*Quantitative Study*

DIGITAL HEALTH

DIGITAL HEALTH
Volume 9: 1–9

DOI: 10.1177/20552076231176644
journals.sagepub.com/home/dhj

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# Determinants of the implementation of artificial intelligence-based screening for diabetic retinopathy—a cross-sectional study with general practitioners in Germany

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## Abstract

**Objective:** Diabetic retinopathy (DR) may lead to irreversible damage to the eye and cause blindness if diagnosed in its advanced stages. Artificial intelligence (AI) may support screening and contribute to a timely diagnosis. The aim of this study was to evaluate factors that might influence the success of implementing AI-supported devices for DR screenings in general practice.

**Methods:** A questionnaire with modules on attitudes toward digital solutions, technical factors, perceived patient perspectives, and sociodemographic data was constructed and 2100 general practitioners (GPs) in Germany were invited to participate via a personal letter.

**Results:** Two hundred nine physicians participated in the survey (10% response rate, mean age = 54 years, 46% women). Acquisition costs (mean = 1.37), remuneration (mean = 1.46), and running costs (mean = 1.40) were considered particularly relevant in the context of AI-based screening tools. GPs indicated that a mean of €27.00 (SD = 19) was considered to be an appropriate reimbursement for an AI-based screening for DR in their practice. Less relevant factors were availability of a smartphone used in the practice (mean = 2.53) and time until the examination result was available (mean = 2.29). Important technical factors were practicability of the device (mean = 1.27), unproblematic installation of any necessary software (mean = 1.34), and the integrability into the practice information system (mean = 1.44). Considering the patient welfare, physicians rated the accuracy of the examination, omission of pupil dilation, and the duration of the examination as the most important factors. Participants ranked the factors broadening the scope of care, strengthening the primary care (PC) range, and signs of modern medical practice as the most important factors for making an AI-based screening tool attractive for their practice.

**Conclusions:** These findings serve as a basis for a successful implementation of AI-assisted screening devices in PC and might facilitate early screenings for ophthalmological diseases in general practice. The most relevant barriers that need to be overcome for a successful implementation of such tools include clarification of the costs and reimbursement policies.

## Keywords

Diabetic retinopathy, diabetes mellitus, screening, artificial intelligence, general practice, primary care

Submission date: 23 October 2022; Acceptance date: 2 May 2023

## Background

Diabetic retinopathy (DR) is a frequent complication of diabetes mellitus (DM) type 1 and 2 that causes severe and irreversible damage such as blindness if diagnosed too late. It is assumed that the global number of DM cases will increase

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due to, for example demographic developments.[1] Early detection is particularly important due to the fact that clinical signs are largely absent in the early stages of the disease. During retinopathy, retinal blood vessels become damaged, leading to the formation of small bulges called microaneurysms on the vessel walls. These microaneurysms can rupture, resulting in retinal hemorrhages as blood enters the retinal tissue.[2] In addition, nerve fibers in the retina may swell, causing white spots on the retina known as cotton wool spots.[3,4] While both microaneurysms and nerve fiber swelling are associated with retinopathy, they represent distinct pathophysiological processes, with the swelling of nerve fibers not directly contributing to the development of microaneurysms or retinal hemorrhages.

The prevalence of DR in Germany has been found to vary according to the duration of the disease and the healthcare sector. For example, in primary care (PC), 24% of type 1 and 10% of type 2 DM patients who have had diabetes for at least 5 years are diagnosed with DR. In contrast, in secondary and tertiary care, the prevalence increases to 27% to 30% for type 1 and 20% to 25% for type 2 DM patients who have had diabetes for at least 10 years.[5] In rural areas, diabetologists and ophthalmologists are scarce and may be difficult to reach.[6] Implementing screening for DR in PC could facilitate reaching patients at an early stage. With the help of artificial intelligence (AI) devices, retinal images could be evaluated on PC without the need for an eye specialist.[7,8] AI-based screening typically involves the use of machine learning algorithms, particularly deep-learning techniques, to analyze retinal images and identify patterns indicative of DR. These algorithms are trained on large datasets of labeled retinal images and can learn to recognize features associated with DR, such as microaneurysms, hemorrhages, and cotton wool spots. Once trained, these AI models can rapidly and accurately evaluate new retinal images for the presence of DR, potentially improving the efficiency and accessibility of DR screening programs.

However, little is known about the factors that may influence the adoption of such screening devices into daily practice in PC settings.[9] Several recent studies have assessed concerns of practitioners in PC regarding the implementation of AI-based screenings in their practice, with the cost of implementation and potential technical issues frequently named as reasons that hinder the implementation.[10–13] At the same time, studies have identified a generally positive attitude of general practitioners (GPs) toward AI-based screening systems.[14,15] A large proportion of e-health projects in recent years did not develop beyond a pilot stage and could not be successfully integrated into daily medical care due to a lack of scientific evaluation.[16,17] With the help of implementation scientists who supply methods that are systematically suitable for the transfer of findings from current research into patient care, it is possible to pave a path to introduce AI methods into daily medical practice. In this way, the effectiveness, efficiency, and quality of health care could be improved.[18] Therefore, the identification of facilitating factors and barriers related to AI devices in the PC field is an important element of implementation science.[19] Exploring the needs and requirements of future users is the basis for transferring the best available evidence into everyday clinical practice.[20]

The aim of this study is therefore to further evaluate factors that might influence the implementation of AI-based devices, including smartphone-based solutions, for the screening of DR in PC.

## Methodology

The study was conducted according to the Strengthening the Reporting of Observational Studies in Epidemiology guideline.[21]

### Questionnaire

The questionnaire was developed on the grounds of a previously conducted qualitative study[22] and the experiences of the researchers (Director of the Institute of General Medicine, economic engineer, and GP). The questionnaire used in this study has not been previously validated. However, it was piloted by four GPs to assess its comprehensibility and face validity. During this process, only minor amendments were made. The questionnaire consisted of six modules (see Supplemental file for the full questionnaire). The first module related to attitudes regarding digital solutions for PC physicians. The second module captured the relevance of technical factors during implementation. The third module captured the perceived patient perspective. Part four dealt with the impact of AI-supported screening on the profession of a GP. Modules five and six included questions on practice management and sociodemographic data. The questionnaire was distributed in German and was translated into English solely for the purpose of this publication.

### Recruitment

This cross-sectional study was conducted over a period of three months, from November 2021 to February 2022. A total of 2100 GPs were randomly invited to participate via a personal letter. They were chosen from the databases of the Associations of Statutory Health Insurance Physicians of the federal states of Brandenburg, Baden-Württemberg, North Rhine-Westphalia, and Mecklenburg-Western Pomerania. Inclusion criteria for participation in this study were GPs registered with the Associations of Statutory Health Insurance Physicians in the federal states of Brandenburg, Baden-Württemberg, North Rhine-Westphalia, and Mecklenburg-Western Pomerania. Exclusion criteria were physicians who specialized in fields other than general practice.

After three weeks, a reminder letter and another invitation to the survey were sent out. Another three weeks

**Table 1.** Relevance of determinants during the implementation of AI-based screenings for DR in primary care.

| Items* | Mean (SD) | CI 95% | Median (IQR) |
|---|---|---|---|
| Acquisition costs | 1.37 (0.71) | 1.28–1.50 | 1 (1; 2) |
| Running costs | 1.40 (0.69) | 1.32–1.54 | 1 (1; 2) |
| Validity of the examination | 1.44 (0.69) | 1.34–1.55 | 1 (1; 2) |
| Remuneration | 1.46 (0.78) | 1.37–1.63 | 1 (1; 2) |
| Simplicity of billing | 1.46 (0.79) | 1.30–1.52 | 1 (1; 2) |
| Contact person for technology/IT | 1.48 (0.82) | 1.33–1.58 | 1 (1; 2) |
| Low-threshold contact with ophthalmologists | 1.56 (0.79) | 1.45–1.70 | 1 (1; 2) |
| Duration of the examination | 1.58 (0.79) | 1.46–1.71 | 1 (1; 2) |
| Liability issues | 1.61 (0.99) | 1.49–1.82 | 1 (1; 2) |
| Training of the handling | 1.62 (0.85) | 1.51–1.79 | 1 (1; 2) |
| Delegability of retinal image creation to medical assistants | 1.72 (0.99) | 1.53–1.83 | 1 (1; 2) |
| Openness of the practice team toward new procedures | 1.75 (0.95) | 1.58–1.87 | 1 (1; 2) |
| Competency enhancement for medical assistants | 1.85 (0.90) | 1.69–1.97 | 2 (1; 2) |
| Data security | 1.85 (1.06) | 1.66–2.00 | 1 (1; 2) |
| Training (information about the disease) | 1.86 (0.92) | 1.63–1.98 | 2 (1; 2) |
| Change of established practice processes | 1.93 (0.99) | 1.78–2.10 | 2 (1; 3) |
| Competency enhancement for general practitioners | 1.96 (0.93) | 1.76–2.02 | 2 (1; 2) |
| Established treatment pathways between general practitioners and ophthalmologists | 2.13 (1.18) | 1.95–2.33 | 2 (1; 3) |
| Time until the results come in | 2.29 (1.18) | 2.05–2.42 | 2 (1; 3) |
| Provision of a practice smartphone | 2.53 (1.30) | 2.26–2.66 | 3 (1; 3) |

AI: artificial intelligence; DR: diabetic retinopathy; SD: standard deviation; CI: confidence interval; IQR: interquartile range; IT: information technology.
*Range from 1 (very relevant) to 5 (very irrelevant).

later, a final reminder was sent out, this time with the survey enclosed in paper form in order to reach the less digitally affine target group and increase the response rate. No incentive was offered.

## Statistical analysis

Analyses were performed using SPSS 27.0 (SPSS Inc., IBM, Armonk, USA).

First, the sociodemographic characteristics of the sample were described. Continuous data were summarized using means, standard deviations, medians, and interquartile ranges. Categorical data were presented as frequency counts and percentages. Most items within the questionnaire used a five-point Likert scale (1 = very positive to 5 = very negative or 1 = very relevant to 5 = very irrelevant). Therefore, for these different items mean, standard deviation, and confidence interval as well as median and interquartile range were calculated.

Subgroup analyses using chi²-test and Mann–Whitney *U*-test were performed regarding the age and gender of the participants as well as the interval-scaled variable "distance ophthalmologist's practice." This variable was dichotomized. The cutoff was calculated on the basis of

**Table 2.** Relevance of technical factors during the implementation of AI-based screening for DR in primary care.

| Items* | Mean (SD) | CI 95% | Median (IQR) |
|---|---|---|---|
| Practicability | 1.27 (0.63) | 1.16–1.33 | 1 (1; 1) |
| Simplicity of the installation of the necessary software | 1.34 (0.70) | 1.23–1.44 | 1 (1; 1) |
| Integrability into the practice information system | 1.44 (0.78) | 1.30–1.52 | 1 (1; 2) |
| Disinfection ability | 1.48 (0.80) | 1.37–1.61 | 1 (1; 2) |
| Automatic patient data input into the diagnostic software | 1.50 (0.79) | 1.37–1.60 | 1 (1; 2) |
| Handiness | 1.50 (0.80) | 1.38–1.61 | 1 (1; 2) |
| Automatic detection of image quality | 1.65 (0.81) | 1.54–1.79 | 1 (1; 2) |
| Robustness | 1.68 (0.93) | 1.54–1.81 | 1 (1; 2) |
| Possibility to pass on retinal images to ophthalmologists, for example, via mail | 1.73 (0.93) | 1.59–1.87 | 2 (1; 2) |
| Possibility to detect various retinal pathologies | 1.94 (1.03) | 1.76–2.06 | 2 (1; 2) |
| Compatibility with different smartphone systems (e.g. Android and IOS) | 2.06 (1.25) | 1.86–2.23 | 2 (1; 3) |
| Cloud-based (usable from anywhere) | 2.28 (1.32) | 2.05–2.43 | 2 (1; 3) |
| Possibility of mobile use | 2.81 (1.32) | 2.57–2.95 | 3 (3; 4) |

AI: artificial intelligence; DR: diabetic retinopathy; SD: standard deviation; CI: confidence interval; IQR: interquartile range.
*Range from 1 (very relevant) to 5 (very irrelevant).

the median. Therefore, value 10 was used to divide the group into group one "1 to 9 min" and group two "10 min and more."

## Results

### Sociodemographic data

The sample included 209 of 2100 physicians, which translated to a response rate of ~10%. The surveyed physicians were either working alone in a practice or within small group practices. The average age of the physicians was 54 years.

The gender distribution of the sample was as follows: 51% of the participants were female and 49% were male. Of the subjects, 40% stated that they work in rural areas and 51% in urban areas. The average years of practice was 18 years (SD = 11.7).

### Digital solutions for PC practice

A summary of the responses to the question about the relevance of different aspects of AI-based screening for DR in PC practice was shown in Table 1.

Financial factors, such as acquisition costs (mean = 1.37), remuneration (mean = 1.46), and running costs (mean = 1.40), were rated as very relevant. Respondents indicated a mean of €27.00 (SD = 19) as an appropriate payment for such an examination, which could be done in about ten minutes and could be delegated to a medical assistant. The maximum price that respondents would be willing to invest in the purchase of an AI-assisted eye screening was a mean of €1920.00 (SD = 2001).

The availability of a smartphone used in the practice (mean = 2.53) and time until the examination result was available (mean = 2.29) were rated as less important compared to other factors.

### Technical Implementation

Table 2 shows factors regarding the technical implementation of AI-assisted screening for DR in PC. The factors that were rated to be the most important were the practicability of the device (mean = 1.27), followed by the simplicity of the installation of the necessary software (mean = 1.34) and the integrability into the practice information system (mean = 1.44). The possibility of mobile use was assessed to be the least important factor (mean = 2.81). Also, the need for a cloud-based system (mean = 2.28) and compatibility with different smartphone systems (mean = 2.06) were rated as less important compared to other factors.

**Table 3.** Relevance of determinants of the implementation of AI-based DR screening in primary care concerning patient welfare.

| Items* | Mean (SD) | CI 95% | Median (IQR) |
|---|---|---|---|
| Validity of the examination | 1.28 (0.54) | 1.20–1.38 | 1 (1; 2) |
| Pupil dilation can be omitted | 1.51 (0.74) | 1.37–1.59 | 1 (1; 2) |
| Duration of the examination | 1.52 (0.80) | 1.39–1.64 | 1 (1; 2) |
| Trust in the general practitioner | 1.56 (0.79) | 1.39–1.62 | 1 (1; 2) |
| Routine of the examiner in the handling of the device | 1.56 (0.83) | 1.41–1.64 | 1 (1; 2) |
| Waiting time for an appointment at the ophthalmologist's | 1.58 (0.96) | 1.37–1.65 | 1 (1; 2) |
| Trust in the medical assistant | 1.64 (0.88) | 1.46–1.71 | 1 (1; 2) |
| Data security | 1.77 (1.00) | 1.63–1.95 | 1 (1; 2) |
| Trust in the ophthalmologist | 1.82 (0.93) | 1.68–1.96 | 2 (1; 2) |
| Level of mobility of the patients (e.g. dependence on support from relatives) | 1.93 (0.88) | 1.78–2.04 | 2 (1; 2) |
| Distance to the nearest ophthalmologist | 1.94 (1.09) | 1.74–2.07 | 2 (2; 3) |
| Waiting time at the ophthalmologist's | 1.98 (1.15) | 1.81–2.16 | 1 (1; 2) |
| Time until result | 1.99 (1.03) | 1.85–2.17 | 2 (1; 3) |
| Integration of screening in DMP controls | 2.02 (1.10) | 1.77–2.10 | 2 (1; 3) |
| Protection from individual health services (IGeL) | 2.22 (1.20) | 2.05–2.42 | 2 (1; 3) |
| Affinity toward device-based diagnostics | 2.51 (1.06) | 2.38–2.71 | 3 (2; 3) |
| Attitude toward artificial intelligence | 2.85 (1.17) | 2.67–3.03 | 3 (2; 4) |

AI: artificial intelligence; DR: diabetic retinopathy; SD: standard deviation; CI: confidence interval; IQR: interquartile range; DMP: disease management program.
*Range from 1 (very relevant) to 5 (very irrelevant).

## Perceived perspective of patients

Regarding the perceived perspective of patients, physicians assessed the validity of the examination (mean = 1.28), the omission of pupil dilation (mean = 1.51), and the duration of the examination (mean = 1.52) as very relevant (Table 3). Factors such as the protection provided by individual health services (mean = 2.22) and the integration of screenings into disease management program controls (mean = 2.02) were reported as the least relevant of the given determinants.

## Impact of screening

Figure 1 showed the results of the question: "What impact would the use of an AI-based screening have on you as a general practitioner?" The top three ranked impacts were a local extension of care and expertise (143/209), strengthening of the filter function of PC (109/209), and being a signifier for modern medical practice (106/209).

## Subgroup analysis

Subgroup analysis revealed that the willingness to offer an AI-supported device in their practice was not gender-related. A chi²-test showed that whether physicians practiced in rural or urban areas, it had no statistically significant effect on their behavior with regard to the intention to use an AI-supported device in their practice $\chi^2(1) = 2.854$, $p = .091$. There was a statistically significant difference in terms of age between the physicians who were surveyed and their willingness to use AI-assisted devices in their practice ($p = .019$), with younger physicians being more open toward such devices. However, the year of practice showed no correlation concerning their willingness to use AI-assisted devices in their practice.

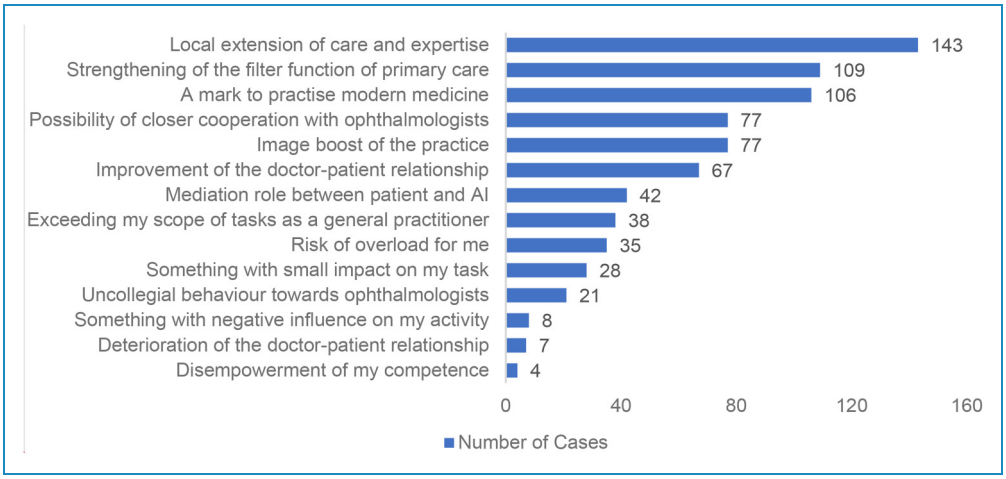


**Figure 1.** Impact of AI-based screening for DR in primary care on the profession of GPs.
AI: artificial intelligence; DR: diabetic retinopathy; GP: general practitioner.

There was no significant difference observed in the physicians' assessment of the need for screening for DR in PC with regards to the distance to the ophthalmologist, with a similar judgment on the need for such a screening across physicians who were close to or far away from the nearest ophthalmologist.

There was also no statistically significant correlation between distance to the ophthalmology practice and GPs' perception that they could reach more patients in the PC practice with AI-assisted screening, with physicians both close to and distant from an ophthalmologist judging that they could reach more patients with such an exam.

The general attitude of the surveyed GPs toward applications with AI in medicine was assessed with a mean value of 2.92 (SD = 1.32). Pearson's correlation analysis showed a significant linear relationship between the general attitude toward AI applications in medicine and the assessment of the need for early detection of DR in GP practice ($r = 0.21$, $p < .003$).

## Discussion

This study examines factors and their interactions that influence the implementation of AI-supported DR screenings in PC. According to the criteria of the database of the Association of Statutory Health Insurance Physicians, the sample of GPs in the present study is very close to the sociodemographic structure. The average age in our sample is 54 years, while the national average of GPs is 55 years. The proportion of female participants is 51%, and 49% in the general population of GPs. The participation rate of male GPs is 49% and 51% in the population.[23] The response rate of 10% was low, which could be due to a lack of interest in the topic because it is too abstract or in research in general, or a lack of time and a high number of surveys that GPs are confronted with on a regular basis.[24,25]

The results of the survey show the important barriers and enablers for a successful implementation amongst German GPs: financial factors are the biggest existing barriers to implementation. Technical concerns encompass the practicability of the device and its integration into the practice system, while mobile use and obtaining the results quickly are of lesser importance. Positive aspects of the implementation of AI-based technologies in PC include a possible extension of their patient pool, and reaching additional patients with a screening for DR.

The practitioners are particularly concerned about the costs of implementing and maintaining the devices and about the reimbursements from healthcare providers. This finding is in line with other findings from the literature regarding the introduction of AI in health care.[26,27] Reimbursement strategies are a matter of an ongoing discussion.[28] Abràmoff et al. point out that financial incentives for the implementation and maintenance of AI systems are a requirement for their sustainable use in healthcare.[28] However, despite high expenditures, especially in the beginning, there is evidence that examples of automated or semi-automated screenings for DR yield the potential to be cost-effective in the long term from the perspective of the health care system.[29]

The respondents have an ambivalent attitude toward AI-based technology. However, according to our study, they do not see themselves as limited or disempowered in their role as physicians by the use of AI, but rather recognize and want to take advantage of the positive opportunities such a technology may offer. This is in line with a previous survey where GPs indicated that the importance of technical innovations for their practice has the potential to reduce administrative tasks and increase the efficiency overall.[15] In this study, high practicability and easy integration into the practice system are ranked as the most relevant technical factors during implementation. Another factor that is given comparatively high relevance by the GPs is that the use of AI is believed to give a modern impression and an image boost for the practice. Therefore, it can be

concluded that GPs think that patients would have a positive attitude toward AI-based screening technology.

The availability of a workplace smartphone is rated as the least relevant factor, in addition to the time until the examination result is available, while the costs of purchasing and the level of remuneration are assessed to play a greater role. It is possible that factors concerning data security in association with the use of a smartphone do not worry the participating doctors as much as the other proposed factors and as such, a workplace smartphone is considered to be unnecessary. Furthermore, if the examination is conducted in the practice of a specialist, the GPs typically must wait until they receive the examination results from the ophthalmologist anyway. That can be the reason why this aspect is rated to be less important. The motivation to delegate the activities of physicians to non-physician staff was previously reported as relevant by GPs. The findings agree with studies where it was found that almost half of the surveyed family physicians, who have many years of professional experience, expressed a positive attitude toward such delegation. Legal aspects can lead to uncertainties regarding task delegation in PC. However, there is a high level of delegated tasks, mainly concerning largely standardized procedures.[30] The development opportunities for practice staff, which have been rather limited in the past, can also be upgraded with a shift in tasks. Teams that are composed of different disciplines, and also work on an interdisciplinary basis, will be integral to PC. This is the only way to manage the growing demands placed on PC physicians by the healthcare system. Shifting tasks, on the other hand, can result in increased job satisfaction on the part of the physicians, but also on the part of the employees.[30]

AI-assisted screening tools bear the potential to make diagnostic strategies for detecting DR more efficient by shifting them to the PC physician's office.[32–34] Conducting the examination directly at the GPs office allows for a timely and local appointment without the waiting periods to see a specialist and the time required to transfer the results back to the GP. This is of particular benefit to patients who live far away and may have limited access to an ophthalmologist.

However, in our study, we observe no difference in the behavior of PC physicians regardless of whether they practice in rural or urban areas. This is also reflected in their response behavior regarding the distance to the nearest ophthalmologist. Half of the respondents report that an ophthalmologist can be reached within ten minutes by car, which underlines the very good healthcare situation and infrastructure in Germany.

At 4.5 physicians per 1000 inhabitants, Germany's physician density is above average by international standards.[35] In an Organisation for Economic Cooperation and Development comparison, the physician density in Canada, for example, is 2.7 physicians per 1000 inhabitants.[36] In areas with limited access to medical care, the need for AI-based applications might be higher.

The interpretation of the results obtained by AI is always controversial with regard to their applicability in medicine. On one hand, AI-based technology allows for a reliable, continuous assessment of patient data using a system that is less prone to errors compared to a personal evaluation by an individual doctor. Moreover, each practitioner faces a certain time limit for each appointment due to large patient volumes per day, and a fast data assessment using AI-based tools can significantly alleviate time and performance pressure. On the other hand, the intelligence of a deep-learning system is only partial, as it only diagnoses what it has been trained to diagnose. A physician, on the other hand, has a comprehensive perspective that takes the individual characteristics of the patient as a whole into account. This can be reflected by the reported fear of physicians overlooking other eye diseases besides DR in the present study. The financial aspects must also be considered in the large-scale implementation of digital screening tools, as many GPs practices are small and may not have the financial means to obtain new technology without any reimbursement.

## Limitations

The response rate of 10% is quite low and limits the applicability of the results in daily practice. A reason for this response rate could be the fact that the survey was initially distributed via a QR code and only the reminder was distributed in paper form, resulting in a much better response. GPs appear to prefer surveys in paper form, and future studies should take this into account. The low response rate raises concerns about the potential for non-response bias. The lack of information on the characteristics of non-responders prevents us from directly comparing them with the responders, and this might influence the generalizability of our findings. Therefore, the results should be interpreted with caution. Future research could explore strategies to reduce non-response bias, such as offering targeted incentives or employing alternative data collection methods to encourage participation. Gathering information on reasons for non-participation through a short questionnaire could also be beneficial in understanding and mitigating non-response bias.

The participation of GPs in this study was voluntary, and therefore a potential selection bias is likely. Moreover, the topic of AI-based devices may be of particular interest to digital-affine physicians and it is likely that the sample is not representative of all PC physicians.

Most of the participants are inexperienced with AI in their daily life, and the term "AI" was intentionally not defined any further in the questionnaire in order to avoid any bias. Therefore, it is possible that the participants had different and varying ideas of the term "AI" and what it means in their understanding.

The viewpoints of patients and GPs in terms of potential eHealth services may differ. In this study, only the professional view of physicians is considered. Since the patient perspective is very important to include, further studies that examine this aspect are necessary.

A further limitation of our study is the use of a non-validated questionnaire. Although we conducted a pilot test to assess its comprehensibility and face validity, the absence of a validated tool might have affected the reliability and validity of our findings. Moreover, no clear statements in the literature are available concerning the statistical analysis of surveys using Likert scales.[31,37] We handled the Likert scales as an interval which could implicate a potential selection bias. Finally, causal associations cannot be made based on these results due to the cross-sectional nature of this study.

## Conclusion

This study is the first to weigh in on the requirements for AI-assisted screening methods from the perspective of PC physicians in Germany. While AI-based devices for DR screening are not yet established in Germany, GPs are ambivalent toward such devices and may not implement them due to several existing barriers. The most relevant barrier to implementation, according to the GPs in this study, is financial concerns associated with the purchase, implementation, and maintenance of the device. With the consideration of the identified factors, interventions adapted to the needs of physicians and patients can be developed.

**Acknowledgements**: We thank all participants.

**Contributorship:** WL and JS designed the study, WL, JS, and KG analyzed the data, KG performed the statistical analysis, and WL wrote the first draft of the manuscript. All authors contributed substantially to the manuscript. All authors approved the final manuscript.

**Declaration of conflicting interests:** The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Ethical approval:** The ethics application for this study was approved by the University of Luebeck on 5 May 2020. No additional data were evaluated. The study design and procedures were reviewed and approved by the ethics committee.

**Funding:** The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: This work was supported by grants from the Joachim Herz Foundation.

**Guarantor:** WL and JS.

**Informed consent:** In this study, no patients were involved; only GPs were surveyed. Implicit consent was assumed with the return of the completed questionnaire, as approved by the ethics committee. Participants were informed of this in the cover letter, where the study's purpose and procedures were explained, along with the voluntary nature of their participation and the confidentiality of their responses.

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**Supplemental material:** Supplemental material for this article is available online.

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