



APPLICATION OF THE ANALYTIC HIERARCHY PROCESS (AHP) METHOD FOR CHOOSING A PORTABLE RETINOGRAPH IN OPHTHALMOLOGICAL CLINICAL PRACTICE

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ABSTRACT

The selection of portable retinographs has become a significant challenge in teleophthalmology and clinical services that depend on fast and accurate capture of fundus images. The wide variety of models available on the market, each with distinct technical and operational characteristics, requires a structured evaluation based on multiple criteria. This study aimed to apply the Analytic Hierarchy Process (AHP) method to support multi-criteria decision-making in choosing the portable retinograph best suited to clinical practice needs. Criteria such as image quality, portability, battery life, cost, technical support, and compatibility with digital systems were defined. Based on the hierarchical structuring of the problem and the elaboration of paired comparison matrices, the relative weights of each criterion and the performance of the evaluated alternatives were calculated. The results objectively revealed the most appropriate model according to the priorities established by the experts. It was concluded that AHP proved to be effective, transparent, and replicable, making it a valuable tool for decision-making processes involving medical technology.



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I. INTRODUCTION

Fundus photography is an essential procedure for detecting and monitoring ocular pathologies such as diabetic retinopathy, glaucoma, vascular occlusions, and macular diseases [1]. With the expansion of teleophthalmology programs and primary care screening, portable fundus cameras have come to play a central role, enabling examinations outside hospital environments and contributing to early diagnosis in remote populations or those with limited access to specialists [2]. The growth of the portable fundus camera market has brought a variety of models differing in cost, image resolution, battery life, ergonomics, and integration with information systems [3]. This diversity makes the selection process complex, especially when budget constraints and specific operational needs are involved. Decisions based solely on the lowest price or isolated features may compromise exam quality and the effectiveness of the service [4]. In this context, multicriteria decision-making (MCDA) methods emerge as alternatives capable of systematizing judgments and balancing conflicting criteria [5]. Among them, the Analytic Hierarchy Process (AHP), developed by Thomas Saaty, stands out for its ability to organize complex problems into hierarchical structures and transform subjective judgments into consistent mathematical values [6]. The objective of this study is to apply the AHP method to select the portable fundus camera most suitable for the needs of an ophthalmology clinic or telemedicine program. To achieve this, relevant decision criteria were defined, the problem hierarchy was constructed, and pairwise comparisons between criteria and alternatives were carried out, allowing the calculation of relative weights and the identification of the best option. The specific objectives include identifying the decision criteria, structuring the hierarchical model of the problem, applying AHP to the available alternatives, and assessing the consistency of the judgments made.

II. RELATED WORK

The application of multicriteria decision-making methods to the selection and management of health technologies has been widely discussed in the literature, particularly in the context of acquiring medical equipment [7]. Within the use of Multicriteria Decision Analysis (MCDA) for medical equipment management, the AHP stands out as one of the most suitable methods to support evaluation, selection, and investment-prioritization tasks in resource-constrained environments [8]. In this scenario, AHP has become established as a tool capable of reducing uncertainties and providing greater transparency to decisions involving multiple technical, economic, and operational criteria [9],[10]. In more specific studies, various authors have proposed AHP-based models to directly support the selection of medical devices. One application of AHP elicited user needs for acquiring a computed tomography scanner, demonstrating that the method enables the integration of preferences from different stakeholders into a structured model for the procurement of diagnostic imaging equipment [11]. Along similar lines, [12] developed a multicriteria methodology based on AHP to select the most ergonomically suitable ultrasound device, considering criteria related to technical performance and the well-being of healthcare professionals.

Other works reinforce the use of AHP as the core of decision-support tools for hospital procurement. A model for weighting criteria for selecting medical equipment based on AHP highlighted its ability to structure and prioritize factors such as cost, maintenance, reliability, and technical support [13],[14]. More recent studies have advanced toward integrated frameworks that combine AHP with other methods—such as TOPSIS, VIKOR, and PROMETHEE—with the aim of increasing the robustness of decisions and incorporating sensitivity-analysis scenarios in the selection of complex medical devices [15]. In the specific domain of imaging technologies and diagnostic services, [16] employed AHP to rank radiology departments, demonstrating the method's potential for capturing aspects of quality, efficiency, and technological availability in the evaluation of diagnostic imaging services. The performance of two portable retinal cameras—one smartphone-based and the other smartscope-based—was assessed for capturing fundus images, highlighting the growing role of portable devices in ophthalmologic practice and their integration with OCT examinations [17].

A recent review addressed the advancement of portable devices in ophthalmology and their implications for screening diseases such as diabetic retinopathy and age-related macular degeneration [18]. Although these studies do not directly apply AHP to the selection of portable fundus cameras, they highlight the growing relevance of these technologies and the need for structured evaluation methods [19]. In light of these works, the present study contributes by applying AHP specifically to the selection of portable fundus cameras, articulating technical criteria (image quality, digital compatibility), operational criteria (portability, battery life), and organizational criteria (cost, technical support). Unlike broader approaches to selecting medical equipment or other imaging devices, this article focuses on the specific context of teleophthalmology and clinical ophthalmic practice, filling a gap in the literature by proposing and testing an AHP model for the comparative selection of different commercial portable fundus-camera models.

III. LITERATURE REVIEW

III.1 ANALYTIC HIERARCHY PROCESS (AHP) METHOD

The Analytic Hierarchy Process (AHP) was developed by Professor Thomas L. Saaty in the early 1970s and later consolidated in a classical work dedicated to the method [20]. It emerged as a response to the need to structure and quantify subjective judgments in complex decision-making processes in which different qualitative and quantitative criteria must be considered jointly and in a comparable manner [21]. Since then, it has become one of the most widely used multicriteria decision-making methods, applied in fields such as healthcare, engineering, logistics, public management, and technology selection [10]. AHP is based on three fundamental principles: decomposition, comparative judgments, and priority synthesis [22]. Initially, the problem is decomposed into a hierarchical structure that facilitates understanding of the decision process. The upper level contains the overall objective; the intermediate levels contain the criteria and subcriteria; and at the base of the hierarchy are the alternatives. To illustrate this organization, it is recommended to include a figure representing the hierarchical structure of the problem, such as a vertical diagram containing the objective, criteria, and alternatives [23], as shown in Figure 1.

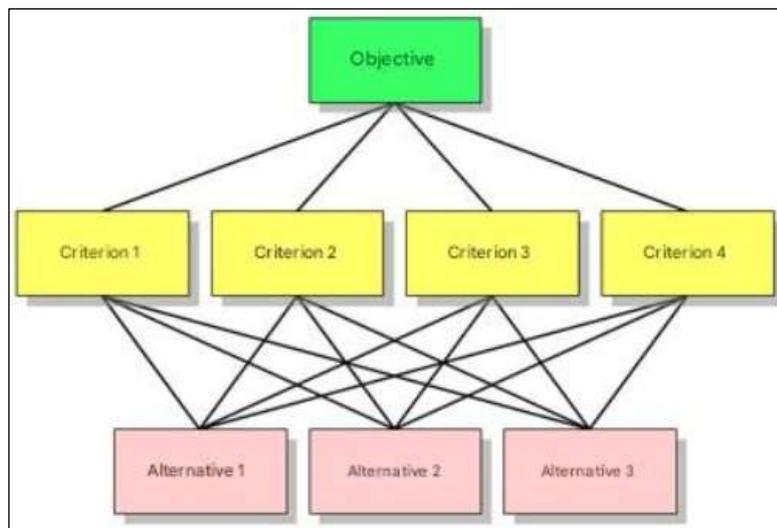


Figure 1: Hierarchical structure of the AHP.

Source: [6].

After the problem has been structured, the stage of comparative judgments begins. The elements at each level of the hierarchy are compared pairwise using Saaty’s Fundamental Scale, which ranges from 1 (equal importance) to 9 (extreme importance), including their reciprocal values. This scale enables the intuitive capture of the relative preference between two elements. To reinforce this understanding, it is recommended to include a Table 1 with Saaty’s Fundamental Scale, containing descriptions and examples.

Table 1: Saaty scale used in the pairwise comparisons.

	Element 1	Element 2	...	Element D
Element 1	1	a_{12}	...	a_{1D}
Element 2	$1/a_{21}$	1	...	a_{2D}
⋮	⋮	⋮	⋮	⋮
Element D	$1/a_{D1}$	$1/a_{D2}$...	1

Source: [6].

The comparisons are organized into square matrices, from which the priority vector is extracted, typically through the principal eigenvector associated with the largest eigenvalue λ_{max} . This vector mathematically represents the weight of each element in relation to the objective [24], [25]. An essential aspect of the method is the verification of the consistency of the judgments made. Because human comparisons may naturally present inconsistencies, a specific procedure was established to assess the quality of these comparisons [26]. This process involves calculating the Consistency Index (CI) and the Consistency Ratio (CR), which relates the CI to a reference value known as the Random Index (RI). When the CR is equal to or less than 0.10, the judgments are considered to have acceptable coherence, indicating that the comparisons follow a logically consistent pattern [27]. Another important contribution of AHP is its ability to integrate judgments from multiple experts. When more than one evaluator is involved, judgments can be aggregated using the geometric mean, preserving independence and valuing collective expertise.

This step is particularly relevant in technological decision-making in healthcare, where shifts in priorities can significantly impact the final choice [28]. Several studies demonstrate the versatility and potential of AHP when applied to complex technological systems. Different authors have used the method in areas such as software selection, educational platform choice, and supplier evaluation in the healthcare sector, highlighting its ability to handle multiple—and often conflicting—criteria. These examples show that AHP is well suited for decision-making processes that require a balance between technical, operational, and economic factors, which supports its application in the analysis and selection of portable fundus cameras [29]. Thus, AHP stands out for its robustness, its ability to handle structured subjectivity, and its methodological clarity, which allows individual perceptions to be transformed into rational, measurable, and justifiable decisions [30].

III.2 PORTABLE FUNDUS IMAGING TECHNOLOGIES

Portable fundus cameras emerged as an alternative to traditional tabletop fundus imaging systems typically used in clinics and hospitals. These devices employ miniaturized optical systems combined with high-resolution digital sensors, enabling the capture of retinal images without pupil dilation or with minimal dilation, depending on the model [31], [32]. Among the leading globally recognized manufacturers are the Optomed Aurora, the Volk Pictor Plus, the Remidio Fundus on Phone, and compact models from Topcon, which—although more robust—offer versions with increased portability. These devices show significant differences in image quality, ergonomics, battery life, and integration with telemedicine software. Despite their advantages, challenges remain, such as balancing optical quality and portability, the high cost of some models, and the need for integration with electronic health record systems. Current trends point toward devices with enhanced connectivity, integration with artificial intelligence algorithms for automated pathology detection, and greater operational autonomy [33].

IV. METHODOLOGY

This study is characterized as applied research, quantitative and descriptive in nature, using the multicriteria AHP method for selecting portable fundus cameras. The methodological application followed a structured sequence beginning with a clear definition of the problem: selecting the most suitable device among the models available on the market. Next, the evaluation criteria were defined based on the literature and expert analysis: image quality, portability, battery life, cost, technical support, and compatibility with electronic record systems. The problem was then organized into a hierarchical structure composed of the objective at the top, the criteria at the intermediate level, and the evaluated alternatives at the base. Three representative market alternatives were considered: a model with high optical precision (A), an intermediate model with good cost-benefit ratio (B), and an ultracompact smartphone-based model (C). For each criterion, experts performed pairwise comparisons using Saaty’s scale. The resulting matrices enabled the calculation of relative weights for the criteria and the priorities of the alternatives. The consistency ratio was calculated for all matrices to verify the reliability of the judgments. The analysis was carried out using automated spreadsheets developed in Excel, allowing extraction of eigenvectors, consistency indices, and the final ranking of alternatives.

IV.1 DATA COLLECTION AND PROCESSING

Data collection was conducted exclusively through documentary research and analysis of technical information provided by the manufacturers of the selected devices. This procedure is widely used in studies applying the AHP method, as it allows the gathering of objective data on characteristics, specifications, and functionalities of the evaluated alternatives, serving as the basis for building the comparisons. Pairwise comparisons between criteria and between alternatives were defined based on the analysis of the collected technical information, using Saaty’s Fundamental Scale (1–9). The assigned values were organized in electronic spreadsheets (Microsoft Excel®), which were also used for calculating eigenvectors, normalization processes, verification of consistency indices, and obtaining the model’s final priorities.

The data processing followed these steps:

- Construction of the judgment matrices
- Normalization of the matrices
- Calculation of priority vectors
- Calculation of the largest eigenvalue (λ_{max})
- Calculation of Consistency Indices

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{1}$$

- **Calculation of the Consistency Ratio (CR):**

$$CR = \frac{CI}{RI} \tag{2}$$

Where RI is the Random Index presented by Saaty (1980). Only matrices with $CR \leq 0.10$ were considered consistent, according to the classical recommendation in the literature [6],[20].

IV.2 DEFINITION OF CRITERIA

The definition of criteria considered three sources:

- (i) specialized literature on teleophthalmology and diagnostic technologies;
- (ii) international guidelines on ophthalmic image quality;
- (iii) technical opinion of the interviewed experts.

The literature highlights that criteria such as image quality, technical support, portability, and digital compatibility are decisive in the adoption of portable diagnostic equipment [34]. Accordingly, six central criteria were defined for the analysis:

- **C1 – Image quality:** directly associated with diagnostic accuracy.
- **C2 – Portability:** fundamental for remote screenings.
- **C3 – Battery life:** relevant in fieldwork and regions without electrical infrastructure.
- **C4 – Cost:** including acquisition and cost-effectiveness.
- **C5 – Technical support and maintenance:** critical for operational continuity.
- **C6 – Digital compatibility:** integration with EHR, PACS, and telemedicine systems.

The choice of these criteria aligns with recommendations from technology assessment studies and the guidelines of the American Telemedicine Association.

IV.3 DETERMINATION OF WEIGHTS

To determine the weights of the criteria, the pairwise comparison method was applied according to the Fundamental Scale [35]. The study compared each criterion with the others in terms of relative importance, resulting in the matrix presented in Table 3. The weights (priority vector) were obtained through:

1. **Normalization of the AHP matrix:**

$$a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \tag{3}$$

1. **Calculation of the weight vector (w_i):**

$$w_i = \frac{1}{n} \sum_{j=1}^n a'_{ij} \tag{4}$$

2. **Mathematical validation using the principal eigenvector:**

$$Aw = \lambda_{max}w \tag{5}$$

The final weights, presented in Table 4, highlighted the predominance of **C1 (0.30)** and **C5 (0.20)**, a finding consistent with previous studies on technology decision-making in clinical settings. The consistency of the judgments was verified by calculating the Consistency Ratio (CR), which in this study resulted in **CR = 0**, indicating full coherence of the comparisons.

IV.4 APPLICATION OF THE AHP METHOD

The application of the Analytic Hierarchy Process (AHP) in this study followed a structured set of steps that allowed the transformation of experts' subjective judgments into quantitative measures used to select the portable fundus camera most suitable for the clinical context. The process began with defining the alternatives, constructing the judgment matrix for the criteria, calculating the relative weights, assessing consistency, and, finally, synthesizing the overall priorities of the evaluated devices.

Initially, three commercially representative models of portable fundus cameras were selected based on their technical relevance and widespread use in teleophthalmology services. These models are presented in Table 2.

Table 2: Portable fundus camera models analyzed.

Commercial Model	Manufacturer	Main Features
Optomed Aurora	Optomed	High resolution, advanced ergonomics, suitable for teleophthalmology.
Volk Pictor Plus	Volk	Good image quality, widely used in screening.
Remidio Fundus on Phone	Remidio	Smartphone-attached system, extreme portability, and high digital integration.

Source: Authors, (2026).

Next, the six evaluation criteria were defined, representing the most relevant factors for choosing the device: image quality, portability, battery life, cost, technical support, and integration with electronic systems. Each criterion was described based on the literature and the evaluators' experience, as shown in Table 3.

Table 3: Evaluation Criteria.

Code	Criterion	Description
C1	Image Quality	Sharpness, resolution, and diagnostic capability of the fundus.
C2	Portability	Weight, size, and ease of transport.
C3	Battery Life	Continuous operating time without recharging.
C4	Cost	Purchase price and cost-effectiveness.
C5	Technical Support and Maintenance	Access to maintenance, training, and manufacturer assistance.
C6	Compatibility with Electronic Systems	Ability to integrate with EHR, PACS, and telemedicine platforms.

Source: Authors, (2026).

With the criteria defined, the pairwise comparison matrix was constructed using Saaty's Fundamental Scale (1 to 9). The experts assessed the relative importance of each pair of criteria, resulting in the matrix presented in Table 4.

Table 4: Pairwise Comparison Matrix of the Criteria.

	C1	C2	C3	C4	C5	C6
C1	1,00	2,00	3,00	2,00	1,50	3,00
C2	0,50	1,00	1,50	1,00	0,75	1,50
C3	0,33	0,67	1,00	0,67	0,50	1,00
C4	0,50	1,00	1,50	1,00	0,75	1,50
C5	0,67	1,33	2,00	1,33	1,00	2,00
C6	0,33	0,67	1,00	0,67	0,50	1,00

Source: Authors, (2026).

From this matrix, the priority vector (normalized principal eigenvector) was calculated, determining the weights of the criteria presented in Table 5.

Table 5: Relative Weights of the Criteria.

Criterion	Description	Relative Weight (wi)
C1	Image Quality	0.30
C2	Portability	0.15
C3	Battery Life	0.10
C4	Cost	0.15
C5	Technical Support and Maintenance	0.20
C6	Digital Compatibility	0.10
Sum		1.00

Source: Authors, (2026).

IV.5 ANALYSIS OF FUNDUS CAMERAS

The analysis of portable fundus cameras considered the three selected models (Table 1), evaluated across the six established criteria. The selection of these models was based on commercial availability, relevance in teleophthalmology programs, and established use in clinics and research, following recommendations from international studies. The models exhibited distinct characteristics, allowing for a robust multicriteria evaluation. The Optomed Aurora stood out for its high image quality and exemplary technical support; the Volk Pictor Plus demonstrated a balance between portability and cost; while the Remidio Fundus on Phone excelled in digital integration and extreme portability. Performance evaluation used scores from 1 to 9 (Saaty Scale), which were subsequently normalized and aggregated using the criteria weights. This procedure follows the additive synthesis process:

$$\text{"Overall Score of the Alternative"} A_k = \sum_{i=1}^n (w_i \cdot p_{ik}) \tag{6}$$

V. RESULTS AND DISCUSSION

The results obtained through the application of the AHP method provided a clear understanding of the relative importance of each criterion in the selection of a portable fundus camera and the influence of these weights on the final ranking of the evaluated alternatives. Analysis of the pairwise comparison matrices revealed that the image quality criterion (C1) emerged as the most relevant in the decision-making process, corresponding to the highest weight among the analyzed criteria. This outcome is consistent with clinical practice, where diagnostic accuracy depends directly on the resolution and sharpness of the captured images. Next, the technical support and maintenance criterion (C5) stood out as an essential element to ensure the operational continuity of the equipment, reduce downtime, and provide qualified user assistance. The cost (C4) and portability (C2) criteria presented intermediate weights, reflecting their relevance, although they do not surpass the importance attributed to diagnostic quality and specialized support. The battery life (C3) and compatibility with electronic health record systems (C6) criteria had a lower relative impact on the decision, suggesting that, while relevant, they are perceived as secondary influencing factors compared to the technical aspects central to ophthalmic practice. These results reinforce patterns described in similar studies, where technological and support criteria carry greater weight in the acquisition of medical equipment. After defining the criteria weights, the alternatives were evaluated. The experts assigned scores from 1 to 9 to each model for each criterion, as presented in Table 6.

Table 6: Model Scores by Criterion (1–9 Scale).

Model / Criterion	C1	C2	C3	C4	C5	C6
A – Optomed Aurora	9	7	8	4	9	8
B – Volk Pictor Plus	8	8	7	5	8	7
C – Remidio Fundus on Phone	7	9	6	7	7	9

Source: Authors, (2026).

These scores were normalized and combined with the relative weights of the criteria, resulting in the overall priorities presented in Table 7.

Table 7: Overall Priorities of the Alternatives.

Model	Description	Overall Priority
A	Optomed Aurora	0,340
B	Remidio Fundus on Phone	0,334
C	Volk Pictor Plus	0,326

Source: Authors, (2026).

The analysis of the overall priorities highlights a significant balance among the evaluated models, indicating that all exhibit competitive performance. However, the Optomed Aurora (Model A) stood out as the most suitable alternative, achieving an overall priority of 0.340. This superior performance is primarily due to the combination of excellent image quality (C1) and robust technical support (C5), which are precisely the most influential criteria in the AHP model. Model C (Remidio FOP) achieved a very close score (0.334), benefiting mainly from its high portability and excellent digital compatibility. Model B (Volk Pictor Plus) obtained an overall priority of 0.326, favored for its good balance between image quality, portability, and cost, although it did not excel in the criteria deemed most critical by the experts. The consistency of the matrices was verified to ensure the reliability of the judgments. Considering the largest calculated eigenvalue ($\lambda_{max} = 6.0$), the following was obtained:

$$CI = 0 \tag{7}$$

$$RI (n = 6) = 1,24 \tag{8}$$

$$CR = 0/1,24 = 0 \tag{9}$$

The CR value of 0 indicates perfect consistency in the pairwise comparisons, fully meeting the parameters defined by Saaty. This ensures that the experts’ judgments were coherent and that the developed model is mathematically stable and reliable. The sensitivity analysis showed that small variations in the criteria weights did not significantly change the final ranking of the alternatives. This result highlights the robustness of the applied AHP model, reinforcing the reliability of the selection made. It is observed that technical and operational criteria, particularly those related to product quality and after-sales support, tend to exert a decisive influence on the selection of medical technologies. The integration of expert judgment, mathematical modeling, and structured analysis allowed the conclusion that the Optomed Aurora is the most suitable alternative for teleophthalmology services and clinical practice, offering the best balance between technical performance, specialized support, and operational applicability.

VI. CONCLUSION

This study aimed to apply the AHP method to support the selection of a portable fundus camera in the context of clinical practice and teleophthalmology, simultaneously considering multiple technical, operational, and economic criteria. Based on the definition of six main criteria—image quality, portability, battery life, cost, technical support, and digital compatibility—and the evaluation of three representative commercial models, it was possible to structure the problem into a clear hierarchy, develop pairwise comparison matrices, calculate relative weights, and synthesize the overall priorities of the alternatives. The results showed that image quality (C1) and technical support and maintenance (C5) were the most influential criteria in the decision-making process, followed by cost (C4) and portability

(C2), while battery life (C3) and digital compatibility (C6) had a relatively lower impact. This hierarchy is consistent with ophthalmic practice, where diagnostic reliability and the operational continuity of equipment are central factors for providing safe and effective care. Prioritization of technical and support criteria also aligns with previous studies on medical equipment selection using AHP or MCDA. In the synthesis of overall priorities, all three analyzed models demonstrated competitive performance. However, the Optomed Aurora (Model A) was identified as the most suitable alternative, with an overall priority of 0.340, closely followed by the Remidio Fundus on Phone (Model C) and the Volk Pictor Plus (Model B). This result indicates that, although the equipment is technically competitive, the combination of excellent image quality and robust technical support distinguishes Model A in the considered use context. The closeness of the scores also suggests that local decisions—such as budget constraints, regional availability of technical support, or institutional telemedicine strategies—may justify the selection of other models in specific scenarios, highlighting the usefulness of AHP as a tool adaptable to the priorities of each service. Consistency verification of the judgments, with a consistency ratio (CR) equal to zero for the criteria matrix, ensured the internal coherence of the comparisons and the mathematical stability of the adopted model. Sensitivity analysis indicated that moderate variations in criteria weights did not alter the ranking of alternatives, suggesting robustness of the solution obtained. These findings support the literature that identifies AHP as a transparent, auditable, and suitable method for supporting health technology acquisition decisions, particularly when multiple stakeholders and criteria must be considered in an integrated manner. The main contributions of this study are: (i) proposing and applying a specific AHP model for the selection of portable fundus cameras, adapted to the demands of teleophthalmology services; (ii) empirically demonstrating that image quality and technical support tend to prevail over strictly economic criteria in the decision-making process; and (iii) providing a replicable methodological framework that can be adjusted to include other models, additional criteria, or different expert profiles. From a practical perspective, the model can be incorporated into clinical engineering processes, procurement committees, or telemedicine programs to support purchase decisions in a systematic and justifiable way. However, some limitations should be acknowledged. The number of experts involved was limited, which may restrict the generalizability of the judgments, although internal consistency was satisfactory. In addition, the study considered only three commercial models, not covering the full spectrum of portable fundus cameras available on the international market. Important criteria such as life-cycle costs, real-world performance indicators (e.g., non-diagnostic exam rates, operator learning curve), and user experience metrics (usability, ergonomics) were not explicitly included in the model. For future research, it is recommended to expand the number of experts and devices evaluated, including fundus cameras from different price ranges and technological generations. Incorporating hybrid approaches, such as fuzzy AHP or integration with methods like TOPSIS, VIKOR, or PROMETHEE, may allow better handling of uncertainties and more complex preference scenarios. It is also suggested to include criteria related to integration with artificial intelligence algorithms for automated retinopathy detection and the evaluation of field clinical indicators, in order to bring the model closer to the real needs of remote ophthalmology screening and diagnostic programs. In this way, the present study constitutes an initial step in developing a systematic approach for selecting portable fundus cameras, paving the way for more comprehensive and integrated decision-support models in ophthalmic technologies.

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