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Virtual Triage Early Detection of Inappropriate Care-Seeking Intent Among Patients with Life-Threatening Cardiac Symptoms

George A. Gellert[1,*], Mateusz Palczewski[2], Maria Marecka[2], Katarzyna Paczkowska[2], Aleksandra Suwinska[2], Jakub Jaszczak[2], Gabriel L. Gellert[3], Piotr M. Orzechowski[2], Tim Price[4] and Stanislaw Gorski[5]

[1]Evidence-Based Impact and Value Demonstration, Infermedica Inc., USA

[2]Infermedica Inc., Poland

[3]Infermedica Inc., Canada

[4]Product Development, Infermedica Inc., UK

[5]Department of Medical Education, Jagiellonian University Medical College, Poland

Abstract: Reports indicate that only 19% of patients with prodromal symptoms of sudden cardiac arrest seek the appropriate level of care acuity, which may be due partly to individuals being unable to distinguish which acute symptoms require urgent care. This study evaluated the degree to which patient-users of artificial intelligence-based virtual triage presenting with prodromal symptoms of a possibly life-threatening cardiac condition intended to seek the needed emergency care. A dataset of 746,282 virtual triage patient-users was examined to assess the characteristics of those reporting symptoms of potentially life-threatening cardiac conditions with no intention to seek emergency care. Of 3,968 patient-users over age 35 with severe cardiac symptoms, 89.4% did not plan to seek emergency care. A majority of patient-users did not appear to understand the level of care acuity to seek, or planned to engage self-care or to visit an outpatient physician, instead of seeking emergency care. These findings reinforce the need for much-improved patient education among patients at risk for potentially life-threatening cardiac symptoms which require urgent medical care. Virtual triage (or symptom checkers) with care referral may have value in patient engagement and education to achieve this objective.

Keywords: virtual clinical triage, sudden cardiac arrest, symptom checker, artificial intelligence, life-threatening symptoms, cardiac disease

1. Introduction

Sudden cardiac arrest (SCA) is a global public health problem and in the US affects around 1,000 people per day [1]. An estimated 400,000 out-of-hospital sudden cardiac arrests occur every year in the US. This number is particularly daunting when considering that SCA is fatal 90% of the time in out-of-hospital cases [1–3]. Perhaps more alarming is the fact that even when patients experiencing SCA receive treatment from EMS and are transported to a hospital, the survival rate remains only around 10% [1–3]. In Europe, SCA is the third-leading cause of death, with only 8% of patients experiencing out-of-hospital SCA surviving until hospital discharge [4, 5]. Efforts to improve these outcomes include public awareness programs, safety initiatives, and dispatched response at the time of 911 calls. Nonetheless, survival remains low [6–8].

*__Corresponding author:__ George A. Gellert, Evidence-Based Impact and Value Demonstration, Infermedica Inc., USA. Email: The research was conducted in Infermedica, USA. Correspondence concerning this article should be addressed to ggellert33@gmail.com

The early detection of sudden cardiac arrest, particularly through the accurate identification of warning symptoms, is imperative to improving survival and can potentially prevent thousands of avoidable deaths. SCA warning symptoms are common, and 30–90% of patients experience at least one prodromal symptom [9–12]. In approximately 80% of individuals, symptoms start more than one hour before SCA [8]. Dyspnea, chest pain, loss of consciousness, and palpitations are the most commonly reported symptoms preceding SCA [5, 10, 13, 14]. Other common symptoms include anginal equivalents such as non-trauma related arm, shoulder, neck, or jaw pain with or without chest pain; neurological symptoms, including syncope and dizziness; gastrointestinal symptoms, such as abdominal pain, nausea, and vomiting; or non-specific complaints like weakness [10, 11, 15].

Even when warning symptoms occur, most patients at elevated risk of SCA do not seek appropriate medical care. Hofgren et al. found that among symptomatic patients, only 33% consulted with healthcare professionals in the week prior to admission to the cardiac unit [16]. Marijon showed that SCA prodromal symptoms occurred in over 50% of patients, but only 19% decided to seek appropriate medical care; notably, the survival rate when a 911 call was placed was 32% versus only 6% among those who did not call [9]. Substantial numbers of at-risk patients may be unable to identify symptoms that require emergency medical care, which results in poor out-of-hospital SCA survival.

This analysis focused on the potential early detection and care referral of SCA by an artificial intelligence (AI)-based automated technology platform. Virtual symptom triage and care referral, commonly referred to as "symptom checkers," are software applications that enable patients to report their symptoms and biodata to an algorithm-based engine. Virtual triage (VT) and care referral are a digital technology accessed on the Internet around the clock to assist in assessing symptoms and the appropriate acuity level of care referral. VT conducts a triage interview, where the patient answers questions about their symptoms experienced and risk factors. Patient-users enter key demographic and personal health information such as their chief complaint, symptoms, age, sex, and medical history. Based on the responses, VT asks further questions according to the specific case and symptom intensity.

To operate independently, VT engines are typically optimized to comprehend and employ low health literacy language, bridging the gap between medical jargon and layman terms. Developers commonly integrate multiple languages into these tools, facilitating rapid health assessments in the patient's mother tongue. Some VT applications use a probabilistic algorithm assessing symptoms using an underlying medical knowledge base and inference algorithm that determines the next question to ask based on prior patient responses, demographic information, past medical history, and disease risk factors. Follow-up questions are generated based on this data. Certain VT engines use artificial intelligence validated by practicing multispecialty physicians, which processes the data and displays a list of diseases that may be causing the patient-user's symptoms.

VT algorithms deploying AI evaluate the severity of the most probable illnesses identified, calculate the probability of most likely conditions, and then autonomously determine the next pertinent questions to ask the patient-user. No prescribed VT interview pathway exists – the system alters hypotheses based on new evidence (as human physicians do). Responses are analyzed on a current basis, and VT rapidly conveys a symptom analysis, explaining probable causative factors, severity, and suggesting an appropriate acuity level of needed health care. Unlike traditional virtual triage algorithms employing a decision tree design, AI-based VT enables patients to report multiple symptoms at the commencement of an interview. The system analyses the patient's responses in the context of all complaints and demographic information provided. This allows the VT engine to explore multiple pathways before furnishing the patient-user with a list of potential causes and an acuity-appropriate urgency assessment. AI-based VT offers the added advantage of detecting critical symptom combinations and diseases that may be the cause of the patient-user's complaints. Each identified potential disease state is linked to a corresponding triage acuity-level recommendation, whether for self-care, ambulatory/outpatient, or emergency care. The VT episode ends with the symptom analysis and a care referral: self-care, outpatient visit to a physician when possible, seeks emergency department (ED) care, or ambulance transport to an ED. VT is classified under Medical Device Directive (93/42/EEC) in the European Union. In the US, enforcement discretion by the Food and Drug Administration (FDA) under the US Food, Drug, and Cosmetic Act stipulates that VT applications need not comply with FDA medical device regulations.

Public use of VT is growing rapidly. In the United Kingdom, VT use increased from 9,700 to 1.2 million VT encounters between 2017 and 2021 [17], with VT helping patient-users navigate complicated healthcare systems and connect with appropriate acuity care services. The objective of VT is to optimize the clinically appropriate use of healthcare services by patient-users [18], and VT use is growing with increasing Internet use and greater patient engagement of self-care. Almost all households (96%) in the United Kingdom can now access the Internet, and approximately 35% of adults have used the Internet for symptom appraisal [19, 20].

VT is a major advance over search using an Internet browser because it offers clinical triage and suggests a care level based on evidence-derived clinical algorithms which advise patients whether they should consult with a physician or engage self-care. The key advantages of VT over traditional Internet search engines for the appraisal of symptoms are as follows: (1) VT performs an instant symptom assessment using patient-users' reported clinical and demographic data; (2) VT responds to patient-users' initial symptoms with clinical questions about all symptoms and risk factors by deploying AI algorithms; (3) VT is independent of search engine optimization, which is driven by marketing rather than clinical factors; (4) VT is created and validated by a multidisciplinary group of licensed, practicing physicians; (5) VT is subject to an evidence-based quality management system; and (6) VT is peer-reviewed with an increasing number of scientific studies validating its use [17, 21, 22]. VT is helpful for individuals who are unclear/uncertain if their symptoms require clinical evaluation and care. VT directs patients to appropriate care acuity services can potentially accelerate care delivery and decrease avoidable healthcare utilization. Healthcare delivery systems can integrate VT into a digital front door within an electronic patient engagement and management ecosystem.

Infermedica's VT engine, Symptomate, uses AI to complete evidence-driven analyses of patient queries and spans over 800 illnesses, 1500 symptoms, and 300 risk factors. Symptomate is built to err on the side of over-triage rather than under-triage in order to ensure patient safety and minimize potential mistriage. Thus, the AI is programmed to refer a patient to higher acuity care than what may be needed, rather than running the risk of referring them to less intensive care than required. The VT engine has been rigorously evaluated using clinical vignettes created by physicians which present a wide range of disease-specific symptoms across various clinical settings, thereby enhancing VT accuracy and validity [22–24]. Infermedica's VT engine offers safe and accurate recommendations in 97.8% of cases [24]. Virtual triage and care referral have been implemented in multiple workflows, including integration with live nurse triage to improve triage efficiency and patient throughput within the digital front door of health systems, as a means of improving after-hours and weekend access to care, and as a guide for health system or plan patient-members to shift to clinically appropriate lower acuity services and settings such as telemedical/virtual care, or to higher acuity care if warranted.

This study evaluated the potential of VT to early detect patients with symptoms that may be evolving to SCA and examined the characteristics of VT users who reported prodromal symptoms of life-threatening cardiovascular disease but whose stated initial care intention was to engage in self-care or seek outpatient physician care, rather than seek emergency care.

2. Methods

2.1. Objective

The study sought to assess the extent to which patient-users of VT presenting with prodromal symptoms of life-threatening cardiac conditions recognized the clinical urgency of their symptoms and intended to engage the needed urgent (ED) level of care acuity.

2.2. Study design, setting, and description of virtual triage engine and engagement

An online survey was conducted of patient-users of a publicly available, cost-free online or virtual clinical triage application, Symptomate, developed by Infermedica, Inc. Symptomate is available in 20 languages and used in more than 30 countries, with more than 18 million VT encounters completed since its launch in 2012. It uses an AI-based engine to analyze patient-users' symptoms and risk factors and employs Bayesian Network technology, a statistical model that represents a set of variables and their conditional dependencies via a directed acyclic graph. When a patient provides symptoms and risk factors, Infermedica's algorithm calculates the probabilities of various medical conditions based on this data. Notably, neither vital signs nor other physiological data are currently captured by the VT engine, but in some cases, they can be input by patients if they have an appropriate measuring device (e.g., blood pressure or heart rate measured by a blood pressure cuff or blood oxygen saturation assessed by a pulse oximeter). The engine identifies the most likely underlying condition(s) from over 800 clinical conditions and generates healthcare referral recommendations driven by the acuity of reported symptoms.

2.3. VT respondent identification and characteristics

Patient-user VT encounters were selected according to the following inclusion criteria: (1) the patient-user reported at least one of the following prodromal symptoms for SCA that prompted the use of VT: chest pain, dyspnea, palpitations, or loss of consciousness; (2) the VT engine, after gathering additional information via the AI-driven interview, advised the patient-user to immediately present to an ED or call an ambulance; (3) the most probable condition suggested by VT was one of the following: myocardial infarction (MI), unstable angina, pulmonary embolism, unstable tachyarrhythmia, or unstable bradyarrhythmia; (4) patient-users were aged 35 years and older (i.e., most at risk of new onset or exacerbation of existing cardiac disease).

The number and percentage of these patient-users who reported an inappropriate, non-urgent initial pre-triage healthcare intention (i.e., they planned to either engage in self-care or visit a physician on an outpatient basis, or their intention was unclear) were calculated and compared demographically to patient-users who reported an appropriate healthcare intention (i.e., presenting to an ED or calling an ambulance).

In addition to symptoms and healthcare intentions, data collected from patients included sex, age, geographical place of residence (and travel history) in the last three months, plus important risk factors such as smoking, recent injury, diabetes, hypertension, and/or high cholesterol. Information about other symptoms was collected based on patient responses to questions asked during the VT interview. All data processed was anonymous and did not require identification of individuals. Patient-users provided consent for the use of their de-identified, anonymized data by accepting the VT terms of service. All data were analyzed and are reported in the aggregate.

2.4. Data collection and analysis

A large dataset of 746,282 VT patient-users was analyzed to assess VT's ability to early detect the elevated risk of SCA and to expedite appropriate care referral of patients at risk of new disease onset or clinical exacerbation, potentially preventing illness escalation, severe morbidity, and death. Data were analyzed for an 8-month study period from February through October 2022. A pre-triage intention survey asked patient-users what kind of care they intended to pursue prior to starting VT with the following possible responses: (1) engage self-care; (2) seek physician care on an ambulatory/outpatient basis; (3) visit an ED or call an ambulance; (4) not sure; and (5) not engage in any care. VT captured additional key medical information to determine whether patient-users had a high probability of experiencing an acute cardiac event (i.e., acute coronary syndrome, unstable arrhythmia, or pulmonary embolism). Using this data, we sought to assess the disconnect or lack of alignment between patient self-perception of disease severity and actual level of acuity and clinical care need (self-care vs. outpatient care vs. emergency care) as determined by AI-based VT.

2.5. Statistical analysis

Statistical analysis was completed using the TIBCO Statistica® Document Management System, version 13.3. Differences in inappropriate care intentions across age groups and gender were evaluated using the chi-squared test, with Yule's coefficient of colligation calculated for gender. In all analyses, $p < 0.05$ was used to determine statistical significance.

3. Results

Over an 8-month observation period, a total of 746,282 virtual triage episodes occurred. Of these, 218,963 (29.3%) were aged 35 years or older. Among this age group, 3,968 (1.8%) reported red flag/high-urgency symptoms deemed by the VT engine to likely have a cardiac origin (i.e., acute coronary syndrome, unstable arrhythmia, or pulmonary embolism). The VT care recommendations in these cases were to present to an ED (325 patient-users, 8.2%) or to call an ambulance (3,643 patient-users, 91.8%).

Of the 3,968 patient-users who met inclusion criteria, 3,547 (89.4%) reported an unclear or inappropriate pre-triage healthcare intention (i.e., engage in self-care or visit a physician on a non-urgent ambulatory/outpatient basis rather than visit an ED or call an ambulance). Only 421 (10.6%) patient-users indicated an appropriate intention to seek emergency care. Among those, the most likely condition identified by VT was acute coronary syndrome (myocardial infarction with concomitant unstable angina), which was suggested in 2,634 cases (66.1%), with 267 (10.1%) patient-users indicating an appropriate intention to seek emergency medical attention. Unstable arrhythmias and pulmonary embolism were suggested by the engine as the most likely conditions in 1,334 cases (33.6%), with 164 patient-users (12.3%) reporting an appropriate intention to seek emergency medical attention.

With respect to demographic variables, males were significantly more likely than females to have an intention to seek appropriate emergency care, as shown in Table 1. However, Yule's coefficient of colligation was 0.07, indicating a weak relationship.

Patient age and clinically appropriate care intention were positively associated and linear. Older patient-users more frequently had an appropriate pre-triage care intention (Table 2).

Table 3 shows pre-triage intentions to seek care stratified by age groups.

Analysis of the pre-triage intention of patients who experienced chest pain radiating to the left arm, a more specific symptom of myocardial infarction, was also performed. Of the 751 patients who reported this symptom, 714 (95.1%) did not intend to seek emergency care, and only 36 (4.8%) indicated an appropriate pre-triage healthcare intention to visit the ED or to call an ambulance.

Table 1. Pre-virtual triage care intentions by gender

Patient-user care intention	All patient-users	Males	Females	P-value
All care intentions	3,968	1,441	2,527	–
Appropriate care intention	421 (10.6%)	193 (13.4%)	228 (9.0%)	<0.001
Inappropriate care intention	3,547 (89.4%)	1,248 (86.6%)	2,299 (91.0%)	<0.001

Table 2. Pre-virtual triage care intentions by age

Patient-user care intention	All ages	Age 35–65	Age ≥ 66	P-value
All care intentions	3,968	3,527	441	–
Appropriate care Intention	421 (10.6%)	332 (9.4%)	89 (20.9%)	<0.001
Inappropriate care intention	3,547 (89.4%)	3,195 (91.6%)	352 (79.1%)	<0.001

Table 3. Age-stratified analysis of pre-virtual triage care intentions

Age	All care intentions	Appropriate care intention	Inappropriate care intention
All ages	3,968	421 (10.6%)	3,547 (89.4%)
35–45	1,879	165 (8.8%)	1,714 (91.2%)
46–55	1,086	102 (9.4%)	984 (90.6%)
56–65	562	65 (13.4%)	407 (86.6%)
66–75	254	51 (20.1%)	203 (79.9%)
76–85	87	23 (26.4%)	64 (73.6%)
≥ 86	100	15 (15.0%)	85 (85.0%)

Table 4. Incidence of life-threatening cardiac conditions among virtual triage patient-users by geographic region

Geographic Region	8-month incidence of high-risk cardiac conditions	12-month incidence of high-risk cardiac conditions
Europe (English speakers)	1,717 per 100,000	2,575 per 100,000
North America (English speakers)	1,651 per 100,000	2,476 per 100,000

We analyzed patient-user location and language in which the VT interview was conducted. Two large groups of patient-users completed the interview in English among European and North American patient-users. During the study period, there were 15,746 English-speaking patient-users from Europe and 51,191 from North America aged 35 years and older. Of these, 260 English-speaking patient-users from Europe and 879 patient-users from North America met the study inclusion criteria. The 8-month incidence of potentially life-threatening cardiac conditions was calculated and combined for myocardial infarction, unstable angina, unstable brady- and tachyarrhythmias, or pulmonary embolism (Table 4). Incidence was then extrapolated over 12 months for direct comparison to available epidemiological data typically reported on an annualized basis.

Myocardial infarction was the leading suspected condition for 572 English-speaking North Americans and for 144 English-speaking Europeans (who met the study inclusion criteria). The incidence of possible myocardial infarction as the most probable diagnosis for each of these groups was calculated. The 8- and 12-month incidence of myocardial infarction was 914 per 100,000 and 1,371 per 100,000 among Europeans and 1,123 per 100,000 and 1,684 per 100,000 among North Americans, respectively.

4. Discussion

This report is the first to analyze VT performance for prodromal symptoms of SCA and the first to assess the potential utility of VT in improving and expediting appropriate acuity care-seeking by patients presenting with prodromal symptoms of SCA. Of the patient-users who met the study inclusion criteria, over 89.4% had a pre-triage intention to not seek urgent medical attention despite reporting symptoms that were highly likely to represent a potentially life-threatening pathology with elevated risk of SCA. Only 10.6% of patient-users reported an appropriate pre-triage healthcare intention to visit an ED or call an ambulance. This high rate of inappropriate pre-VT care intention may reflect the likelihood that a substantial percentage of patients with severe cardiac-related symptoms seek ED care rather than consult a VT engine/website. In effect, this pre-selection implies a selection bias that inflates the percentage of individuals with inappropriate pre-virtual triage care intent and thus limits generalizability to the population at large.

However, this bias is not likely by itself to be fully explanatory for this high level of care acuity misalignment or decoupling from actual clinical need. In addition, the Symptomate VT engine is designed to err on the side of ensuring patient safety, and over-triages to ED by design, sacrificing specificity in favor of higher sensitivity. We estimate the rate of over-triage to ED by Symptomate to be approximately 13.0%, which would reduce our estimate of patient misalignment of care intent with medical need to 76.4%. Yet the implications of these findings for hospitals and health systems, and for their patient engagement strategies and programs, remain significant because of the critical importance of a patient's timely decision and action in securing acuity-appropriate care to prevent or mitigate the impact of SCA, which increases survival five-fold [9].

Given the inherent limitations in the interpretability of the study results, we completed epidemiological rate comparisons to other reported study results. These demonstrate similarity in magnitude with our findings regarding the level of inaccurate patient perception of symptom severity relative to other studies. Our findings align with other studies assessing delayed care engagement when life-threatening warning symptoms occur. Marijon et al. found that only 19% of patients experiencing prodromal symptoms culminating in SCA sought appropriate acuity-level care, significantly impacting survival rates among the remaining 81% [9]. The largest contributor to prehospital care delay was a patient's protracted decision process and time to care engagement, with 75% of inappropriately extended prehospital time attributable to individual decision-making [25]. This was influenced by sociodemographic, clinical, and psychological factors [26, 27]. Our findings replicated prior research indicating that women are less likely than men to have an initial intention to seek acuity-appropriate care and are more likely to engage in outpatient care when emergency care is needed [28]. Studies further demonstrate that patients with less education and/or lower income have longer prehospital delays when presenting with acute, life-threatening symptoms [29, 30]. This delay in care-seeking is also influenced by psychological and emotional factors, including waiting to see whether symptoms resolve, not recognizing the seriousness of symptoms, not wanting to waste doctors' time, and seeking advice from family or friends [29–31].

Efforts to increase patient education and recognition of the clinical signs/symptoms of an acute cardiac event, and the imperative to seek emergency care when present, are essential. Current approaches have been inadequate. Public information/awareness initiatives that address rapidly seeking medical care for acute, life-threatening cardiac symptoms have had a beneficial impact [32]. However, these are often episodic rather than continuous, thus limiting a sustained long-term benefit. Reputable Internet-based medical educational information exists that stress the importance of early recognition of cardiac symptoms and rapid care-seeking. However, these convey generic, non-personalized medical information, lessening impact on patient behavior. Internet users may misinterpret online medical information or view content that is not authoritative and evidence-based [33]. Current national guidelines, for example from the American Heart Association, focus more on treatment rather than prevention of out-of-hospital cardiac arrest [34]. The European Resuscitation Council Guidelines focus more directly on recognition of early warning signs [35].

VT may be another resource in efforts to improve the early detection of life-threatening cardiac symptoms and could potentially accelerate patient decision-making and appropriate care engagement. Assessment of this possibility should be a focus of future research. Patients often require additional clinical guidance before seeking emergency care, and a majority of patients with symptoms of MI delay emergency care, instead opting to contact their family physician [33]. VT can help address these issues by providing evidence-based and clinically validated information about the seriousness of the patients' symptoms and can direct patients to the needed level of care acuity in a timely manner. Integrating vital signs and ECG data from wearable diagnostic and monitoring technologies with VT has the potential to further improve VT sensitivity and specificity in detecting evolving severe cardiac pathology.

In 2018, there were 377,763 deaths from SCA in the United States, a mortality rate of 94.8 per 100,000 population [3]. The annual U.S. incidence of MI was 250 per 100,000 [3]. In the current study, 2,476 per 100,000 patient-users per year in North America were identified at risk of life-threatening cardiac disease, and the 12-month incidence of suspected MI among VT users was estimated to be 1,684 per 100,000, substantially higher. We are only beginning to fully characterize VT patients-users, who may not be comparable to the overall population. VT users are likely more comparable to a patient cohort presenting to an after-hours general practitioner or clinic. An analysis from Norway showed that 2.3% of patients contacting an after-hours general practitioner were patients presenting with potentially life-threatening symptoms, a substantial portion of which were cardiac, aligned with our findings of 1.8% of VT patient-users presenting with life-threatening cardiac emergencies [36]. The British official medical helpline, NHS 111, is a free non-emergency healthcare telephone line that assesses callers' health problems using an NHS-validated triage algorithm and directs patients to appropriate acuity-level care. The service is most often used outside usual medical office hours, and in 2018, among all NHS 111 service callers in England, 9.6% were determined to have symptoms of sufficient acuity and risk of harm to warrant ED assessment [37]. Of these, 13.3% (or 1.25% of all calling patients) needed acute hospital admission [37].

Our use of the above comparative statistics is not intended to substitute for future research that follows VT patient-users with apparent prodromal symptoms of SCA from VT-generated diagnostic possibilities and care referral through subsequent care-seeking for confirmation. The retrospective study design employed did not allow for clinical follow-up and validation of final patient diagnosis. Symptomate does not collect any patient-user identity data, and users agree only to the analysis of their data in the de-identified and anonymized aggregate. Thus, the results reported here are not conclusive evidencing that AI-based VT is an effective screening tool for SCA or severe cardiac conditions. Without clinical validation of the final diagnosis, such a conclusion cannot be drawn. These findings are, however, suggestive and sufficiently compelling to support the next phase of research that should include clinical validation of diagnosis, particularly given the high prevalence of and morbidity and mortality associated with cardiovascular conditions, plus the evidence that early detection to reduce the frequency and duration of care delays can improve patient outcomes [3, 38]. Future studies designed to include clinical follow-up and validation of the actual clinical course and diagnosis of patient-users by a live clinician are warranted based on this initial evidence of potential VT efficacy in the early detection of sudden cardiac arrest.

The power of this evaluation is based on its use of data from thousands of real patients before they contacted healthcare professionals. The most significant limitation is the lack of follow-up to verify patients' final care-seeking decisions, physician diagnoses, and clinical outcomes, which should be evaluated in subsequent research. Clinical outcomes can only be assessed in a care setting, which is beyond the scope of this study. However, external independent validation studies of this particular VT engine (Symptomate) showed high accuracy in identifying the most probable conditions and triaging to appropriate acuity care [22, 24, 39]. We do not suggest that all patients studied would eventually experience SCA, but that they should nonetheless be assessed urgently in an emergency setting given the risk of SCA and potential underlying life-threatening cardiac conditions.

A potential explanation for the findings is that individuals who utilize VT while experiencing prodromal symptoms do not trust the technology sufficiently to heed its care referral guidance. As a result, they dismiss the diagnostic output of their virtual triage encounter and disregard its care referral recommendation. However, this factor would impact care-seeking behavior after the patient-user had decided what course of healthcare seeking to follow, which was not data captured in this particular study. Since Symptomate VT data capture does not include any specific questions to measure the patient-user's level of confidence and trust in the diagnosis and care referral recommendation rendered by VT, we are unable to assess whether or not this could be a dynamic accounting for some portion of patient-users referred for ED care who were not inclined post-VT to seek such care.

It is important in this regard to note that a published survey of 2,113 patient-users of the Symptomate virtual triage and care referral platform found that patient satisfaction was very high; 80.1% stated they were either highly likely or likely to use Symptomate in the future, and patient-user desire to use telemedicine in the future doubled [40]. While patient experience/satisfaction with the VT and care referral engine are not identical to having data directly evidencing high or low patient-user trust in the technology platform, it would seem, logically and intuitively, that trust would align substantially with satisfaction and a positive user experience. In other words, if patients like using Symptomate, it is unlikely that they do not trust it, and contrariwise, patient-users with high distrust of the technology are not likely to be highly satisfied with the Symptomate VT experience. While evaluating patient-user belief or trust in the VT engine was not an objective of this analysis, this question should be researched.

These study findings warrant continued research on VT utility and accuracy in the context of early detection of life-threatening conditions. Given the national and international scale of potentially preventable morbidity and mortality from high-incidence cardiac pathologies and SCA, such research is urgently needed. Research exploring patient-users' journeys following virtual triage, including VT's impact on their final care decisions, is needed to shed light on user engagement and the motivational and clinical effectiveness of VT care referral tools. Aspects of patient-user experience like the graphic design of a VT patient interface and navigation, order of triage questions, and interview flow should also be studied in this context.

Great potential diagnostic value exists through the integration of vital signs or ECG data captured by wearable diagnostic and remote monitoring technologies with VT technology, which would improve the accuracy and timeliness of care referral. Future research should be designed cognizant of the reality that AI-based virtual triage and care referral technology is only one element within an emerging powerful digital health ecosystem that is expanding the options patients have to secure care. VT patient-users may soon be able to input (or Bluetooth) their personally measured digital blood pressure, pulse, respiratory rate, temperature, blood oxygen saturation, serum glucose readings, and other key clinical metrics into the AI-driven VT encounter. Interoperability and integration of such real-time biometric and vital signs data with VT AI will deepen and enhance VT clinical validity, sensitivity, and specificity and refine its care acuity recommendations. Research on the synergistic integration of other virtual digital diagnostic technologies will accelerate the accuracy and power of AI-based VT to earlier identify patients at elevated risk of severe illnesses and reduce care delays [41]. Research into the potential risks and harms of these AI-based tools, as well as ethical and safety analyses, are also important focuses of ongoing investigation. Finally, a key priority for future research will be to evaluate the impact of educational interventions and tailored messaging integrated with virtual triage and care referral to foster rapid and appropriate care-seeking among at-risk patients.

5. Conclusions

Among patient-users of a VT engine with severe prodromal cardiac symptoms indicating an elevated risk of progression to SCA, a very high proportion (89.4% and 76.4% adjusted for VT over-triage to ED) did not plan to seek emergency care. Our findings confirm a great need for substantially improved and expanded patient-user education about recognizing high-urgency cardiac symptoms. VT engines should continue to be evaluated for the potentially valuable role they may have in early detection and acuity-appropriate care referral as well as in patient-user education. In particular, future research should enable clinical follow-up of patients to determine the actual course of illness and outcomes that occur among patients who follow the clinical care referral to emergency services rendered by VT versus those who do not. Furthermore, research should focus on how with AI-based VT and care referral can be integrated with real-time clinical/biometric and vital signs data from wearable devices to improve early detection and reduce care delays for life-threatening cardiac conditions.

Delays in care-seeking during healthcare emergencies negatively impact patient outcomes. Care delays result from patients not understanding, dismissing, or underestimating serious symptoms. Attempting to self-treat serious clinical issues at home, without medical guidance or oversight, also contributes to care delay-related morbidity/mortality. Early detection and prompt, acuity-appropriate treatment are critical to improve MI outcomes, a leading contributor to SCA. Reducing MI and SCA care delays requires expansion of patient education about symptoms warranting early care-seeking [42, 43] and can be integrated with VT [39]. Current approaches to increasing early care-seeking among at-risk populations have been inadequate. Public awareness campaigns on seeking prompt medical care in cases of acute, life-threatening cardiovascular symptoms demonstrate a positive impact [42, 43], but are often episodic/not continuous, and do not achieve a sustained impact. Reliable online medical resources educate about the importance of early recognition and care-seeking for serious cardiac symptoms, but provide general, non-personalized medical information, lessening impact on individual behavior. VT can favorably influence patient care-seeking behavior to enable acuity alignment of care intent and objective clinical need [44] and can drive earlier detection and care engagement by letting a patient-user know their condition may be more serious than they perceive and they should seek ED care.

Ethical Statement

Informed patient consent was waived due to anonymous capture of all information that did not involve the identification of individuals during the virtual triage interview. Patient-users provided informed consent for the analytic use of their de-identified, anonymized data in aggregate form by accepting the VT terms of service. All data were analyzed and are reported in the aggregate.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data that support this work are available upon reasonable request to the corresponding author.

Author Contribution Statement

George A. Gellert: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Mateusz Palczewski:** Conceptualization, Methodology, Software, Validation, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Maria Marecka:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Katarzyna Paczkowska:** Conceptualization, Methodology, Software, Validation, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Aleksandra Suwinska:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Jakub Jaszczak:** Conceptualization, Methodology, Software, Validation, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Gabriel L. Gellert:** Data curation, Writing – review & editing, Visualization, Project administration. **Piotr M. Orzechowski:** Supervision. **Tim Price:** Writing – review & editing, Supervision. **Stanislaw Gorski:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision.

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