Computer Assisted Diagnosis in the Acute Setting: The Emergency Clinician's Perspective.

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ABSTRACT

Background

The use of computer-assisted diagnosis (CAD), autonomous diagnosis (AD), and robotic telemedicine (RTM) is extending to different areas of medicine as the benefit of automation to overstretched health systems becomes increasingly apparent. For such technologies to succeed, clinicians must be supportive of their deployment and function. This research captures and analyses emergency clinicians' perspectives regarding CAD, AD, and RTM use in Emergency Departments (EDs) and establishes whether COVID-19 affected their views.

Methods

Participants were recruited through advertisement on the Royal College of Emergency Medicine website between August 2021 and February 2022. Senior ED clinicians were also encouraged to participate through electronic media messages sent to ED Clinical Directors. Data were collected using a questionnaire and responses were analysed using descriptive statistics and statistical significance testing to determine their views of CAD and RTM, and if it differed from views on AD. A thematic analysis was employed to assess concerns.

Results

105 clinicians completed an online questionnaire. All responses were recorded and analysed. The questionnaire was assessed using Cronbach's alpha and a value of 0.865 confirmed its reliability (0.70 to 0.9 desirable). Sentiment towards CAD was positive; 61% of the participants agreed or strongly agreed that there was a role for CAD in the ED, and would consider it in their decision-making process. There were concerns, particularly with AD, regarding clinical accuracy, responsibility for decision-making and the impact of automation on professional autonomy. However, many clinicians believe that CAD and AD are likely to become mainstream in the future. They stressed the importance of involving clinicians in further development, clinician training and continuously monitoring the technology's impact. COVID-19 did not significantly alter their views.

Conclusions

This study provides an important early step towards assessing clinicians' perspectives on CAD, AD, and RTM adoption into EDs. Notwithstanding notable concerns, clinicians viewed CAD as a useful modality to address growing global healthcare needs. However, novel technology creates challenges that require careful and ongoing management. The results provide a strong basis for further empirical research to enable the continual appraisal of clinicians' perceptions as new technologies are increasingly introduced into clinical practice.

Keywords: Emergency Medicine, Computer-Assisted Diagnosis, Autonomous Diagnosis, Emergency Department, Clinician, Physician, Perspective

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BACKGROUND

The number of patients arriving at Emergency Departments (EDs) in England increased by 12% between 2012 and 2022 [1]. Combined with healthcare staff shortages, which have been an ongoing concern for over three decades [2,3], this has resulted in overcrowded EDs and long patient waiting times. A recorded 1,656,206 patients waited 12 hours or more for treatment in Type 1 EDs in England in 2022 [4]. There are 180 of such Type 1 EDs (consultant-led, 24-hour service with full facilities) in England [5]. It is, thus, critical to explore solutions to alleviate the strain on medical professionals so that their time can be optimised and throughput increased in EDs.

The use of digital technology – such as, computer-assisted diagnosis (CAD), autonomous diagnosis (AD), and robotic telemedicine (RTM) - to collect, organise, and perform initial analysis of patients, potentially frees staff from data collection, reducing waiting times and the door-to-treatment times. CAD defers ultimate decision-making to the clinician, whereas AD aims to propose a diagnosis that may be binding on the views of attending clinicians. RTM, in addition, allows the patient's data to be collected remotely, e.g., before they arrive at the ED. An ED system based on such technology should assist the clinician decision-making and ease the path to clinical interventions.

A number of surveys that assessed patients' perceptions of digital triage [6,7] and satisfaction with its use [6,8-11] demonstrate that patients are generally positive with regards to its usefulness, and that patients who interacted with digital triage were generally satisfied. Digital technologies must be able to consider the undifferentiated nature of ED clinical presentations that include a wide spectrum of users from different age groups, different education levels, with a wide range of socio-economic backgrounds, and with varying severity of illnesses [7-11]. This lack of patient homogeneity presents a complex challenge for developers of CAD and AD systems in the acute setting. They must ensure not only that such technologies and systems are able to accommodate various patients but also that they can be trusted by clinicians [12].

A further challenge is posed by the non-linear rules that inform the clinicians' complex decision-making abilities, a factor that must be considered before safe systems can be designed to aid sound decision making in acute care [13-15]. CAD has been explored in microcosms of acute presentations in the past and with limited success, e.g. abdominal pain [16]. Currently, however, EDs do not routinely utilise CAD for undifferentiated symptoms. The expert systems and machine learning algorithms that previously attempted this had limitations [15]. Since then, CAD is largely confined to radiological triage and diagnosis [17]. The development of new digital technologies must, therefore, both address the challenges identified with previous digital interventions, and include the views of clinicians throughout the process of the technological system's research, design, implementation, and testing.

Research has identified clinicians' aversion to technology use especially when they perceive that it may increase their workload [17], or they need to be custodians of the computer processes. There are also issues around loss of clinical autonomy and integrating AI into existing workflows [17]. However, studies of systems often focus on the clinical utility of CAD/AD [8,18,19] or the perceptions of patients and other service users. To date, there have been limited studies of clinicians' perceptions, particularly around the introduction of CAD, RTM, and AD in EDs. A survey of U.S. physicians by Goldberg et al. [20] considered the use of telehealth for elderly patients, and found that physicians favoured telehealth although they identified the need to address access inequities. More recently, Townsend et al. [12] demonstrated the perspectives of clinicians – both benefits and challenges - to the adoption of an AI-supported triage technology in the ED. While clinicians were overall positive and supportive of such implementation, it was found that clinicians viewed AI adoption as assistive or as a means to

augment the clinician's role, rather than as a substitute for, or replacement of, human medical practitioners. The same study found that trust is a significant driver of use and acceptance of such technologies. Lambert et al. [17] surveyed research papers analysing clinicians' acceptance of AI in all hospital settings, and found that there is little agreement among clinicians on the benefits of AI, and that to facilitate acceptance of AI, clinicians need training at an early stage [21].

Due to the increasing uptake of CAD, AD, and RTM and their encroachment into the acute setting, our research explores the views of clinicians in EDs on their use for acute diagnosis and initial management plan. This is a topic that, although often discussed, has not been empirically explored.

To establish views, we conducted a survey of medical practitioners and personnel who work in EDs within the United Kingdom. These participants are uniquely placed to consider the risks, benefits, and the implications of technological automation in the acute environment of EDs. Our study is questionnaire-based and investigates clinicians' perceptions on the introduction and use of new digital technology for ED assessment and diagnosis. We explored their views on CADs or ADs, and RTM, with the primary aim of establishing whether patients attending EDs in the future would benefit from technology-related interventions and from assistive or autonomous decisions. A secondary aim of the study was to document clinicians' views regarding such future adoption and to understand how the COVID-19 pandemic may have altered clinician views.

Our study reveals positive clinician sentiments towards CAD but less so towards AD. The main concern expressed by clinicians was about lines of clinical responsibility and how these might be affected and altered by AD adoption. A further concern expressed centred on clinical accuracy and on the ability of patients to 'game' or manipulate the system.

This study is beneficial in that it informs the future design, development and deployment of such technologies, and is an important first step to understand the expectations and reservations of frontline ED clinicians, and to facilitate consideration of their views as these platforms are introduced for acute services.

METHODS

Questionnaire development

The questionnaire was developed for this study and focuses on the following topics:

- Computer assisted diagnosis (CAD) with decisions made by the **clinician**,
- Robotic telemedicine (RTM) with decisions made by the **clinician**,
- Autonomous diagnosis (AD) with decisions made by the **computer**.

and aims to:

- understand the views of senior ED Clinicians on the use of CAD/AD and RTM in the Emergency Department;
- understand how the recent pandemic may have altered the views of senior ED clinicians.

We developed the questionnaire using the Royal College of Emergency Medicine's (RCEM) guidelines [22]. The questionnaire was piloted by n=20 clinicians who reported on its ease of use and on appropriateness of the questions, highlighted important areas to survey and advised on the question phrasing over several iterations. Ownership of clinical responsibility was highlighted during the pilot and, hence, this was stressed in the final survey template.

The final questionnaire comprised 20 questions in an online Google form with 18 Likert-type questions (15 five-point tick boxes; *{strongly disagree-disagree-I don't know-agree-strongly*

agree} and 3 three-point tick boxes *{false-maybe-true}*) and 2 questions for 'free text' comments. Respondents could select one box per Likert question. The 20 questions were divided into 3 parts. Part 1 surveyed opinions regarding using CAD/RTM where the clinician makes the decisions (10 x five-point tick boxes). Part 2 surveyed opinions regarding the use of AD where the computer makes the decisions (5 x five-point tick boxes). Part 3 considered whether opinions have changed during COVID-19 pandemic (3 x three-point tick boxes). Two free-text boxes at the end of the questionnaire provided the opportunity for the expression of concerns and suggestions regarding CAD/RTM adoption.

Data analysis of the Likert questions was descriptive and a thematic text analysis was used on the open-text responses.

Setting

An initial small-scale, pilot or feasibility study was conducted in between January and March 2021, involving 20 ED clinicians to validate and fine-tune the survey and questions. Thereafter, participants for the study were recruited through a newsletter advertisement on the RCEM website between August 2021 and February 2022. The RCEM's newsletter provided a clickable link to the online questionnaire (described above). The questionnaire remained accessible to NHS clinicians throughout the United Kingdom for a seven-month period between 15 August 2021 and 28 February 2022. In addition, electronic media messages were sent to NHS Emergency Medicine Clinical Directors present on a nationwide e-forum (WhatsApp mediated) so as to elicit responses from, in particular, senior ED clinicians.

Participants

All participants who responded to the invitation and completed the survey were included in the results. Table 1 shows the breakdown of clinicians' job descriptions. 96% of participants were fully qualified senior clinicians and senior clinicians in training. 3% were less senior and 1% were hospital managers.

Grade	***n* (%)**
ED Consultant (senior clinician - fully-qualified)	85 (81%)
ED Registrar (senior clinician - training)	16 (15%)
ED SAS Doctor (senior clinician, non-training) (SAS: Specialist Grade and Associate Specialist)	2 (2%)
GP (senior clinician with ED focus) (GP: General Practitioner)	1 (1%)
Hospital Manager/Dr	1 (1%)

Table 1. The number and percentage of participants in each job description category.

Sample Size

A total of 105 participants completed the survey in the 7 months it was available. This achieves a +/-9.3% confidence interval (error margin) for a 95% confidence level. This margin of error, although high, is in line with the relative novelty of the topic, and the general anxiety and uncertainty that still perceptibly exists amongst clinicians. No patients were involved in the study.

While the sample size is relatively small, the research provides a systematic search for meaning in the detailed data collected from the responses. This introduces a strong base for future empirical research to further understand challenges and benefits to such technological adoption. Certain of the findings are generalisable and can be translated to inform and support the development of other digital healthcare technologies and to understand the implications of their adoption. As each participant was only surveyed once, no longitudinal data were collected which would have allowed for the exploration of emerging views in greater depth and provided the opportunity to understand changes in views over time.

Data Collection

The questionnaire contained a preamble published by the RCEM to invite participants, and a short explanation of the survey with succinct definitions of CAD, RTM and AD to enable uniformity of understanding of terms. The survey was anonymous and no personal information was collected from participants. Only responses from participants who answered all questions were included in the data analyses. Participants were not offered any financial incentives to complete the survey.

Data Analysis

We calculated Cronbach's alpha across the single category of clinician to measure the internal consistency of the questionnaire [23]. The five-point Likert questions measured 0.865 which indicates good consistency across 105 respondents [23] and is below 0.9 indicating low redundancy across the questions [24]. The three-point Likert questions covered different topics (whether COVID-19 has affected the respondents' views and whether technology is more or less needed). Hence, all three were excluded from the Cronbach's alpha calculation. The last two free-text questions were also excluded as they are contrapositives.

We used simple descriptive statistics to identify clinicians' support for CAD/RTM and AD. Responses for each question were mapped either to a five-point score (strongly disagree=-2, disagree=-1, I don't know=0, agree=1, strongly agree=2) or a three-point score (false=-1, maybe=0, true=1) when calculating the sample mean and standard deviation. This means that where the respondents agree, the sample mean will be positive and where they disagree it will be negative. To highlight any significant difference between clinicians' perception towards CAD/RTM versus AD, we used paired t-tests to compare the participants' responses to the corresponding questions.

RESULTS

Table 2 lists the 18 Likert questions coupled with the mean response and standard deviation (spread) of responses for each question.

ID	Question	Sample Mean	St Dev
Part 1: five-point Likert questions. CAD/RTM: If developed and validated in a clinical setting. Decision Maker: Clinician			
Q1	There is a role for it in the Emergency Department (ED) triage process	0.60	1.02
Q2	I would have no significant concerns about its use in the ED	0.02	1.14
Q3	I will be confident to support its use in my own clinical environment	0.37	0.99
Q4	I will be comfortable to consider it in my clinical decision-making process	0.50	0.96
Q5	In my opinion, many of my clinical colleagues will be accepting of it	-0.25	0.92
Q6	In my opinion, my patients are likely to be receptive to its use	0.22	0.81
Q7	It is likely to help with sign-posting and the bottleneck to ED care	0.28	1.09
Q8	I would have no concerns about the lines of clinical responsibility	-0.26	1.16
Q9	I see it as a threat to my professional autonomy	-0.52	0.98
Q10	It is likely to become mainstream in the future	0.41	0.97
Part 2: five-point Likert questions. "Do you have any concerns about the use of 'Automated Diagnosis' (AD) in the ED?"			
Q11	I would have no significant concerns about its use in the ED	-0.43	1.21
Q12	I will be confident to support its use in my own clinical environment	-0.15	1.17
Q13	I would have no concerns about the lines of clinical responsibility	-0.61	1.17
Q14	I see it as a threat to my professional autonomy	-0.10	1.16
Q15	It is likely to become mainstream in the future	0.05	1.01
Part 3: three-point Likert questions. "In light of COVID-19, how has the recent pandemic affected your view of 'Computer Assisted Diagnosis' (CAD)?"			
Q16	It has significantly affected my views	-0.37	0.72
Q17	I think that it is even more needed	0.01	0.85
Q18	I think that it is now less needed	-0.47	0.73

Table 2. 18 Likert questions from the questionnaire (divided into three parts) coupled with the sample mean and standard deviation for each question. A positive mean indicates agreement with the statement and a negative mean indicates disagreement.

Figure 1 shows the number of responses for each Likert category for the 15 five-point Likert questions (n=105).

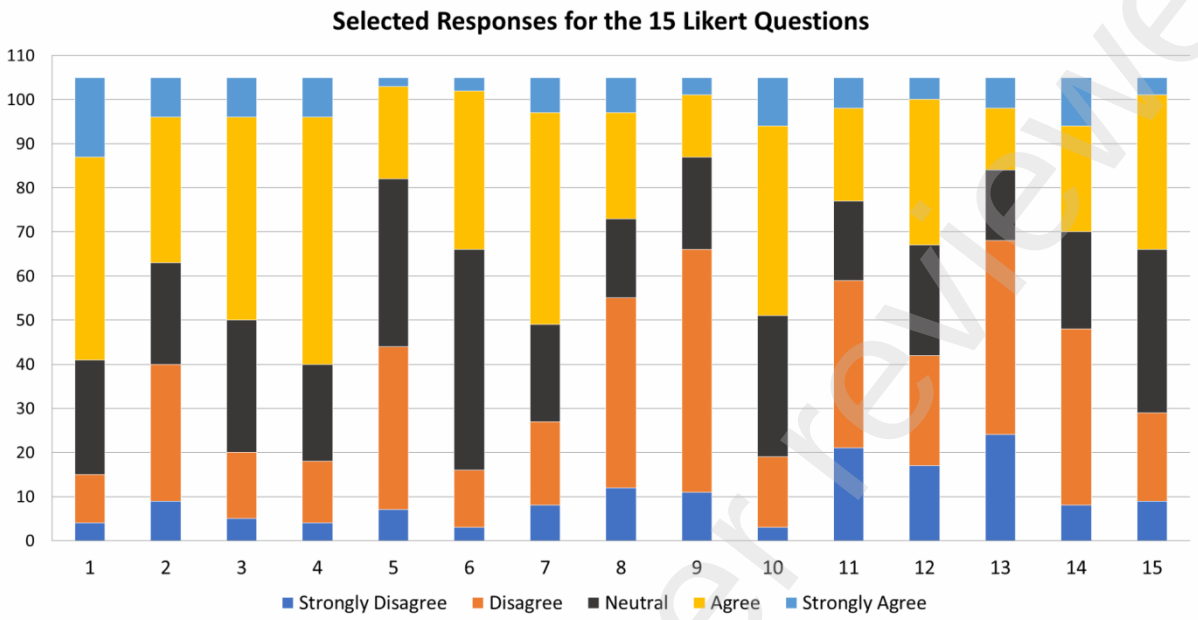

Figure 1. Stacked bar chart showing the responses for the five-point Likert questions (shown as the total number of responses for each Likert category).

From the five-point Likert questions (Q1-Q15, table 2), the strongest support observed is for CAD/RTM having '*a role in the ED triage process*' (0.60, Q1) and the lowest support is for having '*no concerns about the lines of clinical responsibility for AD*' (-0.61, Q13).

A comparison of responses between CAD with a clinician decision-maker and AD using autonomous decisions was made possible by comparing the relevant CAD questions (Q2, Q3, Q8, Q9 and Q10) with the analogous AD questions (Q11, Q12, Q13, Q14 and Q15), see Table 3.

Questions	Q2 / Q11	Q3 / Q12	Q8 / Q13	Q9 / Q14	Q10 / Q15
Paired t-test	1×10^{-4}	1×10^{-8}	7×10^{-4}	1×10^{-4}	8×10^{-4}

Table 3. Paired t-tests for the five question pairs comparing responses for CAD vs AD

Table 3 shows a paired t-test for means [25] that compares the responses to question pairs. There is a statistically significant difference ($p<0.05$) between the responses for all five pairs as shown. Considering the sample means from Table 2 for these question pairs, clinicians, observably therefore, are more supportive of clinical decision support systems but sceptical of autonomous decision-making systems [26]. Clinicians would support CAD (0.37, Q3) but not AD (-0.15, Q12) in their clinical environment. They see CAD as less of a threat (-0.52, Q9) than AD (-0.10, Q14) though neither was perceived as truly threatening their professional autonomy.

Analysis of the three-point Likert questions demonstrates that the clinicians do not feel that COVID-19 has significantly affected their views on CAD/AD (-0.37, Q16).

The two free text questions (F1 and F2) and the responses are shown in Table 4. We used quantitative content analysis (via Representational Thematic Text Analysis) to extract response

categories. The counts for the number of clinicians responding to each category are shown in the charts in Figure 2 with responses to F1 in the first chart and responses to F2 in the second chart.

F1		n = 105
	"Do you have any other particular concerns about the use of Computer Assisted Diagnosis in EM triage?"	
1	No text input	66
2	"No concerns" documented in text	16
3	Concerns about Clinical Accuracy	7
4	Risky, Technology being rolled out too quickly, concerns regarding availability of equipment	5
5	Patients may learn to "game" the system	4
6	Patients may dislike it	3
7	CAD/AD may be too risk averse	3
	Total free-text responses	**39**
F2		n = 105
	"Do you have any suggestions on how the use of CAD might assist with clinical practice, or specific conditions/situations that it may be useful for?"	
1	No text input	67
2	Use CAD for Triage, streaming or pre-screening	16
3	"No comment" documented in text	9
4	CAD to be used for training clinicians	5
5	Unsuitable to be introduced at this time	2
	Total free-text responses	**38**

Table 4. Free text questions presented to respondents at the end of the survey. We have grouped the participants' responses by theme and only include themes with 2 or more responses. Other responses are included in the discussion section as narrative support.

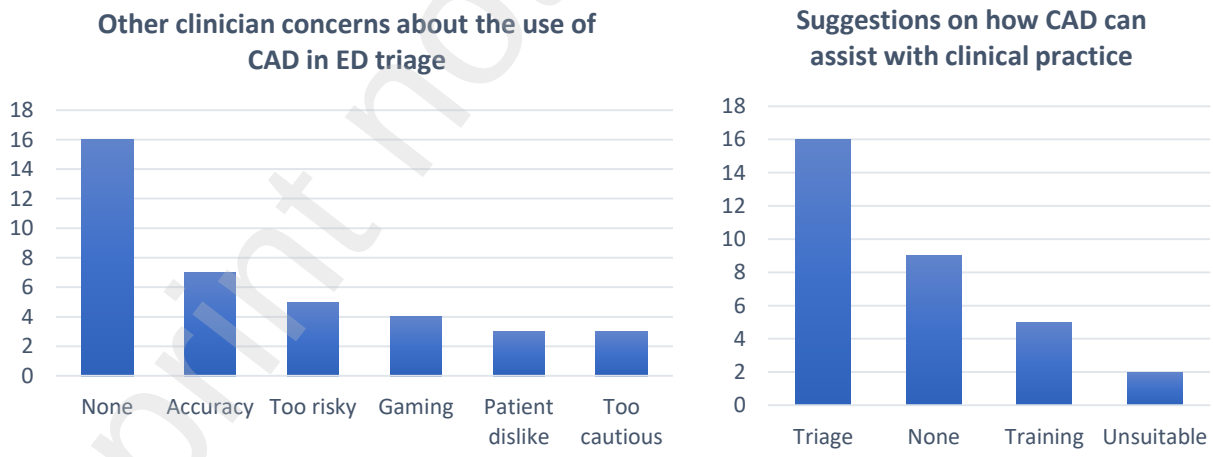

Figure 2. Charts showing the clinician responses to the two free-text response survey questions grouped by theme (themes with 2 or more responses are shown). Responses to question F1 are shown in the left chart and responses to F2 in the right chart.

DISCUSSION

There was substantial acceptance that a role exists for CAD in the formalities of ED triage process, front-door sign-posting and access-point bottleneck management. One respondent felt digital triage would help by "*redirecting in evidence based way and freeing up nursing staff*." Similarly, it was deemed "*useful for assessing waiting room patients particularly when capacity is stretched and bottlenecks occur*".

On a professional level, there was indication that a significant proportion of ED clinicians will confidently adopt CAD and comfortably consider it in their own decision-making process. Responses included that: "*It might help in triage settings in the ED while patients are waiting to be seen in flagging out, possibly, patients needed to be prioritized or in instances of escalation of care*." The view was that it will also "*provide standardised care*". Clinicians also believed that their patients will be receptive to CAD use and that it is likely to become mainstream practice in future. It was also believed that such technology would help to "*target high volume presentation and start investigation at point of arrival. There will be some over-investigation but will reduce risk and improve patient journey*."

In spite of overall optimism, certain clinicians remained cautious and sceptical about the potential adoption of such technology by their colleagues. Training was indicated as critical to successful adoption. One free text response noted: "*clinicians need to receive training in how to interpret and use CAD. We also need research to guide this training*." This is consistent with findings in the literature where [17] and [27] both recommend clinician training for a smooth introduction of CAD/AD.

A further reservation was that the digital triage may not be sufficiently accurate. A participant stated: "*I worry about its ability to correctly triage*" and "*it's all dependent on the information entered".* However, [18] posits that AI for ED triage is becoming more accurate as it develops. It was also identified that patients could 'game' or manipulate the system to speed up their treatment, with a respondent noting: "*it could generate work, simply because patients do not tell the truth when speaking to triage nurses, GPs and 111. They could game it to get seen faster*." An additional non-clinical issue which was raised was that "*equipment availability and theft may be a significant issue*."

The issue of risk was viewed from opposing perspective. While 3% of respondents expressed concerns about the system being too risk averse, 5% expressed concerns that the concept and system may be too risky. It stresses, in our view, the need to work with clinicians as these systems are developed in order to maintain a balance between the seemingly divergent views.

Autonomous Diagnosis (AD) was contrastingly not viewed in a similar perspective as CAD, and clinicians were neither confident nor comfortable to use it or support its deployment. One respondent stated: "*I will be wary of leaving it to autonomously have the final say in all clinical decisions. This I feel still would need to be cross-checked by human clinicians*". Another noted that "*algorithms can easily massively over-triage in order to be risk averse*" so clinician oversight is needed. Our analysis showed the opinion difference between CAD and AD to be statistically significant. If we compare clinicians' responses for CAD and AD for the same 5 questions, there is a statistically significant difference in their responses for CAD vs AD ($p<0.05$). It is interesting to note, however, that many clinicians believe that AD is also likely to become mainstream in future, despite the strong concerns that they identified, and their unwillingness to adopt or support it. Other authors have similarly noted that, as AI develops and becomes more accurate, it is more likely to be adopted in clinical settings, including the ED [18, 27].

Mostly, clinicians did not feel a significant threat to their professional autonomy from either modality of CAD or AD. However, there is a relative level of anxiety around AD with twice as

many clinicians perceiving a threat as they did with CAD (34% vs 17%). This difference of perception correlates with the anxiety around lines of responsibility previously expressed about AD with one respondent specifically stating: *"I am OK if it is only used for guidance*". Clinical ownership lies at the core of medical practice and a perceived encroachment into this domain may unsurprisingly be seen as a threat [28]. We stress here, like Adebayo et al. [27], that information and education are key and that "*educating trauma physicians on the capabilities and the impact AI/ML/DL models can have would be an important future step to promote widespread implementation of these models*".

One free-text response stated: "*I fear poor staffing models means desperate need for ED support and this may mean [ED support will be] too quickly rolled out with too early over-reliance*". Another clinician was concerned that "*there may be issues with intentional (or subconscious) deceit. Trivially an example is self-reported pain score, which at the 'subconscious' end may tell you more about the person than the severity of the condition, and at the other is easily manipulated if it increases (for example) triage priority*." Another's "*biggest concern is that any system is designed to be so risk-averse that it ends up hindering more than it helps*." It is important, therefore, that the development of this digital technology must address identified concerns, seek, and incorporate the early input of clinicians, include clinician training and thorough system testing, and longitudinally monitor the opinions of all stakeholders.

Finally, clinicians felt that the COVID-19 pandemic itself had not affected their views on CAD, although some indicated a more pressing need for its introduction post COVID-19 due to increased wait times in EDs.

Limitations

The questionnaire was live from August 2021 to February 2022 during the COVID-19 pandemic. This may have affected response rates and created confounding factors such as low morale and fatigue among clinicians which affected self-reported opinions. All responses were anonymised so we are unable to measure any confounding demographic factors that may influence responses.

Implications and Future

EDs play a vital role in assuring the health of the community. They provide a round-the-clock point of access to acute health issues, and amongst other functions, they manage patient flows, treat, admit or discharge patients, avoid unnecessary treatments while maintaining hospital capacities. For such a task, acute health systems are continually looking to introduce new technologies that will assist or perform some of the actions of a qualified clinician [29].

ED clinical teams are usually led by consultants who use expert knowledge and skill to diagnose and treat patients. The consultant, in addition, retains significant clinical responsibility not only for the patients seen by themselves, but for patients seen by other non-consultant clinicians working alongside them during and sometimes after the course of a clinical session [30]. These are in accordance with the strict ethical principles under which they must practice. Introduction of new methods of work in the ED environment must therefore consider the opinion of these senior ED clinicians and their views must be sought during the conception, development, and maintenance of acute care CADs. This survey assessed their opinions regarding the introduction and use of new technologies to complement, assist or supersede some of their current clinical and diagnostic responsibilities.

It will be valuable to conduct future surveys as a longitudinal analysis with repeated application as increasing ED technology is introduced into the ED and to monitor its impact and measure sentiment. It will also be beneficial to expand the analyses to clinicians at different levels of seniority and to analyse patients' views

CONCLUSIONS

Global trends in technological advancements will continue to encroach into the different aspects of medical practice, and acute diagnostics is not exempt. The increasing burden of front-door care makes it more likely that automation will be used to manage its mounting challenges. Our findings demonstrate that clinicians are receptive to assistive technology in the acute setting. However, their views and concerns must be constantly explored to aid the development and safe adoption of such technology. The roadmap to future clinical automation must be viewed against the lessons learnt from previous attempts at such systems and must be guided by current expert opinion.

DECLARATIONS

Ethics approval and consent to participate

The study was discussed with the Medical Research Council, The NHS Health Research Authority and the NHS Research Ethics Committee (all in the UK). The decisions were:

- the survey was not considered research by the NHS Health Research Authority,
- an NHS Research Ethics Committee Review was not required

Informed consent was obtained from participants via the online newsletter and electronic media messages which included details of the questionnaire, and a data collection and processing statement.

Consent for publication

Not applicable

Availability of data and materials

The datasets of responses generated and analysed during the current study are not publicly available to respect the respondents' privacy (as some of the free text comments may partially reveal the respondent) but fully anonymized questionnaire responses are available from the authors on reasonable request.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships and that the authors have no competing interests.

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Authors' contributions

OA: study concept and design, acquisition of the data, and drafting of the manuscript,
VH: analysis and interpretation of the data, statistical expertise, and drafting of the manuscript,
BT: analysis and interpretation of the data, and drafting of the manuscript,
IH: critical revision of the manuscript for important intellectual content, and acquisition of funding,
RC: critical revision of the manuscript for important intellectual content, and acquisition of funding.

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