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# European Nephrologists' Attitudes toward the Application of Artificial Intelligence in Clinical Practice: A Comprehensive Survey

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**Keywords**
Artificial intelligence · Survey · Nephrologists · Dialysis

**Abstract**

***Introduction:*** The rapid advancement of artificial intelligence and big data analytics, including descriptive, diagnostic, predictive, and prescriptive analytics, has the potential to revolutionize many areas of medicine, including nephrology and dialysis. Artificial intelligence and big data analytics can be used to analyze large amounts of patient medical records, including laboratory results and imaging studies, to improve the accuracy of diagnosis, enhance early detection, identify patterns and trends, and personalize treatment plans for patients with kidney disease. Additionally, artificial intelligence and big data analytics can be used to identify patients' treatment who are not receiving adequate care, highlighting care inefficiencies in the dialysis provider, optimizing patient outcomes, reducing healthcare costs, and consequently creating values for all the involved stakeholders. ***Objectives:*** We present the results of a comprehensive survey aimed at exploring the attitudes of European physicians from eight countries working within a major hemodialysis network (Fresenius Medical Care NephroCare) toward the application of artificial intelligence in clinical practice. ***Methods:*** An electronic survey on the implementation of artificial intelligence in hemodialysis clinics was distributed to 1,067 physicians. Of the 1,067 individuals invited to participate in the study, 404 (37.9%)

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professionals agreed to participate in the survey. ***Results:*** The survey showed that a substantial proportion of respondents believe that artificial intelligence has the potential to support physicians in reducing medical malpractice or mistakes. ***Conclusion:*** While artificial intelligence's potential benefits are recognized in reducing medical errors and improving decision-making, concerns about treatment plan consistency, personalization, privacy, and the human aspects of patient care persist. Addressing these concerns will be crucial for successfully integrating artificial intelligence solutions in nephrology practice.



## Introduction

The rapid advancements in artificial intelligence (AI) have enriched the landscape of modern medicine, offering promising opportunities to transform patient care and augment clinical decision-making [1, 2]. Among the various medical specialties, nephrology stands to greatly benefit from the integration of AI, given the complexity and intricacies of kidney diseases, as well as the growing burden of chronic kidney disease and end-stage renal disease worldwide [3, 4].

AI and big data analytics can be used to analyze large amounts of patient medical records, including laboratory results and imaging studies. In hemodialysis, AI and big data analytics, including descriptive, diagnostic, and predictive analytics, can be used to recommend the best dialysis modality for a particular patient and to analyze patient data to identify patterns and trends that can help physicians treat uremic disease and comorbidities more accurately. AI and big data analytics can be used to present patient medical records in a way that is easy to understand, identify patients at risk of complications, and optimize dialysis treatment by adjusting the dose and frequency of dialysis to meet the individual needs of each patient. AI and big data analytics can also support physicians in tailoring drug prescriptions to individual patient preferences and needs. By using AI and data analytics, it is possible to predict the percentage of patients that should be on target for a specific medical key performance indicator (e.g., the percentage of patients with a hemoglobin level in the range of 10–12 g/dL). AI and big data analytics have the potential to identify patients in hemodialysis treatment who are not receiving adequate care, highlighting care inefficiencies in the dialysis provider, optimizing patient outcomes, reducing healthcare costs, and creating value for all stakeholders involved [5].

Despite the potential of AI in nephrology, its successful integration into clinical practice hinges on the attitudes and perceptions of nephrologists, who ultimately decide the extent of AI adoption in their daily workflow [6]. Understanding nephrologists' perspectives on AI is essential to address potential barriers, concerns, and knowledge gaps [7].

In this paper, we present the results of a comprehensive survey aimed at exploring the attitudes of nephrologists toward the application of AI in clinical practice. The survey delves into the perceived benefits and limitations of AI and nephrologists' readiness to adopt AI-driven solutions and data analytics in patient care, research, and education. Additionally, the survey investigates the factors influencing the willingness of nephrologists to integrate AI into their practice, including their familiarity with AI concepts, training opportunities, and institutional support [6]. This study aims to provide valuable insights to policymakers, educators, and technology developers working toward successfully integrating AI in nephrology, improving patient care and outcomes in the field. The primary goal of this manuscript is to gather the perspectives of European physicians from different countries working within a major hemodialysis network Fresenius Medical Care (FMC) NephroCare. The aim was to better understand their knowledge and views on the introduction of AI into a field that has not yet been widely impacted by these innovative approaches.

## Materials and Methods

An electronic survey on the implementation of AI in hemodialysis clinics was created using the Microsoft Forms platform and distributed to 1,067 physicians working for the FMC NephroCare clinics network across eight countries (Czech Republic, Spain, Germany, Poland, Italy, Portugal, Romania, and Turkey) through internal email addresses using a link to the online survey. Participation was voluntary, and participants were informed about the survey's objectives in the distribution email. Survey questions were developed after reviewing previous survey literature and consulting with the country medical directors of the involved countries to ensure face validity. The survey consisted of 18 multiple-choice questions, focusing on participants' demographic characteristics and experience, previous AI use, their perceptions regarding using these applications in clinical practice, concerns, and barriers. The questionnaire was validated internally for clarity of content and test-retest reliability. All participants in this online survey were physicians from FMC NephroCare. They were adequately informed about the survey's objectives. Informed consent to participate was not directly obtained but inferred by completion of the questionnaire. The survey consisted solely of practice-related questions, and no interventions were delivered to the participants. Given the anonymity of the survey, the risk of

informational or psychological harm to the FMC physicians was assessed as minimal or non-existent. Therefore, it was deemed that the need for ethical oversight from an Ethical Review Board was unnecessary [8].

*Statistical Analysis*

Data are presented as absolute frequency and percentage. The test-retest reliability of the responses to the survey was assessed by calculating the overall agreement in a subgroup of participants randomly extracted from the total sample of responders (sampling fraction = 20%). The same participants provided answers at baseline and after 15 days. A 15-day time interval between assessments was chosen to minimize the "learning effect." Data analysis was performed using STATA Version 17, StataCorp, Lakeway Drive, College Station, TX, USA.

## Results

Of the 1,067 individuals invited to participate in the study, 404 (37.9%) professionals from eight European countries agreed to participate in the survey. Eighty-three participants were from Spain, 78 from Poland, 59 from Germany, 52 from Romania, 46 from the Czech Republic, 34 from Italy, 31 from Turkey, and 21 from Portugal (shown in Fig. 1).

The main characteristics of 404 participants in the survey are included in Table 1. Among these, 189 were males and 215 were females. Sixty-nine participants were aged between 30 and 40 years (17.1%), 110 (27.2%) between 41 and 50 years, 147 (36.4%) between 51 and 60 years, and the remaining 78 participants were over 60 years old (19.3%). Most survey participants were nephrologists ($n$ = 356, 88.1%), while a minority were not ($n$ = 48, 11.9%). Three hundred and twenty-five participants (80.4%) had more than 10 years of clinical experience in treating dialysis patients, 47 (11.6%) had between 5 and 10 years, 20 (5.0%) had between 2 and 5 years, and only 10 (2.5%) had less than 2 years. Two participants did not provide this information (0.5%).

The responses given by participants ($n$ = 404) to the questions of the survey are included in the Table 2. Regarding the first question (shown in Tables 2), and 187 participants (46.3%) agreed that a nephrologist/physician could obtain all relevant medical information from a patient's medical file, while 201 (49.8%) only partially agreed, 15 (3.7%) disagreed, and one did not answer. When asked whether AI could obtain all relevant medical information from a patient's medical file (question 2), 149 participants (36.9%) agreed, 222 (54.9%) partially agreed, and 33 (8.2%) disagreed. Most participants (240, 59.4%) agreed that AI could support physicians in reducing medical malpractice/mistakes (question 3), 158 (39.1%) partially agreed, and only 6 (1.5%) disagreed.

Regarding the consistency between treatment plans made by nephrologists/clinicians and the current state of the art in hemodialysis (question 4), most participants (291, 72%) agreed that this is expected, 109 (27.0%) partially agreed, and 3 (0.8%) disagreed, while 1 participant (0.2%) did not provide an answer. Participants were less confident about the consistency between treatment plans made by AI (rather than nephrologists/physicians) and the current state of the art in hemodialysis (question 5). In fact, only one-third of participants agreed that adequate agreement between AI and the current state of the art in hemodialysis was expected (155, 38.4%). More than fifty percent of participants partially agreed (232, 57.4%), 15 (3.7%) disagreed, and 2 (0.5%) did not provide an answer.

When asked if patient care could become more personalized by using AI (question 6), 139 participants (34.4%) agreed, 225 (55.7%) partially agreed, and 40 (9.9%) disagreed. Regarding the potential contribution of AI in making some clinical decisions easier (question 7), the majority of participants agreed (231, 57.2%), 168 (41.6%) partially agreed, and only 5 (1.2%) disagreed. Concerning the contribution of AI in increasing the time a nephrologist/physician can spend with patients (question 8), 140 participants (34.6%) agreed, 237 (58.7%) partially agreed, and 27 (6.7%) disagreed.

Question 9 explored whether participants believed that the role of nephrologists/physicians could become redundant with the use of AI. Most participants (218, 54%) disagreed, about one-third partially agreed (153, 37.9%), and only a minority agreed (31, 7.7%), while 2 participants (0.4%) did not provide an answer. About one-third of participants (35.4%) were worried that AI devices could reduce human aspects of relations in the treatment process (question 10), 205 (50.7%) partially agreed with this concern, and 55 (13.6%) were not worried at all. One participant did not answer this question (0.3%).

Regarding privacy concerns, about one-quarter of participants (93, 23.0%) did not consider the use of AI to pose serious privacy issues. In contrast, 59 participants (14.6%) believed that this could be a problem, while most participants (252, 62.4%) were uncertain and only partially agreed that it could be a matter of concern. When asked about Elon Musk's 2018 statement that "artificial intelligence is more dangerous than nuclear weapons," 61 participants agreed (15.1%), 255 (63.1%) partially agreed, and the remaining 88 participants (21.8%) disagreed.

Lastly, regarding the frequency of AI use among participants, the majority (174, 43.1%) reported no use or

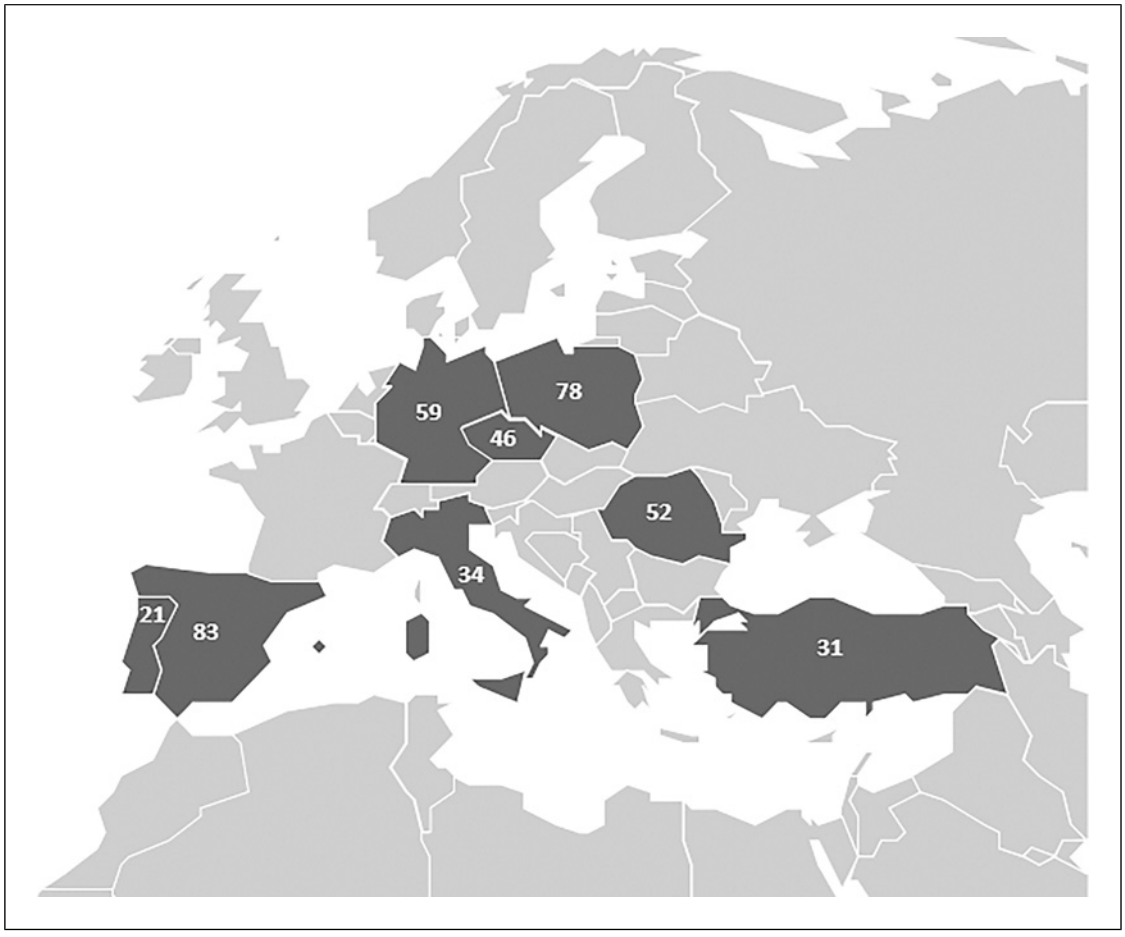


**Fig. 1.** Overview of country of origin and number of respondents to the survey. Spain: 83; Poland: 78; Germany: 59; Romania: 52; Czech Republic: 46; Italy: 34; Turkey: 31; Portugal: 21.

very limited use (just once a day, 112, 27.7%). Eighty-six (21.3%) and 31 (7.7%) participants declared using AI 2–3 times or more than 3 times a day, respectively, while 1 participant (0.2%) did not provide an answer.

The frequency of responses at the first and second assessments (see Methods-Statistical Analysis) was assessed in a subgroup of 83 participants (see online suppl. Table 1; for all online suppl. material, see https://doi.org/10.1159/000534604) who provided the responses to the questionnaire twice. Seventeen participants were from Spain, 15 from Poland, 12 from Romania, 11 from Germany, 9 from Czech Republic, 7 from Italy, 6 from Portugal, and 6 from Turkey (shown in online suppl. Fig. 1). The distribution of responses was similar between the first and second assessments (shown in online suppl. Table 2). The overall agreement between the two assessments was 71%. In online supplementary Table 3, the answers to questions 1–12 are provided according to the responses given to question no. 13, which latter pertaining to the frequency of using AI. As expected, this analysis showed that frequent users are more prone to consider useful AI when compared to non-users. A further analysis carried out by analyzing the answers to the questions 1–13 according to the time spent working (below/above 10 years) in FMC showed no effect of seniority of work on the answers given to the questionnaire (shown online suppl. Table 4).

## Discussion

In this survey, we aimed to assess the attitudes of nephrologists working in the FMC NephroCare clinic network across eight countries concerning the application of AI in clinical practice. The results offer essential insights into the perceptions and concerns of these medical

**Table 1.** Main characteristics of all participants in the survey ($n$ = 404)

| Variables | $n$ (%) |
|---|---|
| Age strata, years | |
| 30–40 | 69 (17.1) |
| 41–50 | 110 (27.2) |
| 51–60 | 147 (36.4) |
| >60 | 78 (19.3) |
| Gender | |
| Females | 215 (53.2) |
| Males | 189 (46.8) |
| Specialist in nephrology and dialysis | |
| Yes | 356 (88.1) |
| No | 48 (11.9) |
| Years spent in treating patients with end stage renal disease on hemodialysis | |
| >10 | 325 (80.4) |
| >5 – ≤10 | 47 (11.6) |
| >2 – ≤5 | 20 (5.0) |
| ≤2 | 10 (2.5) |
| Missing | 2 (0.5) |
| For how many years have you been treating patients with end stage renal disease on hemodialysis in Fresenius Medical Care NephroCare clinics? | |
| >10 | 227 (56.2) |
| >5 – ≤10 | 68 (16.8) |
| >2 – ≤5 | 68 (16.8) |
| ≤2 | 41 (10.1) |

Data are absolute numbers and percentages.

professionals as AI continues to play an increasingly vital role in the healthcare landscape.

The survey showed that a substantial proportion of respondents believe that AI has the potential to support physicians in reducing medical malpractice or mistakes, with 59.4% agreeing and 39.1% partially agreeing. This result is consistent with the existing literature, suggesting that AI applications could improve diagnostic accuracy, reduce errors, and enhance decision-making in healthcare settings [2]. A recent paper by Zoccali et al. [9] emphasized the potential advantages of integrating AI in nephrology practice, particularly in areas such as personalized medicine, risk prediction, and clinical decision support.

In this survey, participants demonstrated mixed opinions regarding the consistency of treatment plans generated by AI compared to those developed by nephrologists/physicians. While most respondents agreed that nephrologists/physicians' treatment plans were consistent with the current state of the art in hemodialysis, only 38.4% of participants expressed confidence in the adequacy of AI-generated treatment plans. This finding highlights the need for further research and development to enhance the performance of AI algorithms in nephrology and increase healthcare professionals' trust in these new ways to diagnose, treat, and manage diseases [10]. This may take time and education.

Participants were also divided on the issue of whether AI could contribute to more personalized patient care. While 34.4% agreed that AI could enhance personalization, 55.7% only partially agreed, and 9.9% disagreed. This finding suggests that some nephrologists may still be skeptical about AI's ability to account for individual patient needs, preferences, and circumstances, underscoring the importance of continued education and communication about AI's potential benefits in patient care [11].

Participants also raised privacy concerns, with 62.4% partially agreeing that AI could pose serious privacy issues. This result underscores the need to address data privacy and security concerns when implementing AI in clinical practice to protect patient information [12].

Finally, it is worth noting that a large number of participants in our survey reported limited use of AI tools in their daily practice. This finding may reflect the current state of AI adoption in nephrology and suggests that there is still significant room for growth in the utilization of AI solutions.

While providing valuable insights into the attitudes of nephrologists toward the implementation of AI in clinical practice, the present survey has several limitations that need to be considered when interpreting the findings. First is the sample size. The survey was conducted among 1,067 physicians, but only 404 (37.9%) participated. A larger sample size and higher response rate would have provided a more accurate representation of the target population's attitudes. The second limitation relates to geographic distribution: The survey was limited to eight countries within the FMC NephroCare clinic network where physicians utilize EuCliD AI solutions [13]. Mixing physicians trained and not trained with EuCliD AI solutions could potentially bias the survey results. The attitudes of nephrologists in other countries, particularly in low-income countries or non-European settings, may differ substantially. Expanding the survey to include a more diverse range of countries and healthcare systems would provide a more comprehensive global understanding of nephrologists' views on AI in clinical practice. The third limitation is inherent to the design. In volunteer-based studies like ours, participants have strong opinions on the issue being surveyed. Obvious advantages of surveys based on volunteers are their inexpensiveness, ease of performance, and feasibility. The results of this survey reflect the attitudes and

**Table 2.** Responses given by participants ($n = 404$) to the questions of the survey

| Questions | *n* (%) |
|---|---|
| 1) Is it possible for a nephrologist/physician to obtain all relevant medical information from a patient's medical file? | |
| Agree | 187 (46.3) |
| Partially agree | 201 (49.8) |
| Disagree | 15 (3.7) |
| No response | 1 (0.2) |
| 2) Is it possible for artificial intelligence to obtain all relevant medical information from a patient's medical file? | |
| Agree | 149 (36.9) |
| Partially agree | 222 (54.9) |
| Disagree | 33 (8.2) |
| 3) Is artificial intelligence able to support physicians in reducing medical malpractice/mistakes? | |
| Agree | 240 (59.4) |
| Partially agree | 158 (39.1) |
| Disagree | 6 (1.5) |
| 4) Will hemodialysis and home treatment plans made by a nephrologist/physician correspond to the current state-of-the-art in hemodialysis? | |
| Agree | 291 (72.0) |
| Partially agree | 109 (27.0) |
| Disagree | 3 (0.8) |
| No response | 1 (0.2) |
| 5) Will hemodialysis and home treatment plans made by an artificial intelligence correspond to the current state-of-the-art in hemodialysis? | |
| Agree | 155 (38.4) |
| Partially agree | 232 (57.4) |
| Disagree | 15 (3.7) |
| No response | 2 (0.5) |
| 6) Will patient care become more personalized by using artificial intelligence? | |
| Agree | 139 (34.4) |
| Partially agree | 225 (55.7) |
| Disagree | 40 (9.9) |
| 7) Do you see that artificial intelligence can help making some of the clinical decisions easier for the nephrologist/physician? | |
| Agree | 231 (57.2) |
| Partially agree | 168 (41.6) |
| Disagree | 5 (1.2) |
| 8) Will the use of artificial intelligence increase the time a nephrologist/physician can spend with the patients? | |
| Agree | 140 (34.6) |
| Partially agree | 237 (58.7) |
| Disagree | 27 (6.7) |
| 9) Will the role of the nephrologist/physician become redundant by using artificial intelligence? | |
| Agree | 31 (7.7) |
| Partially agree | 153 (37.9) |
| Disagree | 218 (54) |
| No response | 2 (0.4) |
| 10) Will artificial intelligence devices reduce human aspects of relations in the treatment process? | |
| Agree | 143 (35.4) |
| Partially agree | 205 (50.7) |
| Disagree | 55 (13.6) |
| No response | 1 (0.3) |
| 11) Do you expect serious privacy issues with the use of artificial intelligence? | |
| Agree | 93 (23) |
| Partially agree | 252 (62.4) |
| Disagree | 59 (14.6) |
| 12) How much do you agree with the following statement: "Artificial intelligence is more dangerous than nuclear weapons" (Musk, 2018) | |
| Agree | 61 (15.1) |
| Partially agree | 255 (63.1) |
| Disagree | 88 (21.8) |
| 13) How many applications of artificial intelligence have you come across in your daily work? | |
| More than three | 31 (7.7) |
| None | 174 (43.1) |
| One | 112 (27.7) |
| Two to three | 86 (21.3) |
| No response | 1 (0.2) |

Data are absolute numbers and percentages.



opinions of the 38% most motivated nephrologists, or 404 nephrologists in absolute terms, in FMC NephroCare organization. However, since the findings in this survey were based on nephrologists from an international dialysis network, replication of this survey among nephrologists external to FMC NephroCare dialysis network is needed to confirm the external generalizability of our findings. Reservations about the application of AI in clinical practice are most likely higher in the nephrology population that did not participate in the survey (62%). The survey was cross-sectional, capturing nephrologists' opinions at a single time point. As AI technology evolves rapidly and its adoption in nephrology progresses, attitudes may change. Longitudinal studies or repeated surveys could help track changes in attitudes over time and provide insights into how increased exposure to AI in clinical practice may influence nephrologists' opinions.

Fourth, participants' self-assessment of their knowledge and experience with AI may not accurately reflect their true competencies. Finally, the questionnaire consisted of 18 multiple-choice questions, which may have limited the depth and nuance of the participants' responses. Open-ended questions or qualitative interviews could provide richer insights into nephrologists' attitudes, concerns, and expectations regarding AI in clinical practice.

Despite these limitations, the survey provides novel insights into the attitudes and perceptions of nephrologists regarding the implementation of AI in clinical practice. Finally, it is important to recognize that generative AI, a type of AI able of generating text, images, or other media in response to specific prompts, offers novel interactions and tools that will surely get physicians more curious and wary of the result. The implementation of AI into nephrology and dialysis practices is a complex process. It is important to address the ethical tensions and practical challenges associated with the use of AI to ensure that it is used safely and effectively. Currently, there are no well-defined regulations in place to address the legal and ethical issues that may arise due to the use of AI in healthcare settings. The use of patient personal data is governed by a number of global data privacy regulations (e.g., General Data Protection Regulation in the European Union). In addition to these regulations, there are several ethical principles that should be followed when using patient personal data including respect for privacy, transparency (patients should be informed about how their data are being collected and utilized), security, and organizations must respect data privacy regulations and ethical principles. By following these regulations and principles, organizations can ensure that they are using patient personal data in an ethical and responsible way. A more widespread application of AI solutions in nephrology and dialysis should stimulate regulators, engineers, clinicians, and patients to collaborate multidisciplinarly to develop specific guidelines on data quality, security, and transparency about AI models. Clinical staff and patients should be educated to correctly utilize AI solutions, understanding their limitations, and correctly applying the results to ensure that AI is used safely and effectively to improve patient care, offering evidence-based management and providing medical decision-guides.

In conclusion, this survey describes nephrologists' attitudes toward AI in clinical practice within the FMC NephroCare clinic network. While AI's potential benefits are recognized in reducing medical errors and improving decision-making, concerns about treatment plan consistency, personalization, privacy, and the human aspects of patient care persist. Addressing these concerns through further research, development, and education will be crucial for successfully integrating AI and data analytics in nephrology practice.


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## Statement of Ethics

Ethical approval is not required for this study in accordance with local or national guidelines. Informed consent to participate was not directly obtained but inferred by completion of the questionnaire/participation in the interview.

## Conflict of Interest Statement

M.S., M.E.B.S., P.P., D.V., M.P., T.J., S.K.K., W.M., M.C., L.N., L.U., J.L.H., F.W.M., and S.S. are Fresenius Medical Care employees. C.Z. and G.T. have no conflict of interest. The results presented in this paper have not been published previously in whole or in part.


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## Author Contributions

Matteo Savoia and Giovanni Tripepi contributed equally to this study. Stefano Stuard contributed to the study conception and design. Matteo Savoia contributed to material preparation and data collection. The statistical analysis was performed by Giovanni Tripepi. The first draft of the manuscript was written by Carmine Zoccali, Giovanni Tripepi, Matteo Savoia, and Stefano Stuard. Matteo Savoia, Giovanni Tripepi, Berit Goethel-Paal, Maria Eva Baró Salvador, Pedro Ponced, Daniela Voiculescu, Martin Pachmann, Tomas Jirka, Serkan Kubilay Koc, Wojciech Marcinkowski, Mario Cioffi, Luca Neri, Len Usvyat, Jeffrey L. Hymes, Franklin W. Maddux, Carmine Zoccali, and Stefano Stuard commented on previous versions of the manuscript. All authors read and approved the final manuscript.

## Data Availability Statement

The data that support the findings of this study are not publicly available due to their containing information that could potentially compromise the privacy of research participants but are available from the corresponding author [S.S.].

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