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Integral index of composite treatment effectiveness for nephroureterolithiasis as a tool for comparative evaluation of endourological methods

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Abstract. In contemporary urology, the effectiveness of nephroureterolithiasis treatment is traditionally assessed using individual indicators such as the stone-free rate, the incidence of postoperative complications, and the duration of the surgical procedure. However, the use of isolated criteria limits the scope for comprehensive interpretation of treatment outcomes and hinders objective comparison of different endourological techniques. The aim of the present study was to develop and provide a methodological rationale for an Integral index of composite treatment effectiveness (ICTE) for nephroureterolithiasis, intended for the comparative evaluation of endourological methods. The study employed methods of contemporary scientific literature analysis, formalisation of the principles of composite assessment of clinical outcomes, and development of a mathematical model of an integral indicator based on the stone-free rate, complication rate, and operative duration. The necessity of developing an integral quantitative indicator combining the key parameters of clinical outcomes and providing a more comprehensive and comparable assessment of treatment effectiveness was substantiated. An integral index of composite treatment effectiveness was proposed, based on the combination of the stone-free rate, the incidence of postoperative complications, and operative duration as an indicator of procedural resource utilisation. The developed mathematical model enables quantitative integration of the principal characteristics of treatment outcomes into a single indicator, ensuring comparability of the obtained data and facilitating the interpretation of clinical results. It was demonstrated that the use of the integral index provides a basis for a more objective comparison of different treatment methods, taking into account their clinical effectiveness, safety, and resource requirements. An example of the index calculation is presented to illustrate the practical applicability of the proposed model. The proposed approach enables a transition from the fragmented assessment of individual parameters to a comprehensive quantitative analysis of treatment outcomes and expands the possibilities for comparative research. The use of the integral index may contribute to optimising treatment strategy selection in patients with nephroureterolithiasis; however, further clinical validation is required

Keywords: urinary stone disease; urolithiasis; stone-free rate; postoperative complications; operative duration; treatment effectiveness assessment

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Introduction

Nephroureterolithiasis is among the most common urological disorders and remains a major challenge in contemporary clinical urology. The high recurrence rate, the need for repeated interventions, and the substantial demands placed on healthcare resources make the management of urinary stone disease an important issue from both clinical and organisational-economic perspectives. Since the late twentieth and early twenty-first centuries, approaches to the treatment of nephroureterolithiasis have undergone considerable changes. The development of endourological technologies has led to the widespread adoption of minimally invasive techniques for the removal of urinary tract calculi. In modern practice, percutaneous nephrolithotripsy, ureterorenoscopy and remote shock-wave lithotripsy are the most commonly used techniques. The use of these technologies has made it possible to significantly reduce the invasiveness of procedures, shorten hospital stays and speed up patients' recovery. Consequently, endourological methods are, in most cases, regarded as the standard of care for urolithiasis.

Despite the significant advances in modern endourology, the issue of objectively assessing the efficacy of various treatment methods for nephro-ureterolithiasis remains a topical and contentious one. According to data from K. Wróblewski *et al.* [1], in clinical practice, the outcomes of treatment for urolithiasis are traditionally assessed using individual indicators, each of which reflects only one aspect of the clinical outcome. According to H. Kim *et al.* [2], one of the most widely used criteria for the efficacy of endourological interventions is the stone-free rate; however, its use in isolation does not allow for a comprehensive assessment of the clinical outcome, including safety and resource costs, a point also noted in recent studies of real-world clinical practice. Similar conclusions were presented in a study by H. Zhao *et al.* [3], which showed that the accuracy of treatment outcome assessment depends on a multitude of factors, including the characteristics of the stones and the clinical features of the patients.

Researcher R.M. Geraghty *et al.* [4] noted that indicators of operative duration and other organisational parameters reflect the resource-related aspects of healthcare delivery to a greater extent than the direct clinical efficacy of treatment. At the same time, as demonstrated in a number of studies, an analysis of post-operative complications allows the safety of the procedure to be assessed, but does not characterise its effectiveness in terms of stone removal. Thus, as emphasised by K.R. Ghani *et al.* [5], the use of individual indicators does not provide a comprehensive assessment of the clinical outcome. When comparing different endourological methods, it is not uncommon to observe a situation where greater efficacy in stone removal is accompanied by an increased incidence of complications or a longer duration of the procedure, which complicates the selection of the optimal treatment strategy.

Additional challenges arise when comparing treatment outcomes across different regions. According to M. Akram & B. Somani [6], the prevalence and clinical course of urolithiasis vary significantly depending on geographical and climatic factors. Similar patterns have been observed in studies conducted in the Kyrgyz Republic. For instance, J.S. Mambetov *et al.* [7] demonstrated that the development of urolithiasis in Kyrgyzstan is associated with the influence of high-altitude conditions, dietary characteristics, increased water mineralisation and metabolic disorders. In the study by U.K. Bektasheva *et al.* [8], it was established that stone formation processes among residents of the southern region of the country are driven by complex physico-chemical and metabolic mechanisms that determine the composition and structure of the calculi. In this regard, an approach involving a comprehensive assessment of treatment outcomes has been developing in the urological literature in recent years. According to data from I. Ahmed *et al.* [9], when comparing different treatment methods, the "trifecta" concept is used, which involves the simultaneous achievement of complete stone removal, the absence of clinically significant complications, and acceptable surgical parameters. Similar conclusions were reached by A.R. El-Nahas *et al.* [10], who demonstrated that the application of the trifecta allows for a more comprehensive assessment of the outcomes of endourological interventions.

Nevertheless, as these authors note, the trifecta concept is predominantly qualitative in nature and does not involve the use of a single quantitative indicator, which limits the scope for statistical analysis and direct comparison of different treatment methods. In other fields of medicine, composite indicators are used to address similar issues. In particular, the work of M.F. Drummond *et al.* [11] demonstrates that composite indices allow for the simultaneous consideration of the clinical efficacy of an intervention, its risks and resource costs. At the same time, the available literature lacks sufficiently developed methods for integrating key clinical outcome parameters into a single composite index that allows for the simultaneous consideration of treatment efficacy, safety and resource intensity. The absence of a standardised quantitative measure limits the scope for statistical analysis, the comparison of results from different studies, and an objective comparison of endourological methods across different clinical and regional settings. Thus, the development of a integral index of the composite effectiveness of treatment for nephroureterolithiasis, which combines the main clinical outcome parameters within a single quantitative indicator, appears to be a justified and timely task. The aim of the present study was to develop and provide a methodological rationale for an integral index of

treatment effectiveness for nephroureterolithiasis that combines the criteria of treatment effectiveness, safety, and resource utilisation within a unified framework and is intended for the comparative evaluation of endourological methods.

Materials and Methods

Methodological foundations for the development of an integral index

The development of integral indices in clinical medicine is based on the principles of composite assessment of treatment outcomes, which are widely applied in clinical epidemiology, medical decision analysis, and health economics [12]. The fundamental concept underlying these approaches is the quantitative comparison of the beneficial clinical effect of a medical intervention with factors that reduce its overall clinical value, such as complications, risks, or additional resource utilisation. Within this framework, integral indices are constructed according to the principle of the ratio between treatment benefit and unfavourable factors. In its generalised form, this model may be expressed as follows:

$$I = E/(1 + P_1 + P_2 + ... + P_n), \quad (1)$$

where I – the integral effectiveness index, E – the indicator of the beneficial clinical effect of the intervention, P_1-P_n – factors that reduce the overall clinical value of the treatment. The indicator of beneficial clinical effect (E) may vary across different fields of medicine and should reflect the principal treatment outcome. Such indicators may include, for example, patient survival, the rate of clinical remission, the proportion of patients achieving successful treatment outcomes, or other measures characterising the effectiveness of a medical intervention.

The factors P_1-P_n represent parameters that diminish the overall clinical value of the intervention. Depending on the nature of the medical technology, these may include the incidence of complications, the risk of adverse outcomes, treatment duration, operative duration, length of hospital stay, or additional healthcare resource utilisation. This principle is widely employed in the development of composite clinical outcome measures and health technology assessment models [13]. In clinical epidemiology and pharmacoeconomics, similar approaches are used to evaluate the benefit-risk balance of medical interventions and to assess the effectiveness of healthcare technologies. Based on these methodological principles [14-16], the development of the integral index of composite treatment effectiveness (ICTE) for nephroureterolithiasis was founded on the ratio between the beneficial clinical effect and factors reflecting the risks and resource requirements of the intervention. The rate of complete removal of urinary tract stones was selected as the primary indicator of treatment effectiveness, whereas the incidence of complications and operative duration were considered factors reducing the overall clinical value of treatment.

Structure and mathematical model of the ICTE

Based on the methodological principles outlined above, a calculation model for the ICTE for nephroureterolithiasis was developed. The index incorporates three key parameters representing the principal aspects of endourological treatment outcomes: treatment effectiveness, procedural safety, and treatment resource utilisation (Fig. 1).

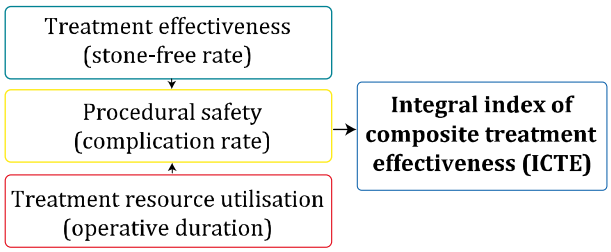


Figure 1. Structure of the integral index of composite treatment effectiveness for nephroureterolithiasis
Source: developed by the authors using the BioRender platform [17]

The stone-free rate (SFR) was selected as the primary indicator of clinical effectiveness, representing the proportion of patients in whom no residual urinary tract stones are detected following the intervention [18]. This measure is one of the most widely used criteria for evaluating treatment outcomes in urinary stone disease and is employed in the majority of clinical studies investigating endourological techniques. Within the proposed model, procedural safety is represented by the incidence of postoperative complications. This parameter reflects the combined influence of the invasiveness of the procedure, its technical complexity, and patient-related factors. An increase in the complication rate objectively reduces the overall clinical value of treatment and is therefore incorporated into the index model as a factor that decreases its value.

The mean operative duration was selected as the indicator of treatment resource utilisation. Operative duration is an important characteristic of endourological procedures because it reflects the technical complexity of the intervention, the burden placed on the patient, and the utilisation of operating theatre resources. Based on these parameters, the ICTE is calculated using Equation (2):

$$\mathrm{ICTE} = \frac{SFR}{1+\frac{Comp}{10}+\frac{t\,operation}{60}}, \quad (2)$$

where SFR – the stone-free rate, $Comp$ – the number of procedures performed per unit of time, $t_{operation}$ – the time required to perform a single operation (minutes). Within the structure of the formula, the stone-free rate

is placed in the numerator of the index, reflecting its central role as the primary criterion of clinical effectiveness in the treatment of nephroureterolithiasis. The complication rate and operative duration are incorporated into the denominator as factors that reduce the overall clinical value of the intervention.

To ensure comparability between variables with different units of measurement, the parameters are normalised within the formula. Dividing the complication rate by 10 brings this variable onto a scale comparable with the other components of the index. Similarly, dividing operative duration by 60 converts the time from minutes to a standardised hourly scale, thereby preventing this parameter from exerting a disproportionate influence on the final index value.

Results

Calculation of the ICTE

To illustrate the application of the proposed model, a hypothetical example of index calculation may be considered. It was assumed that, for a particular endourological technique, the stone-free rate was 85%, the postoperative complication rate was 10%, and the mean operative duration was 60 minutes. According to the proposed formula, the index is calculated as follows ICTE = 85/(1 + 10/10 + 60/60) = 85/3 = 28.3. The value of the index is determined by the ratio between clinical effectiveness and the combined contribution of the factors reflecting procedural safety and treatment resource utilisation. An increase in the stone-free rate increases the numerator of the equation, resulting in a higher ICTE value. Conversely, an increase in either the complication rate or operative duration increases the denominator, thereby reducing the final value of the index. The algorithm for calculating the ICTE is presented in Figure 2.

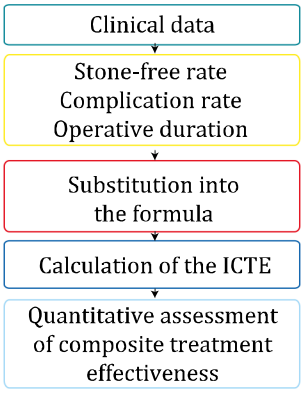


Figure 2. Algorithm for calculating the integral index of composite treatment effectiveness (ICTE) for nephroureterolithiasis

Source: developed by the authors using the BioRender platform [17]

The use of this calculation model makes it possible to simultaneously account for the principal characteristics of treatment outcomes and to generate a single quantitative indicator reflecting the composite effectiveness of endourological treatment for nephroureterolithiasis. Such an approach enables the comparable analysis of treatment outcomes obtained across different clinical centres and facilitates the interpretation of clinical research data. Furthermore, the application of the integral index reduces the influence of individual parameters with opposing effects and expresses the overall effectiveness of the intervention as a single quantitative measure suitable for statistical analysis and comparative evaluation of different treatment modalities.

Structure of the integral index of composite treatment effectiveness for endourological interventions in nephroureterolithiasis

The developed integral index of composite treatment effectiveness comprises three components representing the principal characteristics of endourological treatment outcomes in nephroureterolithiasis: the stone-free rate (SFR), the postoperative complication rate, and operative duration. The structure of the index is based on the distinction between a parameter representing the beneficial clinical outcome and parameters reflecting factors associated with the intervention. The stone-free rate is incorporated into the numerator of the equation as the primary measure of treatment effectiveness, whereas the complication rate and operative duration are included in the denominator. The SFR represents the proportion of patients with no residual urinary tract calculi following endourological intervention. The postoperative complication rate reflects the frequency of adverse events associated with the surgical procedure, including infectious complications, haemorrhage, and other postoperative conditions. Operative duration represents the time required to perform the surgical procedure and is used as a quantitative measure of treatment resource utilisation.

The resulting values of the integral index of composite treatment effectiveness provide a quantitative measure of the outcomes of endourological interventions. For a fixed stone-free rate, an increase in either the complication rate or operative duration results in a lower index value. Conversely, when the values of these risk-related factors remain comparable, an increase in the stone-free rate leads to a higher ICTE value. Thus, changes in each component exert a predictable influence on the final value of the index, allowing the contribution of individual parameters to be incorporated within a single quantitative model.

Postoperative complication rate and indicators of treatment resource utilisation

The safety of endourological interventions is one of the most important factors determining the clinical value of a treatment modality. Despite the minimally invasive nature of contemporary endourological techniques,

surgical treatment of urinary stone disease may be associated with various complications, including infectious complications, haemorrhage, urinary tract injury, and other adverse events. The postoperative complication rate reflects the combined influence of the invasiveness of the procedure, its technical complexity, and patient-related factors. When comparing different endourological techniques, this parameter provides an assessment of the level of risk associated with each treatment modality. An increase in the complication rate objectively reduces the clinical value of treatment, even when stone clearance is highly effective. Consequently, this parameter was incorporated into the index as a factor that reduces the final ICTE value. This approach enables the balance between treatment effectiveness and procedural safety to be taken into account.

In addition to treatment effectiveness and safety, treatment resource utilisation is an important aspect in the evaluation of healthcare technologies. In surgical practice, one of the most objective and reproducible indicators of resource utilisation is operative duration. The duration of surgery reflects the technical complexity of the procedure, the degree of surgical invasiveness, and the utilisation of operating theatre resources. Longer procedures are generally associated with a greater burden on both the patient and healthcare personnel, while also requiring more substantial organisational resources. Furthermore, operative duration is often correlated with the likelihood of postoperative complications and the length of patient recovery. Accordingly, this parameter may be regarded as an indirect indicator of the overall complexity and resource requirements of the treatment modality.

The inclusion of operative duration in the structure of the integral index of composite treatment effectiveness makes it possible to account not only for the direct clinical outcome of treatment but also for the organisational aspects associated with the use of different endourological techniques. This is particularly important when comparing treatment modalities in healthcare systems with limited resources. Thus, the selected components of the ICTE – the stone-free rate, the postoperative complication rate, and operative duration – represent the three principal dimensions of treatment outcomes: effectiveness, safety, and treatment resource utilisation. Their integration within a single mathematical model provides a more comprehensive and objective assessment of the outcomes of endourological interventions for nephroureterolithiasis.

Advantages of the ICTE and its applications

The use of the ICTE enables a transition from the isolated assessment of individual treatment parameters in nephroureterolithiasis to a more comprehensive quantitative evaluation of endourological outcomes. By integrating the key parameters of clinical outcome into a single calculated measure, the index simultaneously accounts for the effectiveness of stone removal, procedural safety, and treatment resource utilisation. One of the principal advantages of the proposed index is its ability to facilitate the objective comparison of different endourological treatment modalities. In situations where different techniques demonstrate comparable stone-free rates but differ in complication rates or operative duration, the use of an integral index provides a more balanced assessment of their overall clinical value.

A further advantage of the index is its simplicity and reproducibility. All variables incorporated into the equation are standard parameters widely used in clinical studies of urinary stone disease and routinely recorded in clinical practice. This makes the index suitable for application both in scientific research and in the evaluation of treatment outcomes in routine clinical settings. The proposed index may also prove valuable for analysing treatment outcomes across different healthcare institutions and geographical regions. The inclusion of a measure of treatment resource utilisation enables organisational aspects of healthcare delivery to be taken into account, which is particularly important when comparing outcomes between institutions with different levels of technical infrastructure and resource availability. Taken together, the ICTE provides a practical tool for the quantitative evaluation of endourological treatment outcomes by integrating the principal dimensions of clinical outcome into a single calculated measure.

The ICTE may be applied in a wide range of clinical and scientific activities related to the management of nephroureterolithiasis. First, it may be used in clinical studies comparing different endourological treatment modalities for urinary stone disease. The use of a single integral measure simplifies the interpretation of study findings and facilitates direct comparisons between different stone removal techniques. In addition, the index may be used to evaluate treatment outcomes within individual healthcare institutions. The application of an integral measure enables a more objective assessment of the performance of a hospital or surgical department by simultaneously considering treatment effectiveness, procedural safety, and resource utilisation. Another important application of the index is the evaluation of regional differences in the management of nephroureterolithiasis. The effectiveness of endourological interventions may vary substantially according to geographical and climatic conditions, disease patterns, and the level of technical equipment available within healthcare institutions. Furthermore, the proposed index may be used in the development of clinical guidelines and in the evaluation of the implementation of new medical technologies. The availability of a quantitative measure integrating the principal parameters of clinical outcome facilitates the comparative assessment of different approaches to the treatment of urinary stone disease.

Discussion

The proposed calculation model enables a transition from the fragmented assessment of treatment outcomes in nephroureterolithiasis to a more comprehensive quantitative analysis that simultaneously accounts for treatment effectiveness, procedural safety, and treatment resource utilisation. This is of particular importance in clinical practice, as individual outcome measures frequently demonstrate divergent trends, thereby complicating the interpretation of results and the selection of the optimal treatment strategy. In recent years, the limitations of analysing individual parameters, such as the SFR, in isolation have been increasingly emphasised in the literature, as this measure neither reflects the risk of complications nor accounts for the burden placed on the patient and the healthcare system. For example, D.Y. Chung *et al.* [16], in a systematic review and network meta-analysis including 35 studies, demonstrated that percutaneous nephrolithotomy (PCNL) achieved a higher SFR than retrograde intrarenal surgery (RIRS) and extracorporeal shock wave lithotripsy. However, the authors emphasised that the use of the SFR alone does not provide a comprehensive assessment of clinical effectiveness, as it fails to consider differences in complication profiles and the invasiveness of the procedures. These findings directly support the need for integral indices capable of incorporating multiple dimensions of clinical outcomes.

An attempt to achieve a more comprehensive evaluation of treatment outcomes has been made through the trifecta concept. E. Pozzi *et al.* [18] reported that trifecta achievement following vacuum-assisted mini-PCNL was observed in approximately 60% of patients, while the likelihood of achieving trifecta decreased with increasing stone burden and involvement of multiple calyces. The authors also found that patients who achieved trifecta had shorter operative times and more favourable postoperative recovery. These findings indicate that combining several outcome parameters provides a more complete characterisation of treatment success. Nevertheless, the trifecta remains a qualitative tool because, in most studies, it is assessed as a binary outcome ("achieved" or "not achieved"), thereby limiting opportunities for statistical analysis and reducing sensitivity when comparing different treatment modalities.

Within this context, the proposed integral index of composite treatment effectiveness (ICTE) may be regarded as a further development of the trifecta concept, providing a transition from qualitative assessment to the quantitative integration of treatment outcome parameters. Unlike binary models, the ICTE accounts for the contribution of each individual component and generates a continuous measure reflecting the balance between treatment effectiveness and procedural safety. From a methodological perspective, this approach is consistent with current developments in comparative effectiveness research. According to the recommendations of D.C. Hoaglin *et al.* [19], indirect treatment comparisons and network meta-analyses make it possible to integrate disparate sources of evidence and generate more comprehensive estimates of the effectiveness of healthcare technologies, particularly when direct comparative studies are unavailable. Although these methods are primarily intended for the synthesis of evidence across multiple studies, their underlying conceptual framework (the integration of several sources of information within a single analytical model) is consistent with the methodological principles underpinning the ICTE.

Further evidence supporting the need to integrate multiple outcome parameters is provided by studies investigating the ranking of treatment modalities. D.C. Hoaglin *et al.* [20] demonstrated that, even when advanced statistical techniques such as network meta-analysis are employed, the interpretation of results depends substantially on the selected outcome measures and their variability. The authors emphasised that ranking treatment modalities without accounting for uncertainty may lead to misleading clinical conclusions, highlighting the need for more robust and comprehensive evaluation models. From a clinical perspective, consideration of risk factors for complications is equally important. O. Ucer *et al.* [21] demonstrated that, in the treatment of renal calculi measuring 2-4 cm, PCNL achieved a higher stone-free rate (94% versus 73% for RIRS), but was associated with longer hospitalisation and a greater need for blood transfusion, while no significant differences in patient quality of life were observed. These findings demonstrate that the clinical value of a treatment modality depends not only on the effectiveness of stone clearance but also on its safety profile and its overall impact on the patient.

Similar conclusions were reported by L. Boeri *et al.* [22], who demonstrated that Hounsfield unit (HU) values are independent predictors of infectious complications. Specifically, an HU value ≥ 6.3 was associated with pyohydronephrosis, whereas an HU value ≥ 7.3 was associated with an increased risk of postoperative sepsis. These findings indicate that treatment outcomes are determined not only by the technical success of the intervention but also by the patient's baseline clinical condition, further supporting the need for a comprehensive approach to outcome assessment. Overall, current evidence indicates that the clinical evaluation of endourological interventions should incorporate several interrelated outcome parameters. The proposed integral index of composite treatment effectiveness addresses this need by integrating the principal components of treatment outcome – stone removal effectiveness, procedural safety, and treatment resource utilisation – within a single mathematical model. This approach not only improves the comparability of findings across different studies but also

provides an assessment of treatment effectiveness that more closely reflects real-world clinical practice. Nevertheless, the proposed index has several limitations. In particular, the model does not incorporate long-term quality of life, recurrence rates, or the duration of postoperative rehabilitation. Furthermore, the normalisation coefficients used in the model require further clinical validation.

Conclusions

During the present study, which was aimed at the development and methodological substantiation of an integral indicator for the comparative evaluation of the outcomes of endourological interventions in nephroureterolithiasis, an integral index of composite treatment effectiveness was proposed. The index was designed to provide a quantitative assessment of treatment outcomes and was developed on the basis of an analysis of the key clinical parameters used in contemporary urological practice. Unlike the traditional approach, which relies on the separate analysis of individual indicators, the proposed index combines the principal characteristics of the clinical outcome, including the effectiveness of stone removal, procedural safety, and the resource utilisation associated with surgery. The structure of the ICTE is based on the use of the SFR as the primary criterion of effectiveness, while the incidence of postoperative complications and operative duration are considered factors influencing the overall clinical value of treatment. This combination of parameters makes it possible to account for changes in indicators that may occur in different directions and to generate an integrated quantitative measure of treatment outcomes.

Conceptually, the proposed index is similar to the trifecta model widely used in urology, which assumes the simultaneous achievement of several criteria of procedural success. However, unlike the trifecta, which is generally assessed in a binary manner and does not provide quantitative gradation of outcomes, the ICTE is a continuous measure that allows differences between treatment modalities to be represented more flexibly. This enables a more precise comparison of the clinical effectiveness of endourological technologies, particularly in situations where different methods demonstrate comparable SFRs but differ in their complication profiles or operative duration. The use of the integral index therefore makes it possible to consider not only the immediate clinical effect, but also the associated risks and the burden imposed on both the patient and the healthcare system.

The proposed index may be applied both in scientific research and in clinical practice, improving the comparability of results and facilitating the interpretation of clinical data. A significant advantage of the index is its potential use in analysing treatment effectiveness across different regions and healthcare settings, thereby allowing for differences in disease patterns, the level of technological equipment available in medical institutions, and resource availability to be taken into account. Nevertheless, the index requires further clinical testing and validation in independent patient cohorts. Promising directions for future research include the investigation of its prognostic value and the expansion of the model through the incorporation of additional clinical and radiological parameters. Evaluation of the applicability of the ICTE across different endourological technologies and clinical scenarios will help to refine its structure and improve the accuracy of the quantitative assessment of treatment outcomes in nephroureterolithiasis.

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Conflict of Interest

None.

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