison of postoperative values; p (Δ) = between-group comparison of change from baseline.

Discussion

This prospective observational study compared the effects of regional and general anaesthesia on perioperative lung aeration in patients undergoing lower extremity orthopaedic surgery using a 12-zone LUS protocol. Regional anaesthesia was associated with better preservation of lung aeration than general anaesthesia, with patients showing a mean ΔLUS of 1.90±3.26 points versus 6.53±2.90 points in the general anaesthesia group (p<0.001). This difference (Cohen's d=1.50) translated into meaningful outcomes: 76.7% of patients receiving general anaesthesia developed clinically significant atelectasis (ΔLUS≥4) compared with 36.7% in the regional anaesthesia group, yielding a number needed to treat of 2.5. The protective effect was consistent across lung zones, with the right lung showing the most pronounced differences (Cohen's d=1.57), followed by the lateral zones (Cohen's d=1.35). Although both groups showed similar postoperative declines in FEV_1 (−10.0% vs. −11.7%; p=0.834) and FVC (p=0.780), general anaesthesia led to greater small airway impairment, as shown by a larger decline in $FEF_{25–75}$ (−19.0±22.1% vs. −5.5±14.9%; p=0.008). This impairment, with mild respiratory acidosis shown by elevated $PaCO_2$ (39.6±5.2 vs. 36.7±4.6 mmHg; p=0.030) and reduced bicarbonate levels (22.5±2.2 vs. 23.9±2.4 mEq/L; p=0.023), suggests mechanisms beyond alveolar collapse, possibly related to volatile anaesthetics, neuromuscular blocking agents, or prolonged supine positioning.

After adjusting for age, BMI, baseline LUS score, and surgery duration, the effect of the anaesthetic technique on ΔLUS remained significant (β=4.79; 95% CI: 3.24–6.33; p<0.001), with the model explaining 51.3% of the variance. Baseline LUS score emerged as a significant predictor (β=-0.30; p=0.013), suggesting that patients with higher preoperative scores may have a lower capacity for deterioration and supporting the utility of preoperative LUS assessment.

Our findings regarding LUS reliability are consistent with those of previous studies. Yu et al.[10] demonstrated that LUS has a sensitivity of 87.7% and specificity of 92.1% for detecting perioperative atelectasis when compared with computed tomography as the gold standard, with a significant correlation between LUS scores and atelectasis volume (r=0.58, p<0.0001). Similarly, Monastesse et al.[8] reported a moderate negative correlation (r=-0.43, p=0.008) between LUS scores and oxygenation parameters in their pilot feasibility study involving 30 patients. Bouhemad et al.[11] further validated the quantitative capability of LUS by demonstrating an excellent correlation (rho=0.88) between LUS-derived aeration scores and PEEP-induced lung recruitment in patients with ARDS.

The high prevalence of postoperative atelectasis observed in our study aligns with the comprehensive review by Lagier et al.,[3] who reported that atelectasis occurs in 85%–90% of patients undergoing general anaesthesia. Duggan and Kavanagh, in their seminal review on perioperative

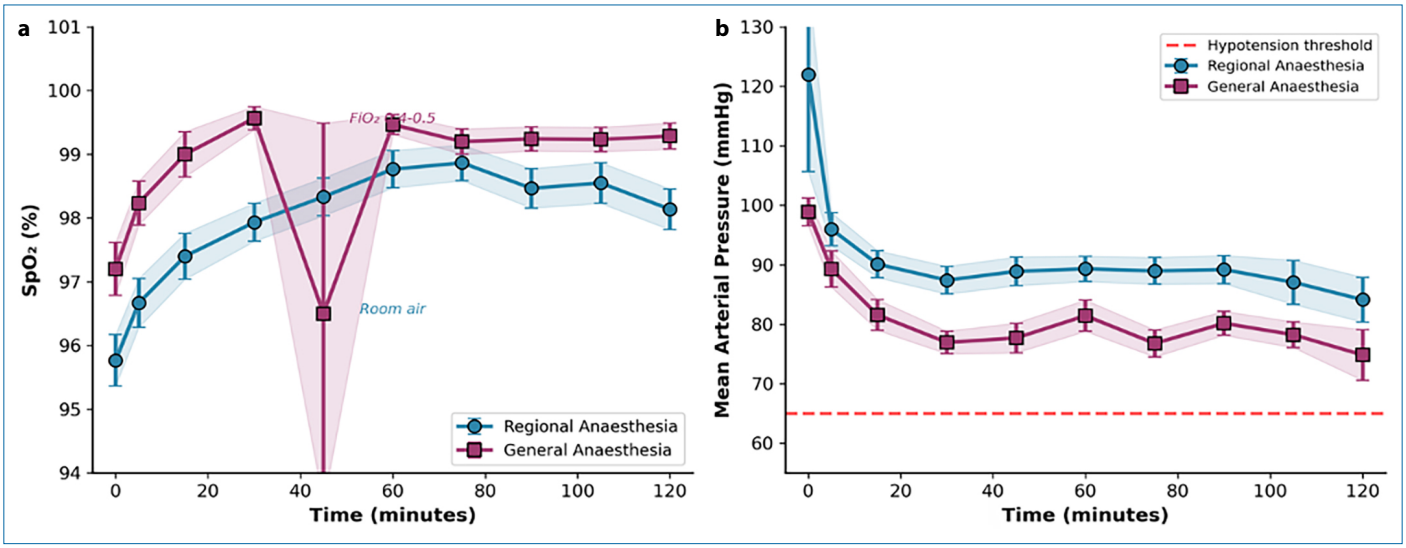

Figure 4. Intraoperative haemodynamic profiles. **(a)** Peripheral oxygen saturation (SpO_2) over time. Regional anaesthesia patients (blue circles) breathed room air (FiO_2 0.21), whilst general anaesthesia patients (magenta squares) received supplemental oxygen (FiO_2 0.4–0.5). Despite lower inspired oxygen fraction, regional anaesthesia patients maintained adequate oxygenation throughout surgery. General anaesthesia patients showed initial SpO_2 elevation followed by a transient decrease around 45–60 minutes, likely corresponding to anaesthesia-induced atelectasis development. **(b)** Mean arterial pressure (MAP) over time. The horizontal red dashed line indicates the hypotension threshold (65 mmHg). Regional anaesthesia patients maintained consistently higher MAP values throughout the procedure compared to general anaesthesia patients. Both groups showed initial decreases following anaesthesia induction, but the general anaesthesia group demonstrated more pronounced and sustained hypotension, approaching the clinical threshold. Data are presented as mean ± SEM with shaded areas representing the standard error. Time points: 0, 5, 15, 30, 45, 60, 75, 90, 105, and 120 minutes from anaesthesia induction.

AAL: Anterior axillary line; ΔLUS: Change in lung ultrasound score; FiO_2: Fraction of inspired oxygen; LUS: Lung ultrasound; MAP: Mean arterial pressure; PAL: Posterior axillary line; SEM: Standard error of the mean; SpO_2: peripheral oxygen saturation.

atelectasis pathophysiology, described 3 primary mechanisms: compression atelectasis from diaphragmatic cephalad displacement, absorption atelectasis from high inspired oxygen concentrations, and loss of surfactant function.[12] In the context of orthopaedic surgery, Song et al.[13] reported a 45.9% incidence of early PPCs following TKA when assessed by CT scan, with atelectasis present in 12.6% and pleural effusion in 38.7% of patients. Chai et al.[1] found that among elderly patients (≥80 years) undergoing femur fracture surgery, the overall PPC rate was 11.7%, with atelectasis accounting for 3.5%.

The protective effect of regional anaesthesia on pulmonary outcomes observed in our study is supported by large-scale evidence. The ICAROS meta-analysis by Memtsoudis et al.,[14] encompassing 94 studies, demonstrated that neuraxial anaesthesia was associated with reduced mortality (OR 0.67–0.83) and fewer pulmonary complications (OR 0.65–0.69) than general anaesthesia in patients who underwent orthopaedic surgery.

An unexpected finding was the absence of significant intergroup differences in postoperative oxygenation, despite the marked disparity in lung aeration scores. The PaO_2/FiO_2 ratio did not differ significantly between the regional and general anaesthesia groups (431.4±96.4 vs. 468.7±92.6; p=0.167), and no correlation was observed between ΔLUS and the postoperative P/F ratio (Spearman ρ=-0.158; p=0.227). This dissociation between structural (ultrasound-detected atelectasis) and functional (oxygenation) parameters may reflect the compensatory mechanisms of hypoxic pulmonary vasoconstriction, the relatively healthy baseline pulmonary status of our cohort, or the possibility that the degree of atelectasis, while statistically significant, remained below the threshold required to produce measurable hypoxaemia in spontaneously breathing patients. Similar discordance has been reported in previous studies, underscoring the importance of multimodal assessment in perioperative pulmonary evaluations.[15]

The findings of this study have several important clinical implications. First, LUS has emerged as a practical bedside tool for perioperative pulmonary monitoring, offering advantages over chest radiography in terms of portability, absence of radiation exposure, and real-time assessment capability. Touw et al.[5] demonstrated that LUS detected clinically relevant PPCs earlier and more accurately than chest X-ray following cardiothoracic surgery. Mayo et al.[7] emphasised in their comprehensive narrative review that thoracic ultrasonography can largely

replace chest imaging in critical care practice due to its ease of use, rapidity, repeatability, and reliability. Second, the integration of point-of-care ultrasound (POCUS) into anaesthesiology practice, as advocated by Gohad and Jain, allows individualised ventilatory management and early detection of respiratory complications.[9] Third, our results suggest that regional anaesthesia techniques may offer pulmonary benefits when feasible, particularly in patients with pre-existing pulmonary risk factors.

Both anaesthetic techniques were well tolerated, with no serious adverse events. The lower incidence of transient intraoperative hypotension (3.3% vs. 10%) and reduced postoperative nausea and vomiting (6.7% vs. 23.3%) in the regional anaesthesia group, although not statistically significant, align with the known advantages of neuraxial anaesthesia. No patient required unplanned intensive care or developed respiratory failure, indicating that the higher incidence of atelectasis in the general anaesthesia group did not cause clinically significant respiratory issues postoperatively.

Limitations

The prospective design with a standardised LUS protocol using 12-region scoring ensured methodological rigor. LUS acquisition was performed by a single trained investigator, while image scoring was conducted by 2 independent blinded physicians, thereby minimising both acquisition and interobserver variability. The inclusion of patients who underwent TKA and THA enhanced the generalisability of the study to major lower extremity surgeries. However, this study has several limitations. The small sample size (n=60) limited the statistical power for subgroup analyses. The single-centre design may restrict generalisability. The non-randomised anaesthetic allocation introduced selection bias, as patients receiving regional anaesthesia may have differed from those receiving general anaesthesia. However, baseline characteristics were comparable between the groups. Nevertheless, unmeasured confounders and confounding by indication cannot be excluded. The lack of CT imaging prevented direct validation of the LUS findings. Short-term follow-up, limited to the postoperative period, did not capture the resolution of atelectasis. We did not assess functional outcomes, such as hospital length of stay or pulmonary complication rates. The operator-dependent nature of LUS may introduce variability in measurements. The lack of correlation between ΔLUS and postoperative oxygenation parameters limits the establishment of a link between ultrasound-detected aeration loss and respiratory impairment. Excluding patients with pre-existing pulmonary disease limits the applicability of the study to higher-risk populations.

Future research should focus on multicentre randomised controlled trials with larger sample sizes, longer follow-up periods, and endpoints including PPCs, hospital stay, and 30-day morbidity. Studies should examine the impact of LUS-guided recruitment manoeuvres on outcomes. Advanced automated interpretation methods may enhance perioperative clinical utility.

Conclusion

In conclusion, this study suggests that general anaesthesia may be associated with greater postoperative lung aeration loss compared with regional anaesthesia in patients undergoing lower extremity orthopaedic surgery. Lung ultrasonography appears to be a valuable, noninvasive bedside tool for the early detection and quantification of perioperative lung atelectasis. These findings indicate a potential advantage of regional anaesthesia in terms of lung aeration and may be associated with a lower risk of pulmonary complications, although clinical outcomes were not directly assessed. These results support the potential role of point-of-care lung ultrasonography in perioperative assessment. Confirmation of the pulmonary benefits of neuraxial techniques through randomised controlled trials is warranted.

Disclosures

Ethics Committee Approval: The study was approved by the Marmara University Ethics Committee (no: 09.2017.133, date: 03/02/2017).

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CASE REPORT

Airway Management During Tracheal Resection: Intraoperative Retrograde Intubation—A Case Report

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ABSTRACT

Tracheal stenosis most commonly occurs following prolonged endotracheal intubation or tracheostomy after intensive care treatment. Airway management during tracheal resection is challenging due to changes in airway anatomy and the need to maintain adequate oxygenation and ventilation while preserving the anastomotic line. This case report presents the anesthetic management of a 29-year-old male patient who developed upper tracheal stenosis following prolonged intubation. During tracheal resection surgery, cross-field ventilation via the tracheostomy site was initially used. Since head and neck extension could not be safely performed due to the risk of anastomotic injury, retrograde intubation was performed intraoperatively using a tube-changing catheter. The procedure was successfully completed with a short apnea period and without complications. The patient was safely extubated and discharged on the eighth postoperative day. This case highlights that retrograde intubation can be an effective and safe alternative airway management technique during tracheal resection when conventional intubation methods cannot be applied.

Keywords: Airway management, anesthetic management, thoracic anesthesia, tracheal resection, tracheal stenosis.

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Introduction

Tracheal stenosis most commonly arises iatrogenically due to prolonged endotracheal intubation or tracheostomy during intensive care following trauma.[1,2] Other causes of tracheal stenosis include chronic inflammatory diseases, benign and malignant neoplasms, and collagen vascular diseases.[3] The incidence of tracheal stenosis has been reported as 6–21% after endotracheal intubation and 0.6–21% after tracheostomy.[3] Pressure-related mucosal injury and regional ischemia caused by exposure to endotracheal tubes and rigid tracheostomy cannulas used for ventilatory support play a role in the etiology.[4] Despite technological advances, iatrogenic tracheal stenosis arising from endotracheal tube and tracheostomy cannula designs remains the primary indication for tracheal resection and reconstruction.[5] High endotracheal tube cuff pressure and rigid tracheostomy cannulas are frequently responsible for this condition.[5,6]

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Airway management in cases of tracheal stenosis varies depending on the location, size, and nature of the stenosis, as well as the planned surgical procedure. In this study, we present the anesthesia management approach applied in a patient who underwent surgery for upper tracheal stenosis due to prolonged intubation in the intensive care unit and who was intubated retrogradely from the tracheostomy site during tracheal resection.

Case Report

A 29-year-old male patient was intubated in the intensive care unit following a motorcycle accident, and a tracheostomy was performed on day 21. On day 70, computed tomography (CT) imaging was performed due to complaints of dyspnea and wheezing (Fig. 1). Proximal tracheal stenosis was suspected, and preoperative fiberoptic bronchoscopy (FOB) was performed. After stenosis was observed 1.5 cm below the vocal cords and above the tracheostomy site, tracheal resection was planned.

The patient was transferred to the operating room with oxygen support via a tracheostomy tube (Bıçakcılar, Türkiye), and preoxygenation with 100% oxygen was administered for five minutes. Standard hemodynamic monitoring, including electrocardiography, non-invasive arterial blood pressure, and pulse oximetry, as well as bispectral index (BIS) monitoring, was performed. The patient was administered 0.03 mg/kg intravenous midazolam. An arterial cannula was placed in the right radial artery for invasive arterial pressure monitoring.

Anesthesia induction was achieved with 1 mg/kg lidocaine, 2 mg/kg propofol, 50 mcg fentanyl, and 0.6 mg/kg rocuronium. Initially, ventilation was provided by connecting the ventilator circuit to the tracheostomy cannula (Fig. 2). Following anesthesia induction, a catheter was inserted into the right jugular vein. Anesthesia maintenance was provided with total intravenous anesthesia using propofol (25–50 mcg/kg/min) and remifentanil (0.1–0.8 mcg/kg/min). BIS values were maintained between 40 and 60. Intraoperative arterial blood gas monitoring was performed (Table 1).

After induction, the tracheostomy cannula was removed. The patient was intubated through the tracheostomy opening with a 6.5-mm internal diameter spiral endotracheal tube (Bıçakcılar, Türkiye), and intraoperative positive pressure ventilation was applied, with peak airway pressure maintained below 30 cmH_2O. A collar incision was performed. The lesion was 4 cm in length and involved the first five tracheal rings. The affected segment was resected proximally (Fig. 3).

To reduce tension on the posterior wall of the anastomosis, the neck was positioned in flexion during surgery. Retrograde intubation was performed because correct anatomical alignment for laryngoscopic intubation could not be achieved. A tube-exchange catheter (Medtronic, USA) was advanced retrogradely from the trachea to the glottis by the surgical team and retrieved orally by the anesthesia team (Fig. 4). After immobilization of the head and neck, a 6.5-mm endotracheal tube (Bıçakcılar, Türkiye) was advanced over the catheter. The apnea period was initiated during this procedure. At the end of the 90-second apnea period, arterial blood gas values were within normal limits (Table 1).

The tube was placed orotracheally into the proximal trachea. Under surgical guidance, the tube was advanced beyond the anastomotic line, and the cuff was inflated distal to the anastomosis, allowing completion of the anastomosis. The operation lasted 285 minutes.

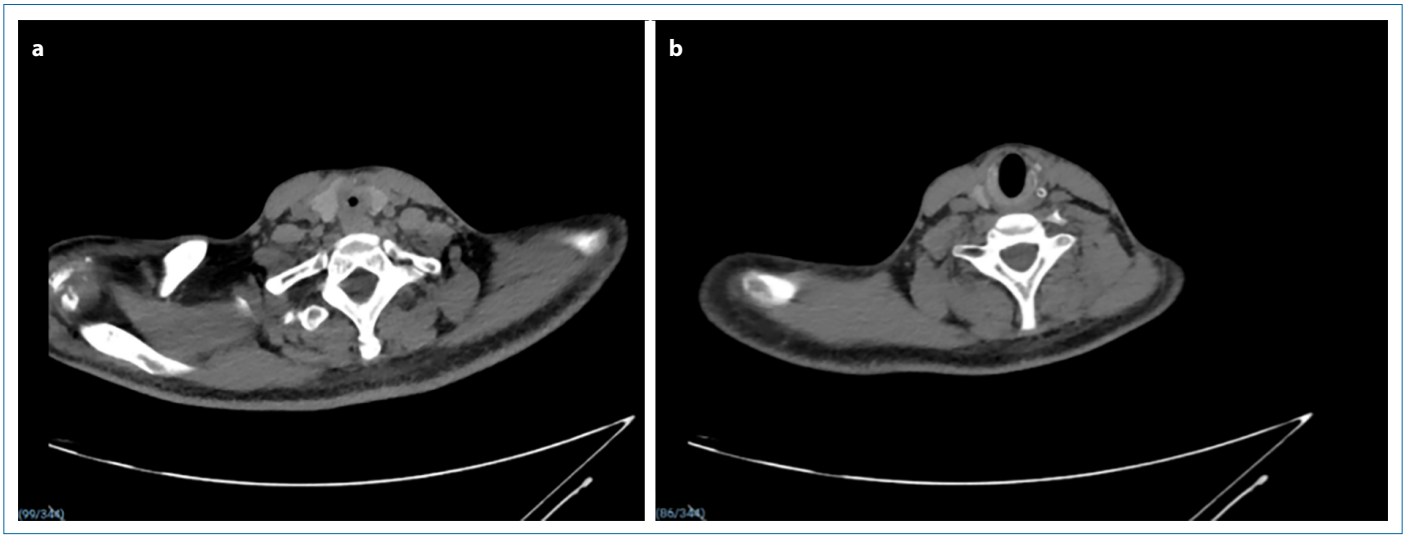

Figure 1. (a) Tracheal lumen at the level of tracheal stenosis. **(b)** Tracheal lumen proximal to the tracheal stenosis.

Figure 2. Intraoperative ventilation through the pre-existing trakeostomy tube before airway reconstruction.

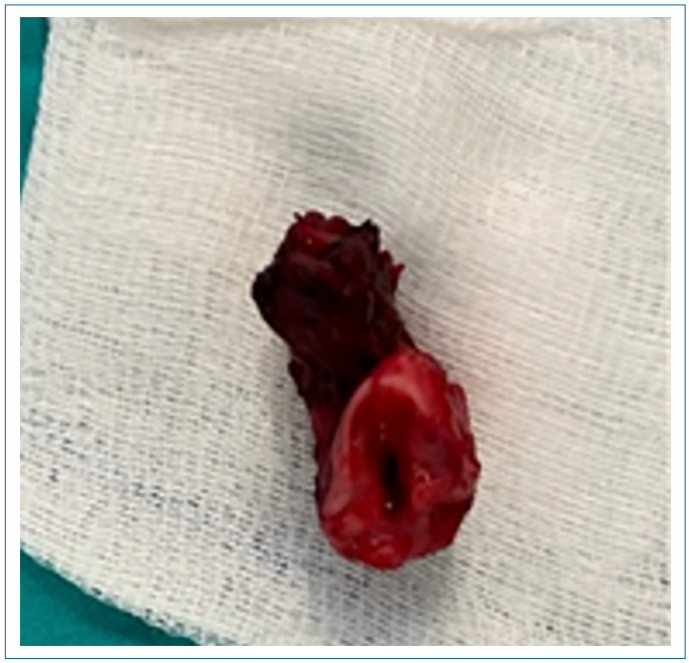

Figure 3. Resected tracheal stenotic segment.

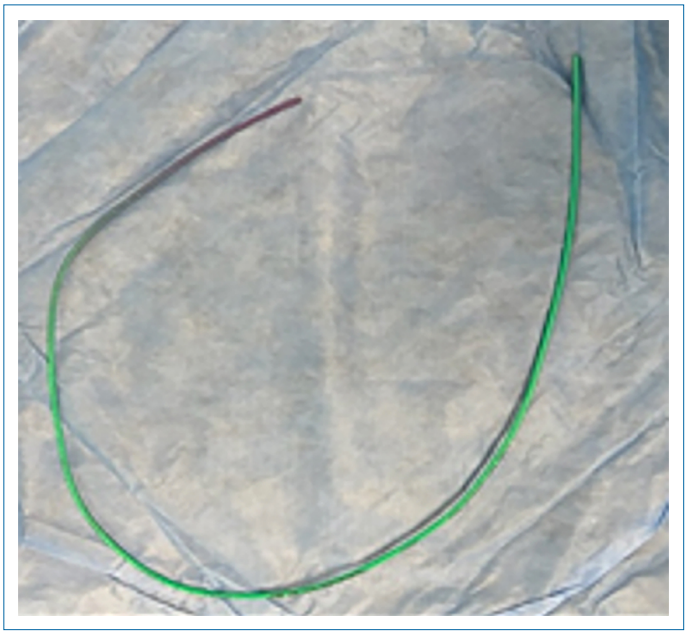

Figure 4. Tube-exchange catheter.

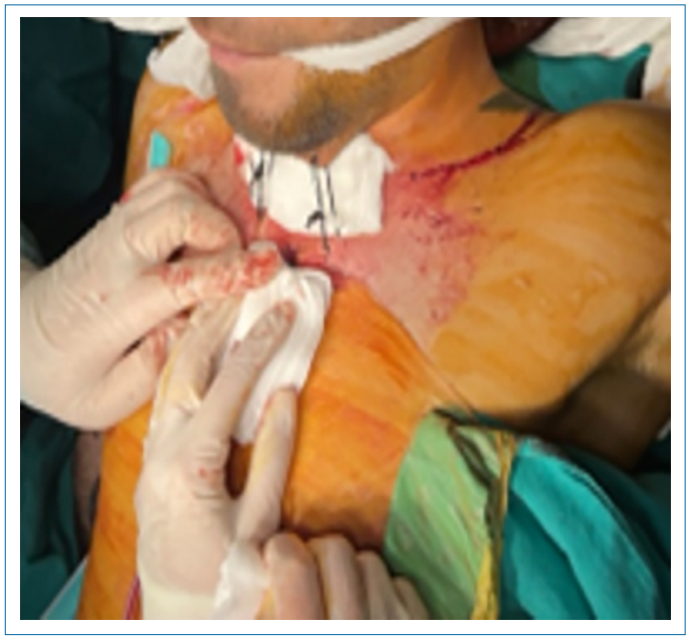

Figure5. Chin-to-chest approximation following tracheal reconstruction.

While the patient's head was flexed, with the chin approximated to the sternum, the chin was sutured to the chest wall (Fig. 5). This prevented involuntary neck movements and protected the posterior wall anastomotic line by maintaining neck flexion. After administration of 2 mg/kg sugammadex, the patient was extubated. The patient developed no complications and was discharged on postoperative day 8.

The steps of the retrograde intubation technique used in this case are schematically illustrated in a figure prepared by the authors (Fig. 6). The complete procedure was explained to the patient, and informed consent was obtained.

Discussion

Anesthetic management in tracheal stenosis is a highly challenging process. The most common causes of tracheal stenosis are iatrogenic and related to intubation and tracheostomy. Risk factors include cartilage and surrounding tissue injury during emergency tracheal

Table 1. Intraoperative arterial blood gas monitoring

Time point	pH	PO_2 (mmHg)	PCO_2 (mmHg)	HCO_3 (actual)	BE (ecf)
15th minute of surgery	7.42	233	40.8	25.9	1.4
75th minute of surgery	7.35	81.1	50.7	27.7	1.3
End of 90-second apnea period	7.30	132.9	57.1	27.9	1.6
15th minute after retrograde intubation	7.38	116.9	42.0	24.4	-0.7
Immediately before extubation	7.44	96.9	39.6	26.6	2.6

BE: Base excess; ECF: Extracellular fluid; HCO_3: Bicarbonate; PCO_2: Partial pressure of carbon dioxide; PO_2: Partial pressure of oxygen.

interventions, high tracheostomy location, high cuff pressure, and irritation related to frequent aspiration.[5,6] The location of the stenosis within the trachea, the patient's general condition, the type of treatment, and the urgency of treatment may vary. The gold standard for diagnosis is demonstration of the stenosis using fiberoptic bronchoscopy.

With advances in imaging techniques, determination of the anatomical location of tracheal stenosis, evaluation of stenosis morphology, and assessment of the percentage of luminal narrowing have increased treatment options. Endoscopic procedures performed under bronchoscopic guidance include steroid injection under granulation tissue; topical application of mitomycin C, 5-fluorouracil, or tranilast to reduce fibroblast proliferation; balloon dilation; laser excision; electrocauterization; argon plasma coagulation; stent placement; and cryotherapy.[7–9] However, endoscopic procedures are generally considered in patients with good overall condition and simple stenosis.[7] In complicated tracheal stenosis after prolonged intubation and tracheostomy, tracheal resection with end-to-end anastomosis is generally the first-line treatment.[6,10] However, due to altered airway anatomy and physiology, a multidisciplinary approach is mandatory.[11] Preoperatively, the anesthesiologist and surgeon should determine a strategy and establish alternative airway management plans.

The main challenge in tracheal resections is the risk of inadequate oxygenation and ventilation due to reduced airway diameter. Providing a safe and maintainable airway during induction and throughout surgery is essential. Adequate clearance of blood and secretions should also be ensured.

Different anesthetic management strategies have been reported in the literature. In patients with limited upper airway lesions, low risk, and the ability to remain immobile under mild sedation, spontaneous ventilation may be considered. Spontaneous ventilation is usually provided with oxygen support under intravenous sedation combined with thoracic epidural anesthesia, cervical plexus block,

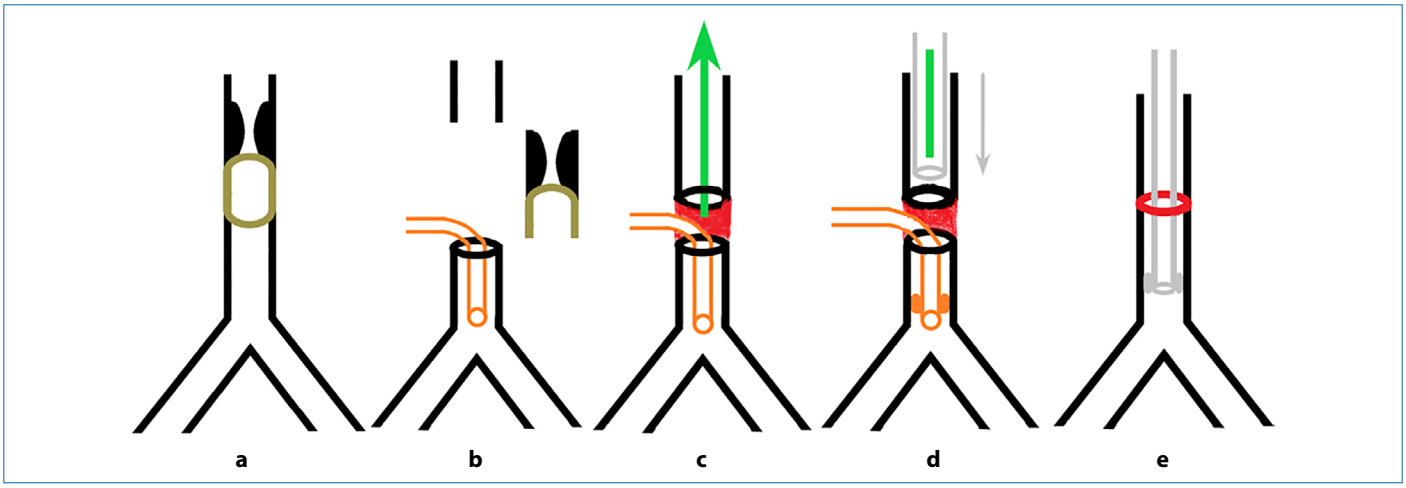

Figure 6. (a) Tracheal stenosis; yellow color indicates the tracheostomy opening. **(b)** Tracheal stenosis removed; orange color indicates the endotracheal tube used for cross-field ventilation. **(c)** Red color indicates the reconstructed posterior wall; green color indicates the direction of the sterile tube exchanger (arrow direction is the same as the advancement direction). **(d)** Endotracheal tube directed from the mouth to the trachea by the anesthesia team using a sterile tube exchanger (arrow direction is the same as the advancement direction). **(e)** Appearance of the endotracheal tube within the tracheal rings approximated with circular sutures; red color indicates the circular suture line of the approximated tracheal rings.

or local infiltration. Surgeries performed under preserved spontaneous breathing may result in fewer complications and faster recovery. Additionally, spontaneous breathing allows easier control of vocal cord movement. However, in cases of intraoperative complications, hypoxia management may be more challenging compared with controlled ventilation with an intubated airway.[10,11]

Supraglottic airway devices are mainly preferred in subglottic stenosis or difficult intubation due to failure of transstenotic tube placement. A laryngeal mask airway (LMA), which allows passage of a fiberoptic bronchoscope, provides improved surgical field visualization after tracheal anastomosis and offers advantages in terms of aspiration risk.[11] Additionally, LMA may reduce stress on the anastomotic line and eliminate endotracheal tube pressure after awakening in appropriate surgeries.[11]

Cross-field ventilation is the most commonly used traditional and safe approach in tracheal resection surgery.[11,12] A sterile endotracheal tube is placed by the surgical team to ventilate the airway distal to the stenosis and connected to the anesthesia machine. After separation of the stenotic segment, the apnea–ventilation–apnea technique is often used to advance an oral endotracheal tube proximal to the stenosis. Then, the sterile endobronchial tube placed by the surgical team is removed, and the standard endotracheal tube is advanced distally. Thus, orotracheal intubation is established. Hypercapnia during the apnea–ventilation–apnea technique is generally tolerated and corrected after anastomosis.[11] In our case, early neck flexion was required to minimize tension on the anastomotic line due to the length of the resected upper tracheal segment. The apnea period lasted 90 seconds, and hypercapnia was monitored with arterial blood gas analysis.

Another option in airway management for tracheal stenosis surgery is venovenous extracorporeal membrane oxygenation (ECMO), especially in centers with sufficient equipment. ECMO may be a reliable alternative in patients with predicted difficult intubation, inability to tolerate hypoxemia or apnea, or a high risk of respiratory or circulatory arrest.[13]

With recent advances, mechanical ventilators combining flow-controlled ventilation and jet ventilation have begun to be used in tracheal resection surgery.[14] Unlike conventional jet ventilation, flow-controlled ventilation allows active expiration and enables end-tidal CO_2 monitoring. Combined use of flow-controlled ventilation and high-frequency jet ventilation may help reduce potential complications.[15]

Successful surgical resection requires adequate preoperative evaluation and localization of the lesion, intraoperative localization and identification of the stricture segment, sufficient mobilization, complete resection of the stenotic segment, and maintenance of tension-free anastomosis.[3] In our case, preoperative evaluation suggested that induction via the tracheostomy cannula would initially be sufficient for airway safety. Intraoperative retrograde intubation was performed to avoid compromising the anastomotic line. Protection of the suture line was critical to prevent postoperative leakage and complications. At the end of surgery, care must be taken to prevent laryngospasm, coughing, and straining, which may negatively affect the anastomosis. In our case, anesthesia depth was monitored using BIS, and the patient was extubated uneventfully. Postoperatively, the patient was able to phonate comfortably, and adequate spontaneous ventilation was observed after extubation.[11]

Conclusion

Anesthetic management in tracheal resection surgery requires careful planning. A secure airway must be established, and effective gas exchange should be maintained by ensuring adequate ventilation. Alternative airway devices and backup plans should be available to experienced anesthesiologists. Different approaches may be selected depending on institutional resources, anesthesiologist experience, and surgical collaboration. Considering these factors in anesthetic management may increase the success rate of tracheal resection surgery.

Disclosures

Ethics Committee Approval: As this study is a single case report, ethics committee approval was not required in accordance with institutional policies.

Informed Consent: The procedure was explained to the patient in detail, and written informed consent was obtained.

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