

Development and Technical Validation of a Novel Digital Decision Support System for Automated CONUT Scoring and Anemia Risk Screening in Outpatient Care

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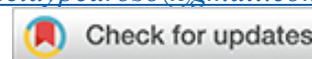
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ABSTRACT

Anemia represents a critical global public health challenge with high prevalence among women of reproductive age and children under five years. Despite its impact, early detection in outpatient settings remains limited due to the scarcity of objective tools that systematically integrate nutritional and hematological parameters for screening purposes. While the Controlling Nutritional Status (CONUT) index is a validated predictor of clinical outcomes, its application is often restricted to hospital settings and relies on manual calculation, which is prone to error and hinders adoption in primary care. In this study, we introduce CONUT-Digital, a novel digital tool designed not only to automate CONUT calculations but also to integrate automated anemia risk assessment directly into the nutritional screening workflow, addressing a critical gap in digital health tools for primary care.

The system was technically validated using a synthetic dataset of 60 clinical profiles, modeled to cover the full spectrum of nutritional risk categories and physiological ranges. The CONUT-Digital system was compared against manual reference calculations, demonstrating 100% agreement in total scores and nutritional classification while successfully processing multiple lymphocyte input formats. These results confirm that digitalization through this tool standardizes the assessment process, minimizes human error, and functions as a strategic screening mechanism to facilitate early detection of anemia risk. By linking routine biochemical parameters to automated clinical risk stratification, CONUT-Digital provides a robust support system for prioritizing nutritional interventions and strengthening public health management.

Keywords: Anemia, Nutritional Screening, Bioinformatics, Clinical Decision Support System, Automated Diagnosis, Primary Care, Malnutrition.

INTRODUCTION

Anemia is a global public health problem, with a high prevalence in women of reproductive age and children under five years old^{1,2}. It is characterized by a decrease in hemoglobin and red blood cells, which reduces oxygen transport and leads to fatigue, weakness, and increased susceptibility to complications^{3,4}. Early detection in outpatient settings is limited, and few studies assess risk using objective nutritional tools, such as the Controlling Nutritional Status (CONUT) score^{5,6}. This index combines determinations of serum albumin,

total cholesterol, and lymphocyte count, and has proven useful as a predictor of clinical outcomes, including anemia, in hospital and geriatric settings^{5,7,8}. However, the evidence is concentrated in hospitals and specific populations, lacking digital applications that automate its calculation in outpatient care^{9,10}.

Globally, in 2021, an estimated 1.92 billion people suffered from anemia (approximately 24% of the population), while in Chile, 21.4% of pregnant women have this condition^{2,11}. These data, along with limitations in early detection and outpatient follow-up, support the need for solutions that integrate nutritional assessment and digital technologies. A digital program that automates the calculation of the CONUT from laboratory results will expedite the early detection of anemia risk, optimize diagnostic accuracy, and support clinical decision-making^{12,13}. In this work, we intend to design, develop, and technically validate, based on simulated clinical scenarios and technical evaluation, a digital calculator for CONUT. In the future, this interdisciplinary approach, combining bioengineering, medical informatics, and clinical nutrition, could help standardize processes, reduce errors, improve the efficiency of nutritional screening, and strengthen anemia prevention in primary care, thereby contributing to public health and clinical practice in Chile.

While CONUT calculators are available digitally, CONUT-Digital represents a novel approach by specifically integrating automated anemia risk estimation into the nutritional screening process—a function not explicitly implemented in current digital tools. Furthermore, its unique capability to process lymphocyte counts in multiple formats (/mm³, 10⁹/L, and %) addresses a significant interoperability challenge between different laboratory information systems. This study introduces the first automated prototype tailored for outpatient settings that links nutritional status directly to anemia probability, thereby filling a critical gap in primary care digital health tools.

MATERIAL AND METHODS

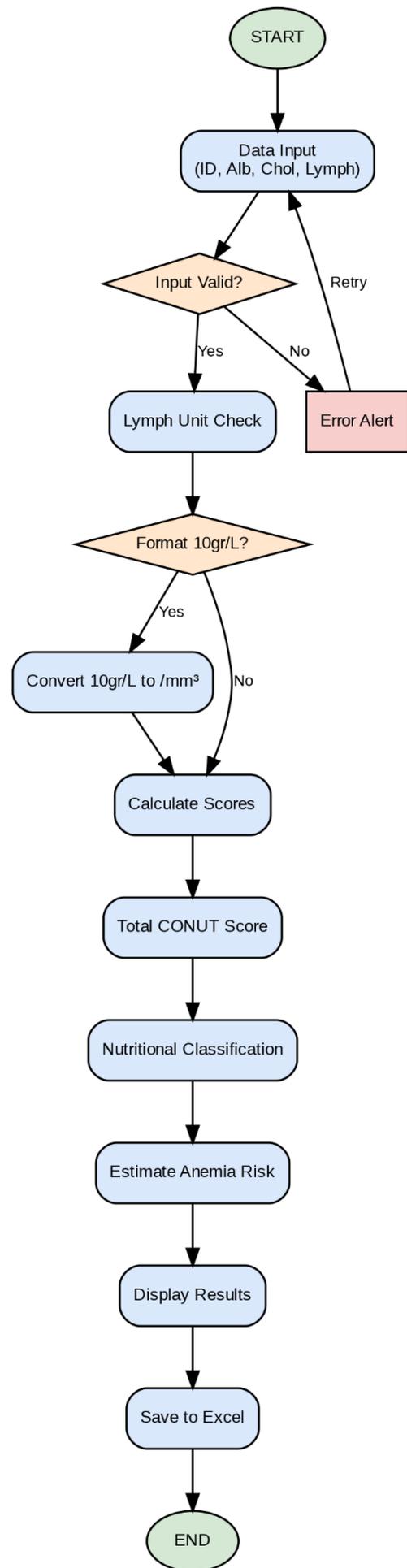
Materials

To perform the calculations, a synthetic dataset of 60 clinical profiles (i.e., patients) was used, specifically modeled to reflect the physiological ranges of hematological patients. These profiles were generated using a controlled randomization process, ensuring the inclusion of biochemical parameters required for the CONUT index (serum albumin, total cholesterol, and total lymphocyte count) across all risk categories (normal, mild, moderate, and severe). Each synthetic case was assigned a unique numerical code to facilitate the comparison between manual calculations and the automated results from the CONUT-Digital system. This approach enabled a rigorous assessment of the calculator's mathematical accuracy and its ability to integrate laboratory parameters without intervention in clinical care.

Visual Studio Code (<https://code.visualstudio.com/>) was used as the programming environment, and Python 3.12 was chosen as the programming language. Several open libraries were employed: Tkinter (For the development and visualization of the user interface), Pandas (For data handling and export), Openpyxl (For creating reports in Excel), Datetime (For temporary file management), Os (for managing operating system files and directories), and Matplotlib (It is used only when the user loads an external database for exploratory analysis; to generate statistical graphs).

Design phase

The design for digitizing the calculation system included several key components: 1) Data entry: the ability to manually enter values or integrate with hospital information systems using interoperability standards¹³. 2) Automatic calculation engine: for immediate assignment of scores to each parameter of the CONUT and generation of the final total score, classifying the patient into ranges of normality or nutritional risk (normal, mild, moderate, or severe). 3) User-friendly interface: presentation of results in a visual and intuitive format (informative tables, risk classification images, exportable reports in PDF/CSV) to facilitate clinical interpretation¹⁴. 4) Alerts and clinical decision support: CDSS module with notifications in cases of high risk of anemia, suggesting additional tests or referral to nutrition or hematology specialists¹². 5) Security and auditing: Compliance with data protection standards, with user traceability, access control, and audit logs.



Methods

The development of the CONUT-Digital system was carried out in a structured manner, following an iterative, modular approach to ensure code clarity, reproducibility, and easy system expansion in future versions. The process was organized into four main stages:

- 1) Logical and structural design of the algorithm.
- 2) Implementation of main functions.
- 3) Creation of the graphical interface.
- 4) Functionality validation and automated saving of results.
- 5) Automatic processing and classification of external databases.

Logical design and general structure of the algorithm

The overall program flow outlines the CONUT score calculation process from data input through the generation of customized and global reports. The code was structured into the following modules to ensure clarity, maintainability, and scalability of the software:

- a) Input module: Controls data capture, registers patient ID and biochemical values (albumin, cholesterol, and lymphocytes in three formats), including numeric format validation and automatic lymphocyte format detection.
- b) Calculation module: Applies the scoring rules defined by the CONUT method for each parameter, assigning a partial score according to the established clinical ranges.
- c) Classification module: Interprets the total score and determines the nutritional category (normal, mild, moderate, or severe) and associated anemia risk, since the anemia risk classification is derived directly from the total CONUT score.
- d) Storage module: Exports results to Excel in individual formats and a general history.
- e) Visual Module: Displays messages, alerts, and interpretive and guidance messages for the user, facilitating the interpretation of the result.

Figure 1. Logic flowchart of the CONUT-Digital algorithm illustrating the data processing steps, unit conversions, score calculations, and decision-making for nutritional classification and anemia risk estimation.

Functional Process Description

The system's execution flow unfolds as follows:

- 1) Start and data entry: The user enters the patient ID and the measured values for albumin (g/dL), cholesterol (mg/dL), and lymphocytes. The system allows lymphocyte entry in three formats: absolute count in mm^3 , absolute count in $10^9/\text{L}$, or percentage (%) with the total leukocyte count.
- 2) Automatic score calculation: Each parameter is evaluated according to its clinical range and assigned a partial score, which was established according to the literature¹⁵. Then, the three scores are added separately to obtain the total CONUT score.
- 3) Nutritional classification: Based on the total score, the system classifies the patient in the following ranges: 0-1 as normal, 2-4 as mild malnutrition, 5-8 as moderate malnutrition, and 9-12 as severe malnutrition.
- 4) Anemia risk estimation: The nutritional category translates into specific anemia risk levels. These levels are: normal CONUT malnutrition classification (low risk of anemia), mild CONUT malnutrition classification (low risk of anemia), moderate CONUT malnutrition classification (moderate risk of anemia), and severe CONUT malnutrition classification (high risk of anemia).

Anemia risk is estimated indirectly from the total CONUT score using classification criteria implemented in the algorithm. 5) Results visualization: The results are displayed on the screen, including the total CONUT score, nutritional classification, estimated anemia risk, informative text, and automatic clinical recommendations based on the assigned category. 6) Data storage: The user can choose to save the results individually and/or incorporate them into the general record, to generate anonymous clinical databases for subsequent studies, or to have a backup for possible future studies of the evolution of each entered/calculated patient. The generated results are dynamically updated in Excel format with each save.

Validation and error control

To ensure the accuracy of the results, the system implements validation controls: 1) Numeric input validation: Through "try" and "except" blocks, the system detects if the entered values are not numeric and prevents the calculation from being executed. 2) Patient ID verification: If an identifier is not entered, the system prevents both calculating and saving the result and displays a warning in both cases. 3) File validation: If the Excel file exists, it is updated without overwriting previous records. If it does not exist, it is automatically created when the professional saves and updates the calculated results from the count applied to the anemia risk prediction.

RESULTS

Algorithm Validation Through Method Comparison

The CONUT-Digital system enabled the automated calculation of the total CONUT score, nutritional classification, and associated anemia risk based on serum albumin, total cholesterol, and lymphocyte count. The tool correctly accepted the three implemented lymphocyte input methods (direct count in /mm³, absolute value in 10⁹/L, and percentage associated with total leukocytes), performing the necessary conversions automatically before assigning the corresponding score.

To validate the correct functioning of the algorithm implemented in the CONUT-Digital system, a systematic comparison was performed among three independent calculation methods: manual calculation of the CONUT Score, automated calculation via the developed interface, and automatic classification obtained by loading a database into the system. This validation was carried out using a sample of 60 synthetic clinical profiles, allowing evaluation of the agreement among the total score, nutritional classification, and anemia risk estimate.

The results demonstrate complete agreement among the three calculation methods, both in the CONUT score and in the nutritional classification and anemia risk level, validating the correct functioning of the implemented algorithm. This consistency confirms that the automated system reliably reproduces the clinical criteria established in the CONUT methodology^{6,15}, minimizing manual calculation errors and ensuring standardized evaluation. These results validate the system's internal mechanisms and demonstrate that the program can reliably reproduce clinical calculations traditionally performed manually.

CONUT Category	Score Range	Frequency (n)	Percentage (%)	Estimated Anemia Risk*
Normal	0 – 1	3	5.0%	Low
Mild Malnutrition	2 – 4	18	30.0%	Low
Moderate Malnutrition	5 – 8	31	51.7%	Moderate
Severe Malnutrition	9 – 12	8	13.3%	High
Total		60	100.0%	

*Estimated anemia risk is inferred from the nutritional status classification, reflecting the established physiological correlation between CONUT components (albumin, cholesterol, lymphocytes) and erythropoiesis.

Table 1. Distribution of nutritional status and estimated anemia risk in the validation cohort (n=60).

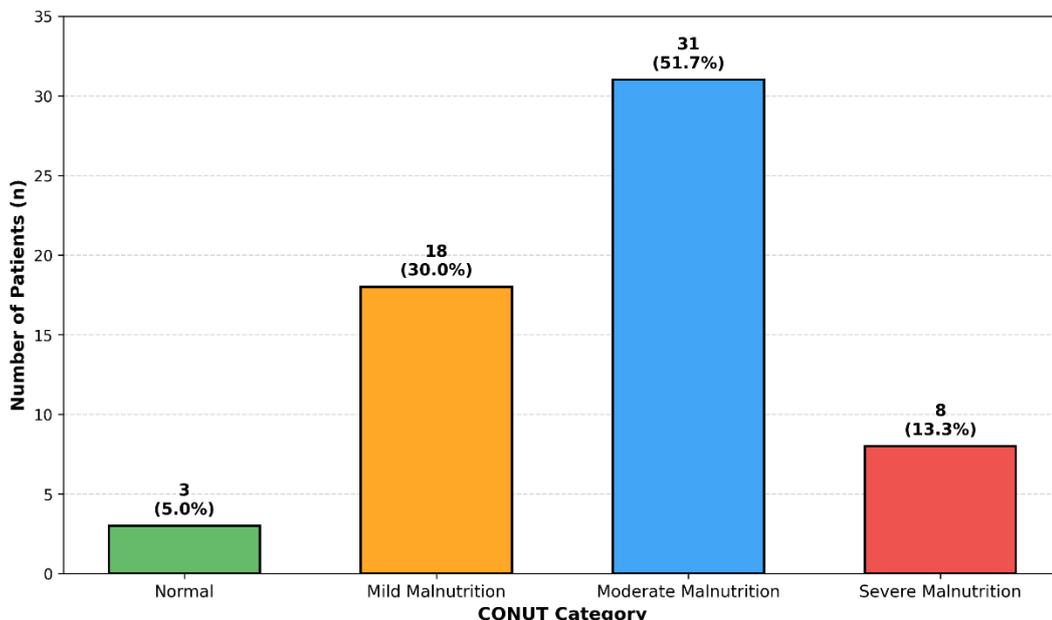


Figure 2. Distribution of nutritional status in the validation cohort (n=60) applied to synthetic clinical profiles. The bar chart illustrates the frequency of patients classified as Normal, Mild, Moderate, or Severe according to the automated CONUT-Digital system applied to real clinical records.

Data Export and Management Results

In addition to the automated calculation of the CONUT score, the CONUT-Digital system includes a graphical interface to facilitate the entry of clinical data, visualization of results, and management of patient records. This section presents the results of the program's execution, user interaction, and the automatic export of generated data.

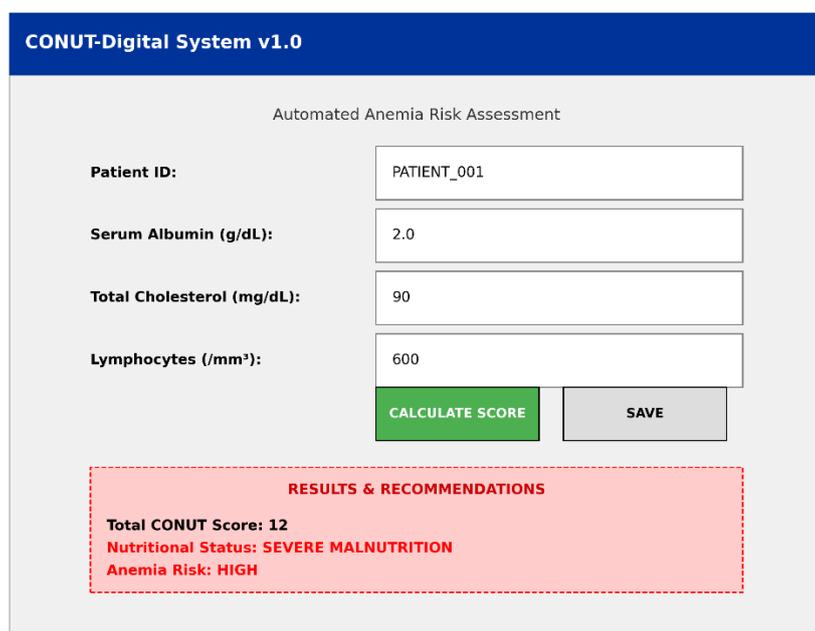


Figure 3. Graphical User Interface (GUI) of the CONUT-Digital system. The interface displays a high-risk clinical scenario (CONUT score 12) illustrating the automated color-coded alerts for severe malnutrition and high anemia risk, along with clinical recommendations.

Regarding the export and storage of results, the system automatically saves the information in Excel (.xlsx) format using two methods: an individual file per patient and a consolidated (general) file that groups all processed records. The exported output contains columns for laboratory values, individual scores, total score, and anemia risk. The background colors represent the severity of the alteration: green (normal), yellow (mild), purple (moderate), and red (severe), facilitating visual identification and optimization of the reading process.

DISCUSSION

The results obtained in this study demonstrate that the CONUT-Digital system accurately and reliably reproduces the calculation of the CONUT Score, the classification of nutritional status, and the estimation of anemia risk, in accordance with the clinical criteria established in the literature^{6,15}. The 100% agreement observed between the manual calculation, the automated calculation via the developed interface, and the initial clinical classification demonstrates the correct implementation of the algorithm and the appropriate translation of the CONUT method's clinical rules into a computational environment.

From a methodological point of view, the automation of the calculation represents a significant advantage over the traditional manual procedure, as it reduces human errors associated with score assignment, standardizes the nutritional assessment process, and optimizes analysis times^{12,14}. This aspect is particularly relevant in clinical settings with a high patient load, where the speed and consistency of nutritional status assessment could directly impact timely clinical decision-making¹⁴. Furthermore, the use of synthetic datasets, selected to replicate diverse scenarios encountered in clinical practice, allowed for the rigorous evaluation of the system's performance. This approach strengthens the consistency of the results, confirming the system's robustness and potential for future integration into clinical workflows. The system's ability to correctly process different lymphocyte count input formats is an additional benefit, as it adapts to the variability with which this data is typically presented in laboratory tests.

The clinical significance of CONUT-Digital lies in its potential to transform routine biochemistry into actionable early warnings. In outpatient settings, where hemoglobin testing is not always performed for every consultation, the ability to estimate anemia risk based on albumin, cholesterol, and lymphocytes—parameters frequently ordered in routine check-ups—provides a strategic advantage. The novelty of this tool is twofold: first, it standardizes a complex nutritional assessment prone to manual error, and second, it serves as a clinical decision support system (CDSS) that prioritizes patients for confirmatory hematological testing. By identifying high-risk patients earlier, the system can reduce the time to diagnosis and intervention, contributing to more efficient public health management of anemia.

Regarding the evaluation of anemia risk, it is crucial to clarify that the CONUT-Digital system estimates this risk based on the physiological and pathological relationships between nutritional status and erythropoiesis. As described in the literature, protein-calorie malnutrition and micronutrient deficiencies (reflected in low levels of albumin, cholesterol, and lymphocytes) are direct causes of anemia^{3,16}. Therefore, the anemia risk categorization implemented in the algorithm (Low, Mild, Moderate, High) is derived directly from the severity of malnutrition diagnosed by the CONUT index. The system does not replace traditional hematological diagnosis (hemoglobin/hematocrit), but functions as a preventive screening tool, alerting to the probability of anemia due to nutritional deficits before severe hematological alterations manifest.

The development of CONUT-Digital demonstrates the potential of computational tools to support clinical practice by integrating established criteria into accessible, reproducible digital solutions. The incorporation of an intuitive graphical interface, along with the structured export of results, reinforces its potential for eventual integration with hospital information systems^{13,14}. While this study focused primarily on verifying its correct algorithmic and computational functioning, future research should include broader clinical evaluations, including an analysis of its impact on clinical decision-making and performance in real-world healthcare settings.

In terms of clinical interpretation, it is also important to consider that physiological conditions, such as pregnancy, can cause serum albumin, lymphocyte count, and total cholesterol levels to vary independently of actual nutritional status. Phenomena such as hemodilution, immunological changes, and lipid metabolism adaptations can alter the score obtained using the standard CONUT scheme, leading to potentially erroneous classifications if not interpreted within their clinical context¹⁸.

CONCLUSIONS

Based on the results and subsequent analysis, it can be established that the CONUT-Digital system guarantees the accurate, reproducible, and standardized calculation of the CONUT Score, classification of nutritional status, and estimation of anemia risk, successfully reproducing the clinical criteria described in the original methodology. The 100% concordance between manual and automated calculations using the developed interface demonstrates the robustness of the implemented algorithm and validates its translation from the clinical setting to a computational environment.

The CONUT-Digital system estimates anemia risk based on the known association between deteriorating nutritional status and the impairment of the erythroid lineage. This approach allows the use of routine biochemical parameters to identify at-risk patients requiring confirmatory nutritional or hematological intervention. The incorporation of three input methods for lymphocyte counts, with automatic conversion to standard units, is a significant practical contribution, as it accommodates the typical variability in the presentation of clinical laboratory results, increasing the system's flexibility and enhancing its potential application across diverse healthcare settings.

The implementation of an intuitive graphical interface, along with modules for structured export and visual coding of results, facilitates clinical interpretation and improves the efficient management of patient information. Overall, the results obtained fulfilled the objectives proposed in this work, demonstrating the technical and methodological viability of CONUT-Digital as a Clinical Decision Support System (CDSS) for professionals in health care, with potential for nutritional assessment and anemia risk estimation, thus establishing a solid foundation for its future application in real-world clinical settings.

Author Contributions: Sofía Villar Yáñez and Miguel Alfonso Gómez: Co-first authors; conceptualization, software development (Python/Tkinter), data processing, algorithm validation, manuscript drafting, and visualization. Noralvis Fleitas-Salazar, PhD, and Seidy Pedroso-Santana, PhD: Supervision, clinical guidance, critical revision of the manuscript, and interpretation of results.

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Informed Consent Statement: Not applicable. This study did not involve human participants or personal data; it was based entirely on the analysis of synthetic data generated for algorithm validation.

Data Availability Statement: The synthetic dataset generated for validation and the Python source code used for the CONUT-Digital system are available upon reasonable request from the corresponding author.

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form. The authors have no conflicts of interest to declare.

AI-Assisted Tools Disclosure: Artificial intelligence tools and cloud-based computational environments (Google Colab) were used exclusively to generate high-resolution scientific figures (specifically Figure 1 using Graphviz, Figure 2 using Matplotlib, and Figure 3 for interface mockup generation). No artificial intelligence system was used to generate, manipulate, or analyze the experimental clinical data, perform statistical analysis, or influence the scientific conclusions. All clinical data processing, CONUT scoring, and validation comparisons were performed directly by the authors using the custom Python algorithm. The authors independently verified all results and analyses, in compliance with the BioNatura Journal policy.

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