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Clicks away from reduced healthcare expenditures: leveraging the electronic health record to reinforce education efforts

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ABSTRACT

Objectives Lupron 11.25 mg has both a narrow indication and a high cost compared to other Lupron presentations. Prior to our study initiation there was no clear distinction between presentations when ordering within the health-system's Electronic Health Record (EHR). This resulted in inappropriate product selection, payment and billing errors that negatively impact our healthcare system. To reinforce prior education efforts, a new approach was considered leveraging the EHR with information to steer prescribers to the proper Lupron presentation based on indication. This study aimed to reduce off-label prescribing for Lupron 11.25 mg (NDC 00074-3663-03) by 25% by 02/28/2022 without negatively impacting the insurance collection rate.

Methods Baseline Lupron 11.25 mg adult kit administrations one year prior to intervention and off-label prescribing was found to account for 22.7% of administrations. In December 2021 intervention order questions were added to Lupron 11.25 mg in the EHR. One and two-month data was obtained after implementing order questions within the EHR. Lupron 11.25 mg administrations were classified into one of four categories to determine impact on off-label prescribing.

Results In the one- and two-month post-implementation periods off-label prescribing was 0% and 15.3% respectively, a reduction of 22.7% to and 7.4% respectively from the baseline assessment. There were no clinical denials found in either post-implementation reporting period.

Conclusion This report adds to the body of evidence that leveraging the EHR can lead to healthcare savings and illustrates how patient and healthcare system burden can be reduced by prompting thought and direction when a medication has indication specific dose requirements.

At our health system, several cases of high-cost administrative denials for Lupron Depot (Lupron) 11.25 mg kit for intramuscular injection occurred. Providers were educated on the proper strength for the desired indication but off-label prescribing, and subsequent denials persisted. Lupron 11.25 mg has both a narrow indication and a high cost compared with other Lupron presentations, yet prior to our study initiation, there was no clear distinction between presentations when ordering within the health system's electronic health record (EHR). Resultantly, providers often selected the inappropriate presentation, leading to payment and billing errors that negatively impact both our healthcare system and patients. Recognising individualised education does not have a profound impact across a multistate health system and desire to prevent selection of Lupron 11.25 mg further upstream, a new approach was considered leveraging the EHR with information to steer prescribers to the proper Lupron presentation based on indication.

Healthcare providers strive to strike a balance between quality and cost-effective care. Complicated insurance policies and flawed EHR systems can lead to cost-ineffective care negatively impacting healthcare systems, providers and patients. In 2001, a national database review of medications prescribed and associated diagnoses found that 21% of prescriptions were written for an off-label indication.[1] Survey data performed in the outpatient setting for paediatrics have found even higher incidences of off-label prescribing ranging from 67% to 96%.[2]

Lupron 11.25 mg has a narrow Food and Drug Administration (FDA) indication of endometriosis and uterine fibroids and its wholesale acquisition cost is US$3398 per dose.[3 4] Lupron carries off-label endorsement for the treatment of gender dysphoria, fertility preservation, ovarian and prostate cancer, premenstrual syndrome and more.[3] Many insurance companies will reimburse for off-label uses so long as they are endorsed by a national compendia guideline or listed in Micromedex DRUGDEX (Micromedex) as a non-FDA class I, IIa or IIb indication; it is prudent to consider prior authorisation

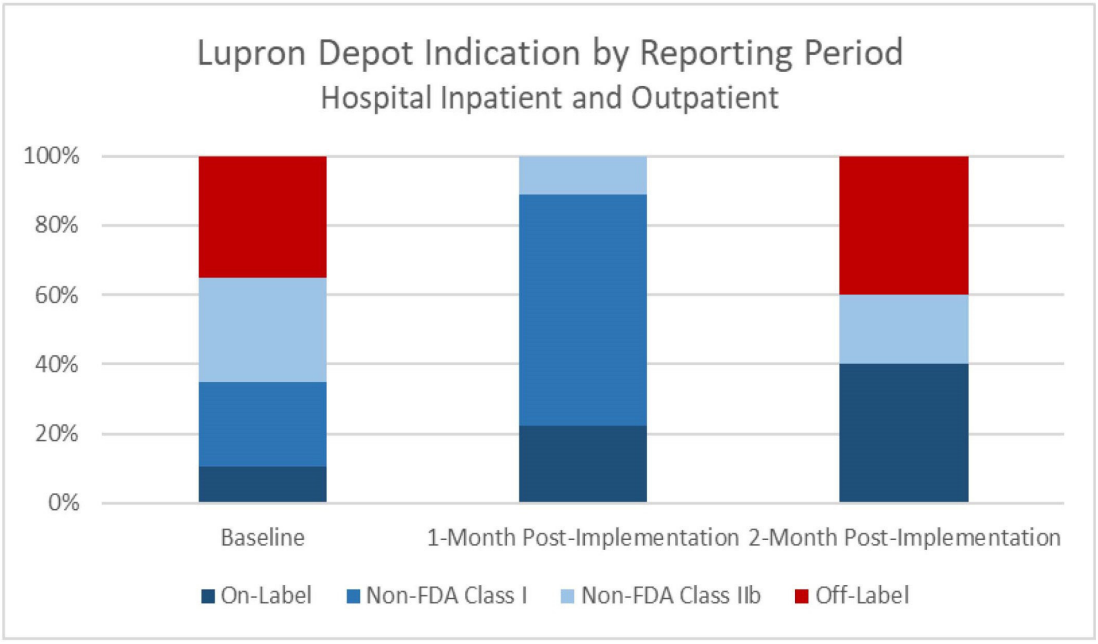

Figure 1 Lupron Depot 11.25 mg Adult Kit Uses by classification[a–c]. [a]Baseline; 1 September 2020–31 August 2021. [b]1-month postimplementation: 1 January 2022–31 January 2022. [c]2-month postimplementation: 1 February 2022–28 February 2022. FDA, Food and Drug Administration.

(PA) before administration particularly when prescribing for off-label uses. The time-consuming steps to obtain PA and appeal insurance denials is necessary, costly and time-consuming.[5]

Complicated and poor EHR system design coupled with high expectations of provider performance may contribute to errors in prescription ordering.[6] By implementing a set of order questions based on both approved and Micromedex endorsed off-label uses, this study aimed to reduce off-label prescribing for Lupron 11.25 mg (NDC 00074-3663-03) by 25% by 28 February 2022 without negatively impacting the insurance collection rate. We expected to improve patient experience by reducing unexpected billing and payment amounts for which patients are responsible.

Baseline Lupron 11.25 mg adult kit administrations among patients were tracked for 1 year prior to intervention. In December 2021, additional provider education

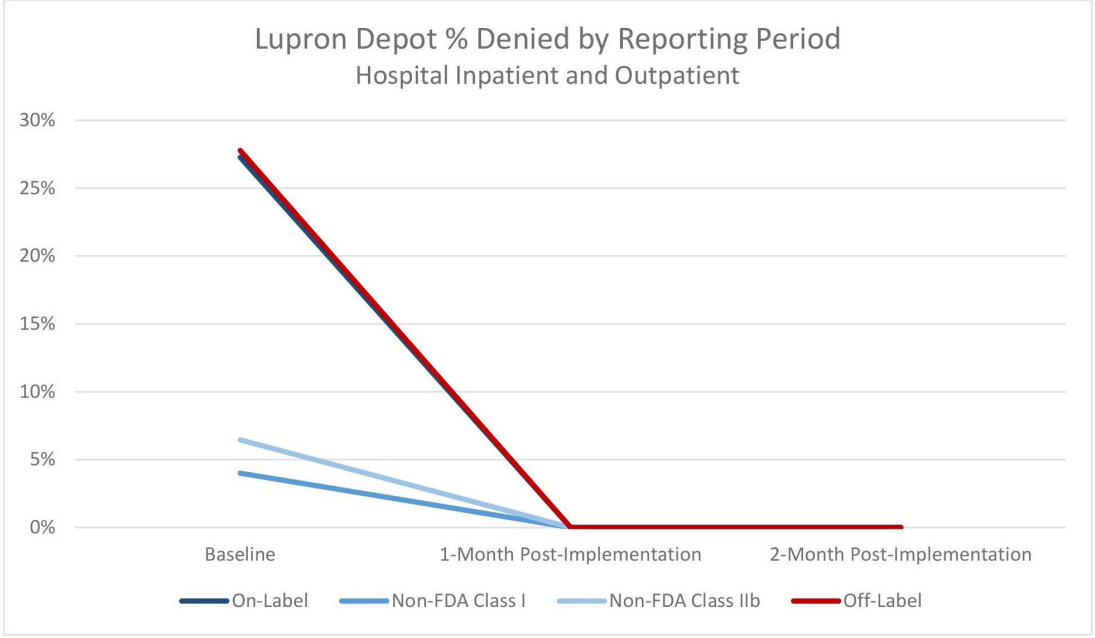

Figure 2 Lupron Depot 11.25 mg Adult Kit Percentage Denied Claims by Reporting Period[a–c]. [a]Baseline: 1 September 2020–31 August 2021. [b]1-month postimplementation: 1 January 2022–31 January 2022. [c]2-month postimplementation: 1 February 2022–28 February 2022. FDA, Food and Drug Administration.

and intervention order questions were added to Lupron 11.25 mg in the EHR. One and 2-month data were obtained after implementing order questions within the EHR. Lupron 11.25 mg administrations were classified into one of four categories: off-label, on-label, non-FDA approved class I or non-FDA approved class IIb indications, and insurance collection rates were tracked. We tracked all administrations and payer types but excluded self-pay collection ratios from insurance collection rates. Insurance collection rates were assessed internally comparing 1 January 2021–30 April 2021 to 1 January 2022–30 April 2022.

At baseline, there were 220 medication administrations for Lupron 11.25 mg including 50 off-label administrations billed with risk of underpayment compared with 49 on-label, 27 non-FDA approved class I, and 94 non-FDA approved class IIb administrations (figure 1). Off-label prescription use was 23% of the total administrations with a corresponding 28% denial rate (figure 2).

The 1-month postintervention revealed 36 Lupron 11.25 mg administrations across the health-system. Of those 36 administrations, the following were assessed: 0 off-label administrations, 14 on-label administrations, 13 non-FDA class I administrations and 9 non-FDA class IIb administrations (figure 1). There were no denials due to clinical indication reported in the 1-month postintervention assessment (figure 2).

The 2-month postintervention revealed 13 Lupron 11.25 mg administrations across the health system. Of those 13 administrations, the following were assessed: two off-label administrations, eight on-label administrations, one non-FDA class I administrations and two non-FDA class IIb administrations (figure 1). Off-label prescription use was 15%, administered in the inpatient setting, but did not result in denial of the claim due to clinical indication (figure 2).

Through provider education and leveraging the EHR to guide prescribers on FDA-approved indications, National Comprehensive Cancer Network guideline supported uses and ensuring an additional selection option to cover off-label use when PA has been obtained, we reduced off-label prescribing without adversely impacting the insurance collection rate. This adds to the body of evidence that leveraging tools within the EHR can result in healthcare savings.[7 8] Furthermore, this report illustrates how patient and healthcare system burden can be reduced by prompting thought and direction when a medication has indication specific dose requirements. Limitations existed in the ability to educate all prescribers across the health system, which may have influenced study results.

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Usability, acceptability and feasibility of a novel technology with visual guidance with video and audio recording during newborn resuscitation: a pilot study

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ABSTRACT

Objective Inadequate adherence to resuscitation for non-crying infants will have poor outcome and thus rationalise a need for real-time guidance and quality improvement technology. This study assessed the usability, feasibility and acceptability of a novel technology of real-time visual guidance, with sound and video recording during resuscitation.

Setting A public hospital in Nepal.

Design A cross-sectional design.

Intervention The technology has an infant warmer with light, equipped with a tablet monitor, NeoBeat and upright bag and mask. The tablet records resuscitation activities, ventilation sound, heart rate and display time since birth. Healthcare providers (HCPs) were trained on the technology before piloting.

Data collection and analysis HCPs who had at least 8 weeks of experience using the technology completed a questionnaire on usability, feasibility and acceptability (ranged 1–5 scale). Overall usability score was calculated (ranged 1–100 scale).

Results Among the 30 HCPs, 25 consented to the study. The usability score was good with the mean score (SD) of 68.4% (10.4). In terms of feasibility, the participants perceived that they did not receive adequate support from the hospital administration for use of the technology, mean score (SD) of 2.44 (1.56). In terms of acceptability, the information provided in the monitor, that is, time elapsed from birth was easy to understand with mean score (SD) of 4.60 (0.76).

Conclusion The study demonstrates reasonable usability, feasibility and acceptability of a technological solution that records audio visual events during resuscitation and provides visual guidance to improve care.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ There have been advances in low-cost technology and equipment to improve newborn resuscitation in low-resource settings.

⇒ Recent developments in machine learning suggest resuscitation activities recorded by tablet with analysis of the events provide the next step of resuscitation. This opens up new possibilities for real-time guidance and quality improvement. This study aims to assess the usability, feasibility and acceptability of a novel technology during newborn resuscitation by healthcare providers (HCPs) in a low-resource setting hospital.

WHAT THIS STUDY ADDS

⇒ In terms of usability of technology, the overall usability (ranging 1–100) was good with the mean score (SD) of 68.4 (10.4). The participant preferred to use the technology more frequently with the mean score (SD) of 4.52 (0.87).

⇒ In terms of feasibility of the technology (range 1–5), the participants received support from their supervisor to use the technology with, the mean score (SD) of 4.28 (1.24); however, they perceive of not receiving adequate support from the hospital administration while using the technology, with mean score (SD) of 2.44 (1.56).

⇒ In terms of acceptability of the technology (range 1–5), the information provided on the monitor, that is, time elapsed from birth, was easy to understand with the mean score (SD) of 4.60 (0.76). The access to NeoBeat and upright bag and mask in the infant warmer was easy with the mean score (SD) of 4.60 (0.91).

INTRODUCTION

Globally, every year, of the 140 million newborns born, 10–15 million do not cry after birth and resuscitation is required for these newborn to accomplish spontaneous breathing.[1–4] Despite progress and efforts to reduce newborn deaths, over 90% of these

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ We are in a process of developing a novel technology based on automatic video and audio analysis as well as activity recognition using deep learning models.

⇒ The study demonstrates that this current (pilot) version of the application was usable, feasible and acceptable by the HCPs, providing rationale to continue the development of machine learning technology.

deaths still occur in low-income and middle-income countries (LMICs), and most intrapartum deaths can be prevented with effective resuscitation.[5] Anxiety and fear among healthcare providers (HCPs), difficulties in assessing the newborn's condition and providing appropriate clinical response usually delay the initiation of bag and mask ventilation.[6]

To improve the competency on newborn resuscitation in LMICs, Helping Babies Breathe (HBB) training has been rolled out since 2010.[7 8] Following the implementation of HBB training, there have been improvement in HCPs skill competence in newborn resuscitation.[9 10] However, there is a rapid skill decay in skill competence of newborn resuscitation over a period of time.[11] To tackle this problem, simulated short-term training sessions, such as structured skill drill in newborn simulator, have shown to maintain and retain skill competence on resuscitation.[12 13] Despite maintenance of skill competency, implementation in clinical care have been low.[14] HCPs have failed to translate their skills into clinical performance, and as a result infants who require resuscitation do not receive timely ventilation[15] (figure 1A,B).

To improve the clinical performance, a periodic reviewing method using Plan–Do–Study–Act (PDSA) have been implemented.[16] Reviewing newborn resuscitation procedures have shown to be highly beneficial for maintaining and improving skills[17–19] and reduce mortality.[20 21] However, review of resuscitation procedure is done after intervention and not during intervention. Therefore, during resuscitation, HCPs depend on their cognitive skills, memory and posted visual reminders for actions to be taken. To mitigate this problem, we are currently in the process to develop an automatic guidance to HCPs during resuscitation with the use of deep learning model, MAchine Learning Application (MALA)[22] (figure 1C,D).

MALA will be a tablet-based MALA, which will use video and audio activities recorded by a tablet in analysing the event and will guide for next step of resuscitation through visual display and audio prompts in real time during resuscitation. The development of MALA will require a large number of video and audio recordings to train the MALA and currently a preversion of MALA has been developed which records video and audio activity. This current (pilot) version of the application provides a visual display of time on the tablet monitor mounted onto the infant warmer.

To guide the research team on further development of MALA application, acceptability of video and audio recordings as well as the current version of the application is needed.[23–25] Therefore, this study aims to assess the usability, feasibility and acceptability of the current version of technology with visual time guidance, video and audio recordings, during newborn resuscitation.

METHODS

Study design

This is a cross-sectional survey of assessing the usability, feasibility and acceptability of the novel technology. The survey was conducted between 19 and 26 January 2022.

Study setting

The study was conducted at Bharatpur Hospital, a referral hospital in Nepal. There are more than 13 000 annual deliveries and 23% by caesarean sections. The delivery unit has in total 21 beds (3 for admissions, 10 for waiting the onset of labour, 5 for labour, 3 for delivery) and 3 newborn resuscitation corners. There are 30 HCPs working in the maternity ward in the hospital, all of them

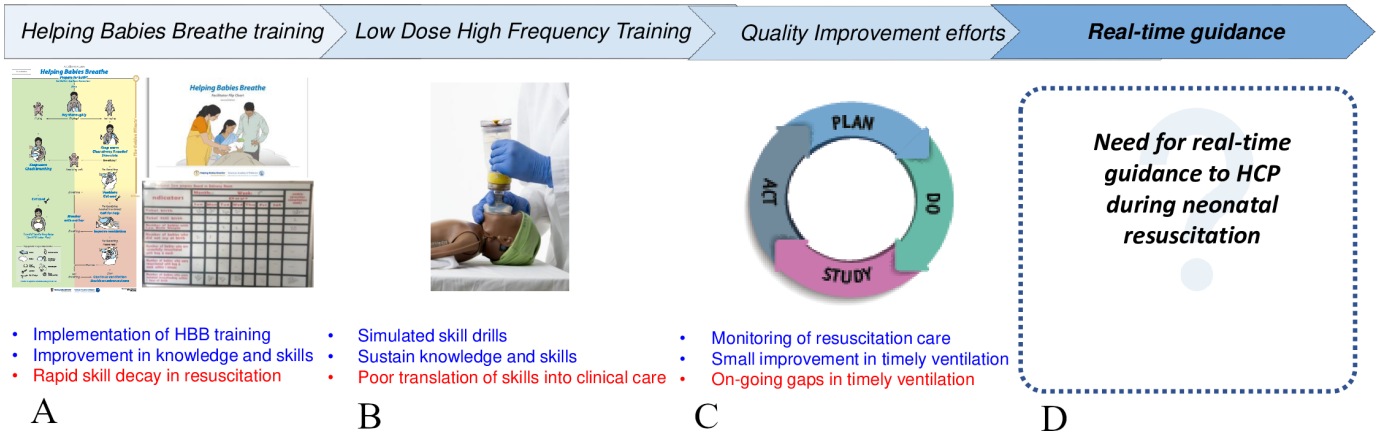

Figure 1 Need for development of automated feedback during resuscitation. HBB, Helping Babies Breathe; HCP, healthcare provider.

received training on HBB as a part of quality improvement project. Before the introduction of technology, HCPs had been doing skill drills on newborn simulator and biweekly reviewing the resuscitation performance through PDSA approach.

Study participants

All HCPs working in maternity unit with the experience of performing resuscitation as well as who received training on technology was included during the pilot period were eligible. Information about duration of their experience on resuscitation was collected with the background information.

Intervention package

The intervention package consisted of a technology, its installation in the local context and training to HCPs. The technology was developed by Laerdal Medical in Stavanger, Norway, with design input from Golden Community (GC) National Research Institute team in Nepal.

Technology

Technology consisted of an infant warmer (Phoenix Medical Systems, Chennai, India), equipped with a tablet for sound and video recording, which provided visual guidance in elapsed time since birth. The tablet monitor was faced towards the bed of infant warmer to record resuscitative activities. HCPs could also see the time from birth in the monitor and continue resuscitation activities (figure 2).

The infant warmer is also equipped with a newborn heart rate monitor (NeoBeat, Laerdal Medical, Stavanger, Norway), a manual suction device, Laerdal Upright bag with PEEP (Positive end-expiratory pressure) functionality and a tube for recording of air pumped through upright bag while ventilating the newborn (figure 2). When 'baby born' was clicked on the Liveborn application at the time of birth, video recording got automatically started by the tablet mounted onto the infant warmer. Newborn resuscitation was observed and annotated in the Liveborn application. And when no further resuscitative care was provided by HCPs, observation was ended in the Liveborn application, and then the video recording got automatically stopped. After that, the annotations along with the recorded video were uploaded to a highly secured data storage system. If a newborn did not need any resuscitative care after birth, the already initiated observation was cancelled in the Liveborn application, which automatically stopped and deleted the video recording.

Technology installation to the local context

Laerdal team demonstrated installation and use of technology step by step including the use of two tablets: one for Liveborn application and the other as video recorder. The training was provided to database manager, research coordinator and planning monitoring evaluation manager of GC. The Liveborn and video application systems were repeatedly practised on neonatalie Live by different users at GC office. Feedback on the application system and performance provided to the Laerdal

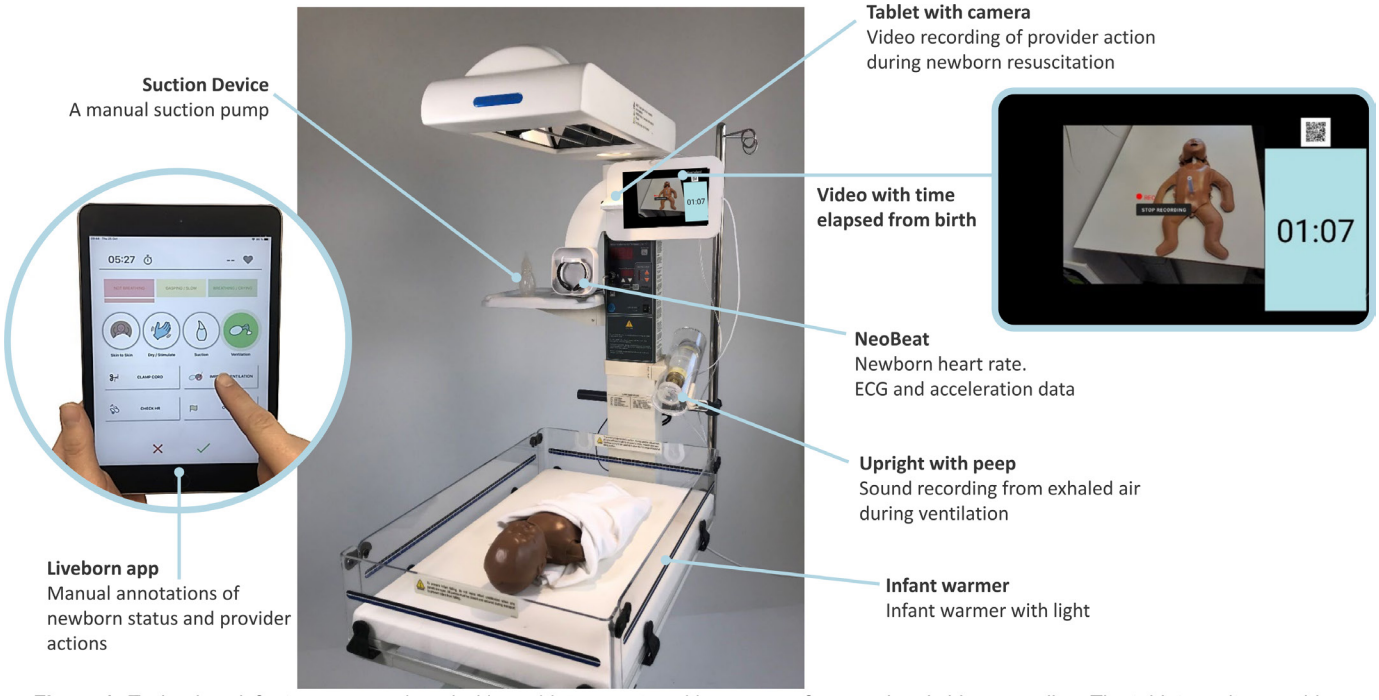

Figure 2 Technology infant warmer equipped with a tablet computer with a camera for sound and video recording. The tablet monitor provides real-time video recordings and time elapsed since birth. The time of birth is based on input from an observer using the Liveborn app. Technology is also equipped with NeoBeat (newborn heart rate metre that provides heart rate and motion data), a manual suction device, and Upright bag with PEEP. PEEP, positive end-expiratory pressure.

Figure 3 Installation and training of data collection team and healthcare providers on the technology.

team helped to refine the interoperability between video recorder and Liveborn applications.

Technology training and facilitation

At Bharatpur Hospital, the technology was first introduced to the hospital management on 22 November 2021. The following day, orientation on the system was provided to the doctors and nursing team on (a) installing the technology on infant warmer (bag and mask container, tablet case, NeoBeat charger along with upright bag and mask with PEEP functionality and tube for sound recording of ventilation quality), (b) installation of Liveborn and Video recorder application in the tablet, (c) linking Liveborn application with Video recorder application. Following this, the data collectors practised a demo video recording in real infant. If no resuscitation was needed, the started observation in Liveborn was cancelled and the video recording was automatically stopped and deleted. The doctors and nurses could see the time from birth in the tablet mounted and conduct resuscitation on the infant warmer (figure 3).

Experience with the technology and participants' involvement

Average number of newborn resuscitations per month at Bharatpur hospital was 50. We designed the study in which the technology can be used in both real and simulation cases, such that all HCPs have adequate hands-on experience with the technology. After 8 weeks of hands-on experience with the technology, HCPs participated in the survey.

Development of the provider survey tool

The questionnaire included demographic questions (position in the hospital, years of experience, and education level), skill (newborn resuscitation and NeoNatalie Live skill drill in the last 1 month), technology usage (computer at home, smart phone, app use) and questions related to technology usability, feasibility and acceptability.

Usability

The usability of the technology was assessed using the System Usability Scale (SUS), which is the most widely used standardised questionnaire for the assessment of perceived usability.[26 27] The SUS consists of 10 statements with 5-point Likert scale for each statement, that it provides a global view of subjective assessment of a system usability. Among 10 statements in SUS, 5 of them are positively formulated (items with odd numbers) and the other 5 statements are negatively formulated (items with even numbers). After cognitive testing of the translated tool among few HCPs other than the study population, wordings of some of the statements had to be simplified for more clear and better understanding of those statements (online supplemental file 1). The originality of the scale was maintained after translation and adaptation.

Feasibility and acceptability

In addition, HCPs completed a self-administered 15 questions assessing perceived feasibility and acceptability of the technology using a Likert scale of 1–5, where 1 represents strongly disagree and 5 presents strongly agree. Feasibility and acceptability-related questions were developed by the research team based on the seven constructs from the 'unified theory of acceptance and use of technology'.[28] The finalised questionnaire was translated into Nepali language and no adaptations in the questionnaires were required based on the cognitive testing.

Data collection

After at least 8 weeks of experience with the technology, data collectors provided usability, feasibility and acceptability questionnaires to the HCPs. Data collection was conducted for a week, from 19 to 26 January 2022. Data collectors collected the questionnaire from the HCPs, which were then entered into the database system. The entered data was extracted into SPSS Software (IBM SPSS Statistics for Windows, V.23.0) and reviewed by the study team.

Data analysis

To calculate the overall SUS Score, the following formula was applied: items 1, 3, 5, 7 and 9 (positive statements) were subtracted by 1 from their scale position and items 2, 4, 6, 8 and 10 (negative statements) were subtracted by 5 from the scale position. The sum of these item scores was then multiplied by 2.5 to obtain the overall value of SUS. The overall SUS scores ranged from 1 to 100 with 1 indicating not at all usable and 100 indicating perfect usability. For stratified analysis (online supplemental file 2), p values were calculated using one-way ANOVA (Analysis of Variance) for the 'Newborn resuscitation and/or NeoNatalie Live skill drill' or independent samples t-test for other variables (years of experience, education and position/role).

Written consent was taken from HCPs for the survey (online supplemental file 3).

RESULTS

Among the 30 HCPs (nurse and midwives) working in the labour and delivery room, 25 (83.3%) of them consented to participate in the survey. All of them were female and 16/25 (64%) of them were nurses. Overall, 11/25 (44%) of them had 2–5 years of experience working, 9/25 (36%) of them had 6–10 years of experience and 4/25 (16 %) had more than 10 years of experience in labour and delivery room. During the last month, 10/25 (40%) of them had performed both at least 1 newborn resuscitation and practised skill drill in Neonatalie Live, 6/25 (24%) had performed newborn resuscitation only and 5/25 (20%) had performed skill drill only. Of the participants, 19/25 (76%) had computer at home and all of them had smart phone. Overall, 24/25 (96%) use mobile-based application in their smart phone on a daily basis (table 1).

In terms of the usability of the technology, the overall usability (ranging 1–100) was good with the mean overall score (SD) of 68.4% (10.4). The participants wanted to use the technology (range 1–5) more frequently with the mean score (SD) of 4.52 (0.87) and did not find the technology unnecessary complex with the mean score (SD) of 2.04 (1.37). They perceive that the person using the technology (range 1–5) needs to be good in technology with the mean score (SD) of 4.28 (1.28). The participant did not perceive that there was lot of inconsistency or mismatch between the components of the technology (range 1–5) with the mean score (SD) of 2.44 (1.45). Participants perceived that they could use and operate the technology quickly with the mean score (SD) of 4.40 (0.65). Participants also perceived that they need to learn more and get continuous education to use the technology (range 0–5) in daily routines with the mean score (SD) of 4.52 (0.65) (figure 4).

When the usability of the technology was stratified by participated HCPs' newborn resuscitation and/or NeoNatalie skill drill, years of experience, education and position/role, participants who had bachelor's degree believed stronger that a person needs to be technology friendly for using the technology than participants who were undergraduates (mean score of 4.88 (0.35) vs 4.00 (1.46); p value=0.03). Participants who had less than 7 years of experience working in labour and delivery also believed stronger that a person needs to be good in technology for using the technology, compared with participants who had 7 or more years of experience (mean score (SD) of 4.82 (0.53) vs 3.13 (1.64); p value=0.02).

Table 1 Characteristics of the healthcare providers

Variables	Number (%) (total=25)
Demographic factors	
Gender	
Female	25 (100)
Position/role	
Nurse	16 (64)
Midwife	2 (8)
Skilled birth attendant	5 (20)
Auxiliary nurse midwife	2 (8)
Years of experience	
Less than 1 year	1 (4)
2–5 years	11 (44)
6–10 years	9 (36)
11–15 years	2 (8)
16–20 years	1 (4)
Over 20 years	1 (4)
Mean (SD) years of experience	7.0 (5.6)
Education	
Diploma level	17 (68)
Bachelor's level	8 (32)
Skills and technology usage	
In the last 1 month, I have performed newborn resuscitation and/or practised skill drill on advanced NeoNatalie	
Both	10 (40)
Only performed newborn resuscitation	6 (24)
Only practised skill drill on advanced NeoNatalie	5 (20)
Neither	4 (16)
I have a computer at home	
Yes	19 (76)
I have a smart phone	
Yes	25 (100)
I use apps in my smart phone	
Never	0
Monthly	1 (4)
Weekly	0
Daily	24 (96)

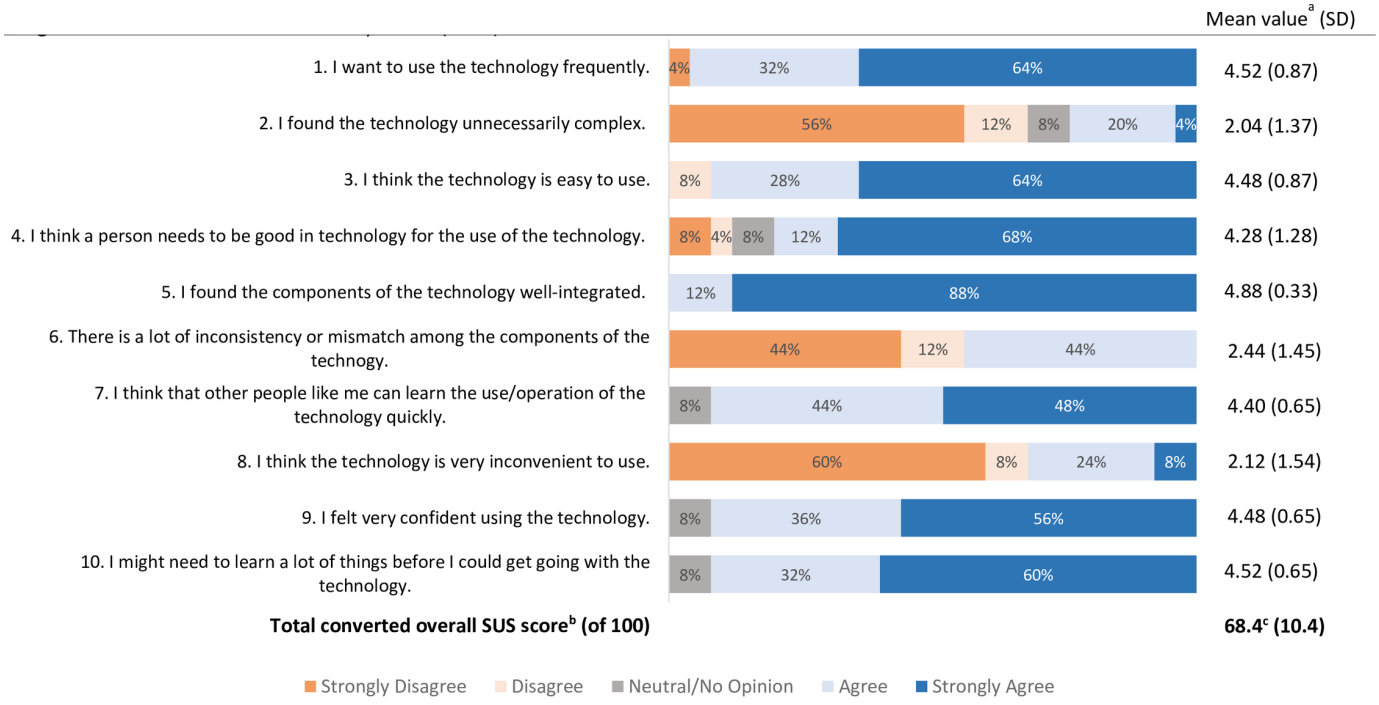

Figure 4 Healthcare providers usability scores (N=25). [a]1=strongly disagree, 2=somewhat disagree, 3=neutral or no opinion, 4=somewhat agree, 5=completely agree. [b]For items 1, 3, 5, 7 and 9, the converted score is the mean score minus 1. For items 2, 4, 6, 8 and 10, the converted score is 5 minus the mean score. [c]The average SUS Score is 68. General guideline on the interpretation of SUS Score: >80.3 (A)=excellent, 68–80.3 (B)=good, 68–58 (C)=okay, 51–58 (D)=poor, <51 (F)=awful. Reference https://measuringu.com/sus/.

Participants who had bachelor's degree thought that there is more inconsistency among the component of the technology, compared with undergraduates (mean score (SD) of 3.38 (1.19) vs 2.00 (1.37); p value=0.02) (online supplemental table 2).

In terms of feasibility of the technology, the participants responded that they need support from their colleague (range 1–5) to use the upright bag and mask and NeoBeat in the infant warmer, mean score (SD) of 2.48 (1.66). While the participants received support from their supervisor for use of the technology, mean score (SD) of 4.28 (1.24), they did not receive support from the hospital administration for use of the technology, mean score (SD) of 2.44 (1.56) (figure 5). The participants who were working in the labour room as a nurse thought that the system (range 1–5) was more compatible for use within the existing clinical service system, compared with participants in other roles (mean score (SD) of 4.00 (1.03) vs 2.56 (1.42); p value=0.02) ((online supplemental file 3)).

In terms of acceptability of the technology, the participants reported that the information provided in the monitor that is, time elapsed from the birth, was easy to understand and the access to NeoBeat and upright bag and mask was easy with the mean score of 4.60 for both. The participants felt comfortable with the video recording of the health workers performing newborn resuscitation with the mean score (SD) of 4.36 (0.86) and wanted the video recording to be continued (mean score (SD) of 4.60 (0.76)) after the pilot study. The participants were relatively comfortable with audio recording during newborn resuscitation with the mean score (SD) of 4.20 (1.00) and they perceived the possibility of getting more realistic guidance during newborn resuscitation would reassure them while taking care of the newborn and performing the resuscitation (mean score (SD) of 4.64 (0.86)) (figure 5).

DISCUSSION

This pilot study evaluated the usability, feasibility and acceptability of a novel technology, which included video and audio recordings of newborn resuscitation, visual guidance of time elapsed from birth and resuscitation equipment (NeoBeat, a manual suction device, and upright bag and mask). Our study showed that the HCPs found the technology useful. HCPs wanted to use the technology more frequently and found the system simple and consistent. Although they found some issues of interoperability between the components of the technology, HCPs perceived that a person familiar with the use of smart phone application use can operate the system better. HCPs thought that the system was compatible to use within the existing clinical service system; however, they required support from their colleagues to use the upright bag and NeoBeat in the infant warmer. As the operators that is, HCPs felt they needed support from another team member to use the technology, a continuous capacity building of the HCPs is required to use the application to make the system compatible in a low-resource environment. Currently, research team provides

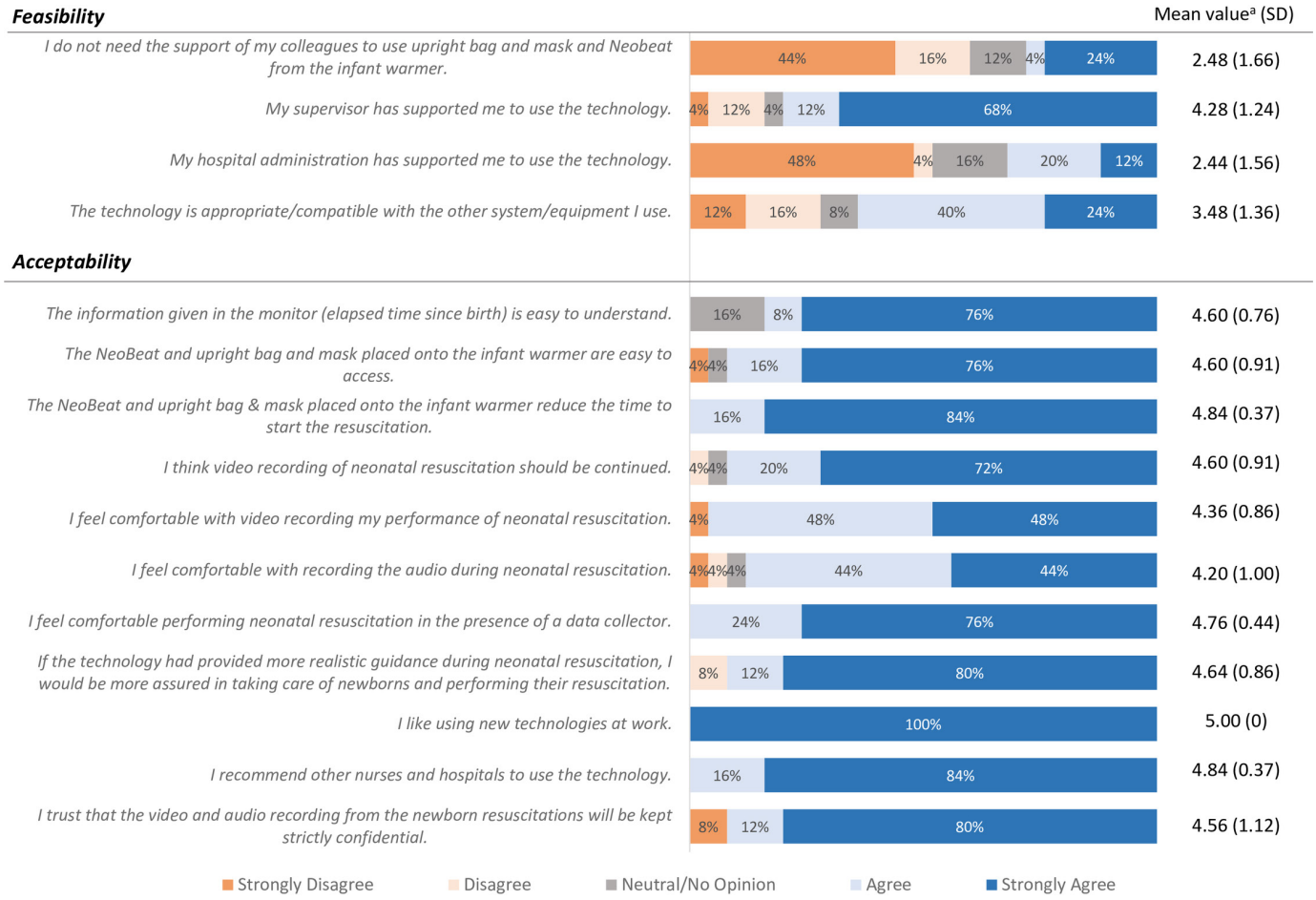

Figure 5 Healthcare providers feasibility and acceptability scores (N=25). [a]1=strongly disagree, 2=somewhat disagree, 3=neutral or no opinion, 4 somewhat agree, 5 completely agree.

continuous quality improvement support to build the capacity of all HCPs (n=30) to use the application.

In our study, HCPs felt relatively comfortable regarding audio and video recording during newborn resuscitation and felt that the audio and video recording for resuscitation should be continued. However, they also felt that if the technology had provided more realistic guidance during resuscitation, they would be even more confident to take care of the newborns. A similar study by Aude Le Bris and team showed that HCPs considered video to be useful and acceptable under certain prerequisite when assured with robust data protection and limiting potential negative impacts on healthcare professionals.[29]

During the study period, the HCPs felt that they received adequate support from their supervisors, while relatively less support was received from the hospital administration. The potential support that HCPs might have expected from the hospital administration could be providing proper infrastructure for setting-up the newborn resuscitation corner, support from medical technicians and staff who could best operate the technology, independently without any external support from the implementing partner. Hospital administration has a central role in the implementation success of any newly introduced intervention.[30 31] A multidisciplinary approach to engage the hospital administrator in introduction of new technology will help facilitate introduction of new intervention.[32]

A previous study done at a tertiary hospital in Nepal found that the staff did not adhere to newborn resuscitation guidelines.[33] During resuscitation, HCPs generally underestimate or are unable to track the passage of time, which might lead to ineffective resuscitation as they are unaware of the amount of time they have wasted in unnecessary drying, suctioning or stimulating.[34 35] Incorporating the MALA system in resuscitation can possibly demonstrate the potential benefits of technology as well as access of all necessary resuscitation equipment for improving the care . In 2021, the WHO provided a Standards-based, Machine-readable, Adaptive, Requirements-based and Testable (SMART) guidelines of using technological solution for improving service delivery and measurement of care.[36] The MALA technology development is in line with SMART guideline for improving service delivery and measurement.

There are number of limitations of this study. First, the feasibility and acceptability questionnaires were developed for this study, but their psychometric properties were studied. Second, most of the participants were nursing staffs working in the same unit of the hospital,

which might have influenced their opinions and perceptions regarding the technology. Third, our results could not be generalised to other institutions or countries as this was a single-site study with a small sample size in a low-resource setting. Lastly, since this pilot study evaluated usability, feasibility and acceptability of the first phase of the technology without real-time automated feedback, further iterative studies of the complete MALA system are warranted.

CONCLUSION

This study showed that the technology was acceptable, feasible and usable by the HCPs, providing rationale for continued development of the MALA system with the aim to provide automated real-time feedback based on machine learning technique. Further improvement in the technology for more advanced guidance is required through codesigning the technology together with HCPs and hospital managers. Availability of MALA technology with real-time guidance will reduce the cost of training, boost up the confidence of HCPs in performing and hence, improve the quality of care for newborns.

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Contributors AKC, HMyklebust and ØM-B conceptualised the study. SHH, ØM-B and ØG developed the technology. OB, HMalla and PB installed the technology in the hospital. RG, PB, YNB, OP, HS, OB and HMalla supervised the project implementation. SYJK developed the acceptability and feasibility tool and adapted the SUS tool. AA provided input to finalise the tool. PB and OB collected the health worker survey tool. AKC and PB developed the first draft. All other provided comment to the first version. AKC acceptes full responsibility for the work and had access to the data and controlled the decision to publish. All others agreed to the final version.

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Competing interests HMyklebust, ØM-B, SHH, ØG and SYJK are employed at Laerdal Medical.

Patient consent for publication Consent obtained directly from patient(s).

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Predicting emerging SARS-CoV-2 variants of concern through a One Class dynamic anomaly detection algorithm

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ABSTRACT

Objectives The objective of this study is the implementation of an automatic procedure to weekly detect new SARS-CoV-2 variants and non-neutral variants (variants of concern (VOC) and variants of interest (VOI)).

Methods We downloaded spike protein primary sequences from the public resource GISAID and we represented each sequence as k-mer counts. For each week since 1 July 2020, we evaluate if each sequence represents an anomaly based on a One Class support vector machine (SVM) classification algorithm trained on neutral protein sequences collected from February to June 2020.

Results We assess the ability of the One Class classifier to detect known VOC and VOI, such as Alpha, Delta or Omicron, ahead of their official classification by health authorities. In median, the classifier predicts a non-neutral variant as outlier 10 weeks before the official date of designation as VOC/VOI.

Discussion The identification of non-neutral variants during a pandemic usually relies on indicators available during time, such as changing population size of a variant. Automatic variant surveillance systems based on protein sequences can enhance the fast identification of variants of potential concern.

Conclusion Machine learning, and in particular One Class SVM classification, can support the detection of potentially VOC/VOI variants during an evolving pandemics.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Virus variants showing enhanced transmissibility, disease severity and other concerning characteristics arise during pandemics and they are usually detected by authorities after being isolated, and after their characteristics have emerged in a public health context.

WHAT THIS STUDY ADDS

⇒ We simulate an automatic variant surveillance system based on anomaly detection, able to detect a new variant as outlier based on its protein sequence.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Automatic variant surveillance systems can support the fast identification of new variants of concerns and variants of interests, thus prioritising interesting sequence variants for target laboratory testing.

INTRODUCTION

The ongoing pandemic caused by SARS-CoV-2 has seen the progressive emergence of different virus variants. The Centers for Disease Control and Prevention (CDC) has classified existing SARS-CoV-2 lineages into neutral variants, variants of interest (VOI) and variants of concern (VOC).[1]

VOI are variants with specific genetic markers that have been associated with receptor binding change, reduced neutralisation by antibodies and efficacy of treatments, potential diagnostic impact, predicted increase in transmissibility or disease severity. VOCs, on the other hand, are variants that, in addition to the possible attributes of a VOI, show impact on diagnostics, treatments or vaccines, interference with diagnostic test targets, substantially decreased susceptibility to therapies and neutralisation by antibodies, reduced vaccine-induced protection from severe disease, increased transmissibility or disease severity. A fourth classification, variants of high impact, is dedicated to variants more dangerous than VOCs, but none of the existing variants has been classified as such so far. Examples of VOCs are Alpha, Beta, Delta and Omicron.

Virus variants are classified after being isolated, and after their characteristics have emerged in a public health context, for example, enhanced transmissibility. For this reason, the countermeasures are always implemented after a variant is known, that is, the virus always has the upper hand in the arms race against the variants. Consequently, recognising a VOI or VOC as early as possible is utterly important to curb its damage, and ultimately save lives.

The virus protein sequences collected over the world are continuously deposited in the GISAID database, which was created in 2008 to promote influenza data sharing.[2] GISAID is an example of informatics infrastructure

implemented before the COVID-19 pandemic. It was of great importance to manage and monitor the COVID-19 emergence in the last 2 years.

Along with suitable strategies to collect and store the data, machine learning (ML) techniques have been extensively applied to analyse COVID-19 data.

Few studies are focused on variant-related predictions, for example, in isolating critical amino acid (AA) positions (or patterns) in the spike protein,[3] or in forecasting novel variant potential waves.[4] Importantly, these studies need input genomes that have already been isolated, that is, do not provide a viable method to generate novel genomes that could carry unknown but potentially dangerous variants. Of note, the Pango lineages framework has a specific ML module (PangoLearn).[5] This module implements two simple ML approaches, decision trees and logistic regression, to classify unknown viral genomes into Pango lineages. The models are based on positional (alignment-dependent) features, and are limited to predicting known classes, that is, they can only predict known lineages.

To detect VOCs from their competitions with other variants, Zhao *et al* developed VOC-alarm, a statistical method based on the concept of mutational entropy.[6] Authors defined the mutational entropy of a variant as a measure of the change of the mutation numbers across the globe for a lineage in a specific time period. In their analysis, Zhao *et al* noticed that some VOCs, such as Alpha, Delta and Omicron, grew from a small population and, as VOCs emerge, competing variants in precedent lineages decrease in population size.[6] The concept of spreading mutations within a time window was also studied by Maher *et al*.[7] A combined methodology was proposed by Makowski *et al* to evaluate single mutations in the spike proteins, based on two ML models, one to predict the impact of receptor binding domain mutations on ACE2 affinity and the other predicting human serum antibody affinity.[8]

Different from the aforementioned approaches, here we propose an ML method to timely predict the variants of concern as they are sequenced, without relying on information that needs to be collected over a period of time, such as changes in population size. That is, we develop an algorithm predicting each variant as being an 'anomaly' or not, using only the spike protein sequence, and ideally before the variants spread enough to manifest their related phenotypes—in other words ahead of their official classification. In recent work, we simulated the implementation of a pandemic surveillance classifier that predicts new non-neutral variants (VOCs and VOIs) monthly. Our system simulates a monthly update of a binary classifier with the new variants detected using supervised incremental learning.[9] Incremental learning algorithms are able to incorporate new knowledge without a complete retraining of model parameters.[10] For this reason, they can aid in evolving situations, such as during a pandemic. Yet, our incremental learning system assumes that the ground-truth class (neutral or non-neutral) for each variant is soon available at the end of the month. In the real case, this assumption does not always hold: for instance, the first Alpha sequence lately labelled as VOC was deposited in GISAID in late July 2020, while the Alpha variant was officially recognised as VOC by CDC only in late December of the same year.[1]

Here, we simulate the implementation of a pandemic surveillance classifier based on anomaly detection. Viruses continuously replicate, and during replications new types of variants that differ from the underlying population can arise. Detected anomalies can be new non-neutral variants. Briefly, we assume that we are in a peak state (in the space of spike protein sequences) when a specific variant is dominating the landscape, and the forthcoming of a new variant can be an *anomaly* that changes the state. Details of our proposed methodology can be found in the 'Methods' section. We will then evaluate the performance of our approach by comparing when our classifier predicts a known VOC/VOI as anomaly (in terms of date), with the date of designation as VOC by WHO as reported by the CDC. By predicting new virus sequences collected over time, the proposed approach can have the ability to raise a flag before to see variants are officially recognised as VOC/VOI by authorities.

METHODS

Dataset

Our dataset consists of spike protein primary sequences from GISAID collected from February 2020 to March 2022. We decided to focus on spike protein sequences because VOC and VOI lineage classifications are based on mutations in spike proteins; moreover, by only focusing on the spike 1350 AAs, we limit the feature space (as opposed to considering all the SARS-CoV-2 proteins). After removing duplicated sequences, we filtered the spike proteins based on both the frequency of uncharacterised AAs, set to a maximum of 1%, and length, set to a minimum of 1000 AAs. From GISAID, we downloaded metadate with various information, such as variant type ('unknown', 'Alpha' and so on) and date of submission for each sequence.

Feature representation

We translate protein sequences into a fixed-length set of numeric features through k-mers, so that each protein, independently from its length, will have a numeric representation. K-mers are a classical method to represent biological nucleic or AA sequences, widely used in bioinformatics.[11] Briefly, k-mers are substrings of user-defined length k contained in a sequence. For example, given k=2, we find in the sequence GATTACA the k-mers 'GA', 'AT', 'TT', 'TA' and 'CA'. Each k-mer has a Boolean value indicating its presence/absence. Since we wanted to represent variations of one to few AAs, we considered small ks, that is, k=3. We removed k-mers containing the 'X' character, indicating a missing value.

Variant surveillance implementation strategy

To simulate the implementation of the variant surveillance system, we hypothesised that in the last week of

Table 1 List of VOCs and VOIs and their date of designation according to the CDC and WHO

Variant name	Class	Date of designation according to the CDC and WHO
Alpha	VOC	29 December 2020
Beta	VOC	29 December 2020
Gamma	VOC	29 December 2020
Epsilon	VOI	26 February 2021
Iota	VOI	26 February 2021
Zeta	VOI	26 February 2021
Kappa	VOI	07 May 2021
Theta	VOI	24 May 2021
Lambda	VOI	04 Jun 2021
Delta	VOC	15 Jun 2021
Mu	VOI	30 Aug 2021

CDC, Centers for Disease Control and Prevention; VOC, variants of concern; VOI, variants of interest.

June 2020 a sufficient number of sequences that met our requirements were found in GISAID. In fact, 347 neutral variants were collected and we started the training process on these data. Moreover, to reduce the number of features (k-mers), we removed k-mers with zero counts in all the training sequences. This filtering step left us with 1922 k-mers. Subsequently, at each week, we collected the sequences from GISAID and the trained one class classifier predicted whether there are outliers (ie, non-neutral variants) among the new sequences. Starting from the predictions made each week, we calculate the confusion matrix weekly, where the negative samples (inlier) represent neutral variants, while positive samples (outlier) are VOC/VOI variants. Each week, it is evaluated whether in that week authorities recognised a new VOC or VOI, as reported in table 1. If so, the one class classifier is retrained on that week with all the sequences (1) in the initial training set and (2) the sequences that were predicted as inlier (ie, neutral) up until that week. A schematic representation of our training and test strategy is shown in figure 1. The classifier is developed using the implementation available in scikit-learn,[12] in particular by using the One Class support vector machine (SVM). SVMs are early examples of supervised ML approaches applied to binary problems. To detect a possible non-linear decision boundary between two classes, SVM projects the data into a non-linear higher dimensional space by using a non-linear function. In such higher dimensional space, the data points belonging to the different classes are separated by a hyperplane that determines the margin between the two classes. One Class SVM is an adaptation of the binary SVM applied to novelty detection.[13] In this case, the algorithm tries to separate the data points from the origin of the higher dimensional space. By doing so, the One Class SVM captures regions in the input space

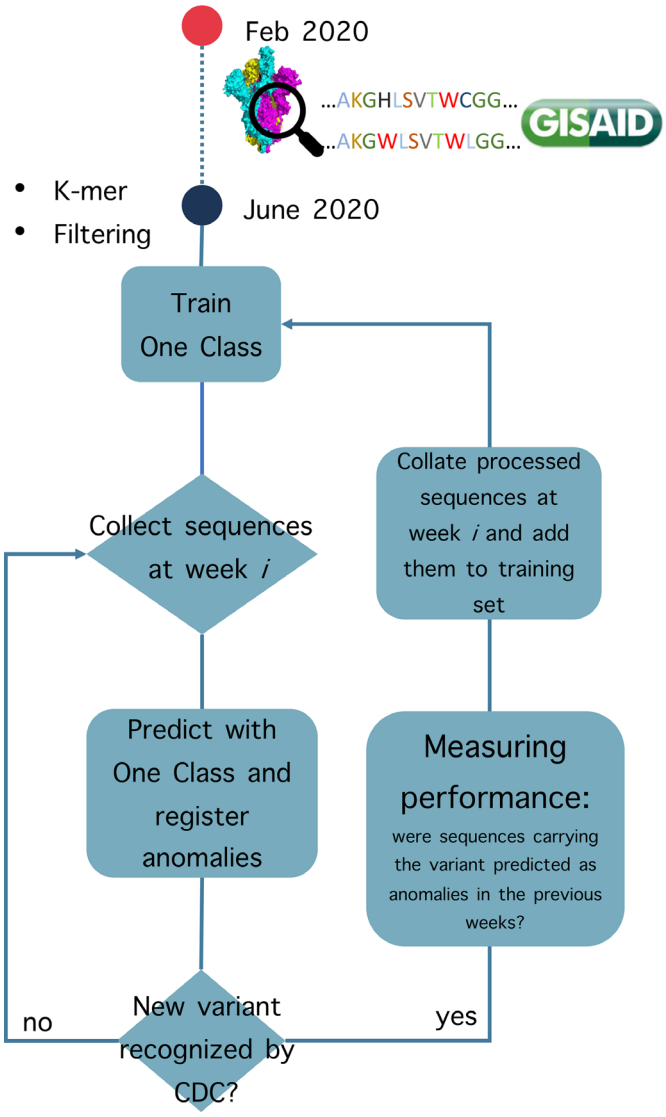

Figure 1 Schematic representation of automatic variant surveillance system. SARS-CoV-2 amino acid sequences deposited in GISAID from February 2020 to June 2020 are collected, transformed into k-mers and filtered. The anomaly detection system (One Class support vector machine (SVM)) is trained on this set of neutral variants. Then, at each following week, the newly uploaded sequences are predicted as either outlier or not. Predicted outliers are registered as anomalies. If authorities have recognised a new variants of concern (VOC)/variants of interest (VOI) in that week, the model is tested by evaluating whether the newly recognised VOC/VOI has already been predicted as an outlier by the One Class SVM in the previous weeks. CDC, Centers for Disease Control and Prevention.

with different data density. One of the parameters that needs to be selected is the variable ν, that characterises the upper bound on the false positive (FP) fraction (training samples considered as outlier) and the lower bound on the number of training samples used as support vectors. In our implementation, we tested different combinations of SVM parameters. Based on the performance, from now on we will refer to the One Class SVM with non-linear kernel (radial basis functions) and low ν (0.01), which

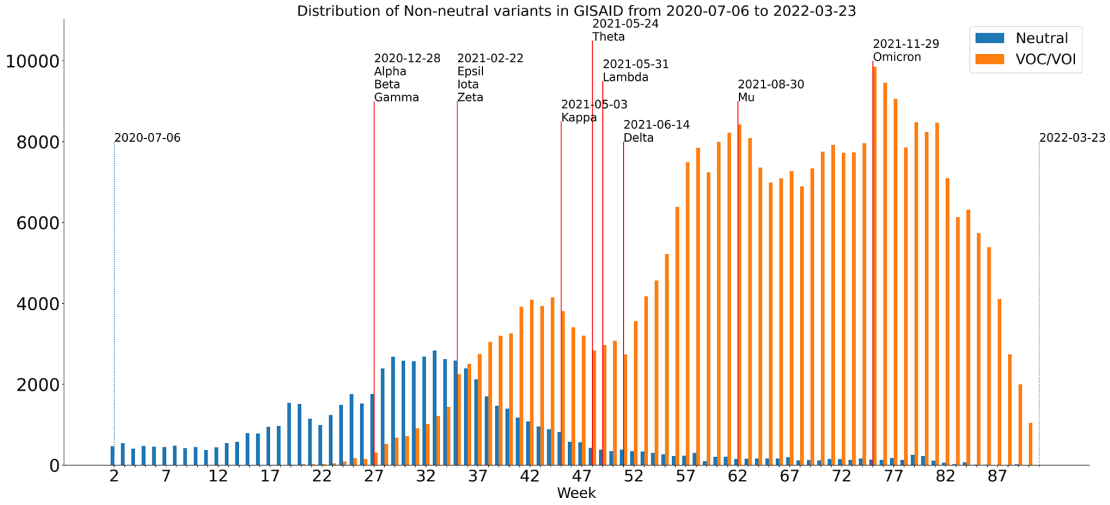

Figure 2 Number of neutral and non-neutral variants (VOC/VOI) for each week starting from 26 July 2020 to 23 March 2022. Red vertical lines indicate when a new variant was officially recognised as VOC/VOI according to the Centers for Disease Control and Prevention and WHO. VOC, variants of concern; VOI, variants of interest.

regulates the number of training samples that are allowed to be wrongly classified as outliers.

To evaluate the model's performance, we took into account the properties that a variant surveillance system should have to be useful in a realistic scenario. First of all, the problem can be highly imbalanced, and the imbalance rate varies across time (figure 2). Each week, new sequences to be predicted are made available. In a simulation of a real case scenario, each week we predict each newly sequenced sample, and the predicted outliers (ie, VOC/VOIs) are sent for further laboratory analysis that would eventually confirm whether or not each predicted-outlier variant is VOC/VOI. Since laboratory testing is time-expensive and costly, we would ideally send as few samples as possible to be analysed to reduce laboratory burden. For this reason, the cost of having a high number of false negatives (VOC/VOIs predicted as inliers) is lower than the cost of having a high number of FP (neutral variants predicted as outlier).

For these reasons, we evaluated our model in terms of the ability to detect at least one true VOC/VOI before the actual authority's recognition and the number of predicted outliers. As far as performance metrics are concerned, we thus focus our attention on precision, which is calculated as the number of truly identified outliers (true positive (TP)) divided by the total number of predicted outliers (TP+FP).

RESULTS

Dataset

Figure 2 shows the number of sequences collected, stratified by the class (neutral or VOC/VOI). For each VOI/VOC, the week containing the designation date by authorities is reported. As we can see, the number of sequences deposited in GISAID increased over time, starting from a few hundreds and reaching up to 10 000 in a week in late 2021. Moreover, while in the first year of pandemics the majority of sequences were neutrals, starting from March 2021 the number of non-neutral variants overtakes the number of neutral variants.

Automatic variant surveillance

Figure 3A and Figure 3B show the number and percentages of predicted outliers each week. As we can see, the percentage of predicted outliers varies, starting from 3.6% at the first week (17 predicted outliers out of 471 variants). The maximum number of predicted outliers occurs in week 60 (1095 predicted outliers out of 8201 sequences, 13.3%). The maximum percentage of predicted outliers is 21%, while the median value is 8%. Another important aspect to evaluate is the number of FP, that is, neutral variants that were incorrectly labelled as outliers, since a high number of FP will eventually increase laboratory burden. As we can observe from figure 3C, the number of FP is relatively low, with a maximum of 257 in week 35, corresponding to the 10% of the total number of neutral sequences analysed that week. In median, 9% of the neutral sequences are predicted as outliers (FP) each week. The ability to maintain low number of FP can be evaluated also from the precision (online supplemental table S1). As we can see from online supplemental table S1, the classifier initially strives to detect TP sequences, but as time passes the precision grows fast until it saturates towards >98%.

Regarding the ability of our variant surveillance system to detect a new VOC/VOI as soon as possible, figure 4 reports, for each known variant type reported in GISAID data, the first time that the One Class classifier predicts at least one sequence of that type (red rhombus) and the actual time of designation by authorities (blue circle). As we can see, for all the variant types except for the Gamma, the classifier was able to detect at least a sequence of that type as outlier before the official designation. Gamma was recognised by the classifier in the same week of the official designation.

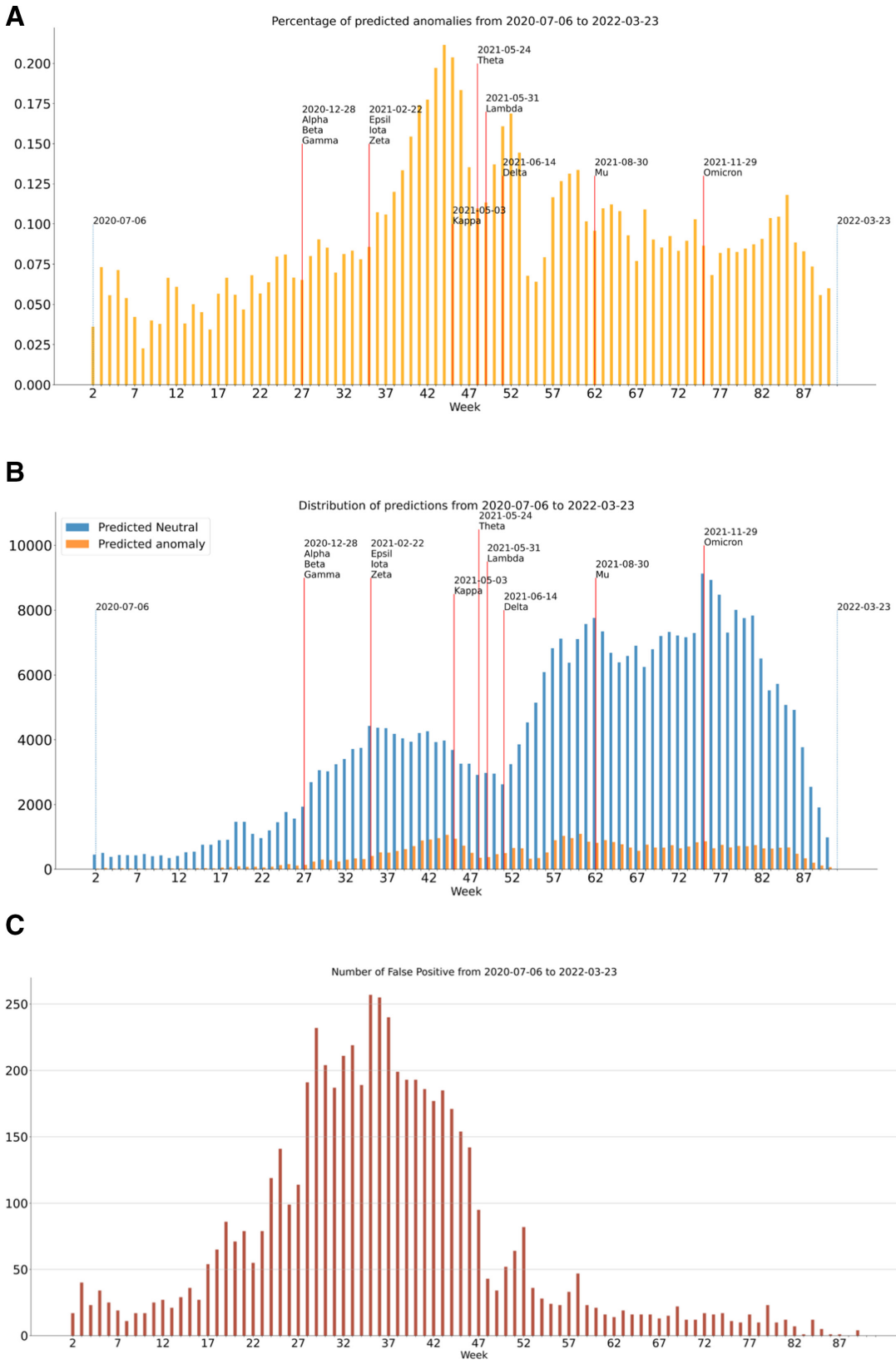

Figure 3 (A) Percentage of predicted outliers each week. (B) Number of predicted inlier and outlier each week. (C) Number of false positives, that is, neutral variants predicted as outliers.

The Alpha and Beta variants were recognised 8 and 7 weeks before, respectively. The Epsilon and the Kappa variants were detected 13 weeks before, while Iota was detected 6 weeks before. Zeta was identified 12 weeks before. Theta was recognised 8 weeks before. Lambda and Delta were detected 20 weeks before, Mu 21 weeks

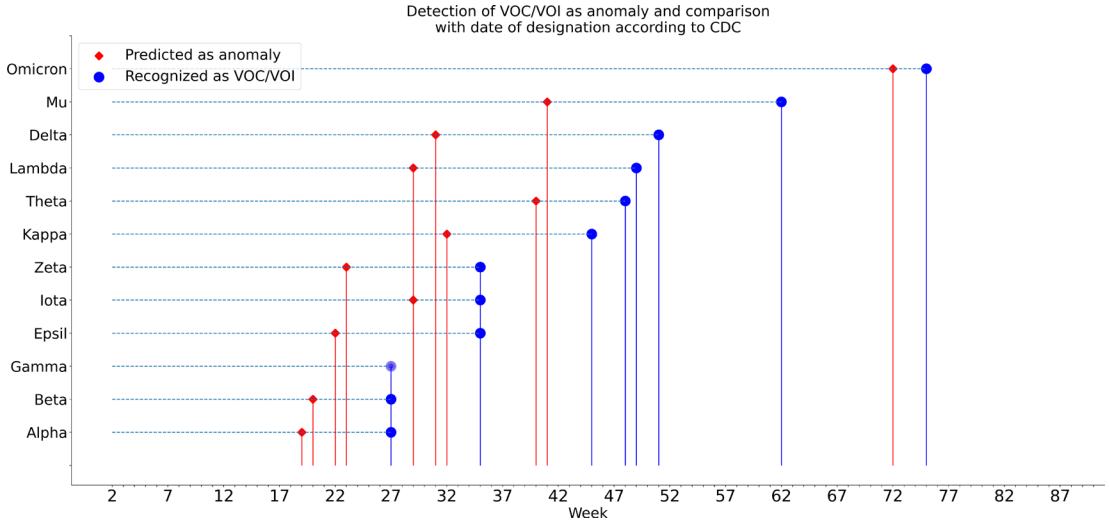

Figure 4 For each variant type, the red rhombus indicates the first time that machine learning detects a variant as an outlier, while the blue circle indicates when the variant was officially recognised by authorities. For the Gamma variant, the week of detection by machine learning overlaps with the official recognition date. CDC, Centers for Disease Control and Prevention; VOC, variants of concern; VOI, variants of interest.

before and Omicron 3 weeks before. In median, a VOC/VOI was recognised as outlier 10 weeks before.

DISCUSSION

During a pandemic caused by viruses such as the SARS-CoV-2, detecting new variants and understanding their effects as soon as possible is of paramount importance. Computational methods, such as ML, can highly support variant surveillance by uncovering patterns embodied in the huge amount of data that can be collected.[14] We used the information encoded in spike protein sequences to spot anomalous variants. We show that our framework can be used in a real case scenario to select the most concerning variants (predicted as outlier by the anomaly detection system) for further laboratory testing to assess their potential harm even before they spread.

The development of ML tools for variant surveillance poses different challenges. First of all, a proper numerical representation of the protein AA sequences needs to be established. We chose to represent each protein with short k-mers. This simple representation proved to be effective in several proteomics and genomics problems.[11 15 16] Unlike previous work,[6] we only used patterns encoded in the AA sequences to predict non-neutral variants, without relying on information collected over time, such as changes in variant population size. As a result, our proposed system allows for the timely identification of non-neutral variants as soon as they are sequenced.

Second, the problem is highly imbalanced, and the number of sequences exponentially increases over time (figure 2). Additionally, the class composition varies: at the beginning, all deposited variants are neutral, while from 2021 the most competing variants, that is, VOCs and VOIs exceed the number of neutrals. This situation is a clear example of dataset shift, which often occurs in healthcare.[17 18] Thus, a variant surveillance system needs to be able to adapt over time as the variant population changes. To do so, in a previous work we employed a binary incremental ML classifier, able to partially refit and consequently to update, the ML model over time.[9] Yet, to achieve acceptable performance, we assume that the true class of variants (neutral vs non-neutral) was soon available at the end of each time step. To develop a more realistic system, here we propose to use One Class classification, in which the aim is to detect outliers, that is, instances that deviate from the normal population. Thus, we were able to train a classifier when zero non-neutral variants emerged, and the system identified deviations from the neutral population over time. To dynamically update the model, we decided to retrain the classifier when a new ground-truth classification was available, that is, when WHO officially recognises a new variant as VOC/VOI. At a given time step, the retraining is performed by using the initial training dataset plus the predicted inlier variants collected up until that time. This means that the classifier is retrained using also false negative variants, that is, VOC/VOI that were not predicted as outliers. As a matter of fact, using VOC/VOI as belonging to the inlier population does not affect the outcome of our procedure: we are not interested in predicting *many* (ie, the majority) of VOC/VOI as outliers, but we are interested in detecting few outliers that can be experimentally studied. Additionally, this retraining assumption allows the classifier to progressively predict less outliers for a given variant type that had emerged later in time, thus reducing the laboratory burden on variants that were already detected as outliers in the previous weeks. In fact, as we can see in online supplemental figures, the distribution of the predicted anomalies stratified by variant types showed that the number of predicted outliers is progressively decreasing after the peaks.

This work represents a proof-of-concept to show the feasibility of this apparently complex task with a simple feature representation (k-mers) and a solid ML algorithm (SVM). We recognised that other implementations, both for feature representation and prediction, can be applied to deal with this problem. For instance, deep learning, which is increasingly applied in a variety of fields, may be used in this case both for feature representation, through protein embedding,[19] and as a predictive model for anomaly detection. In a recent work,[20] authors analyse the features (in terms of mutations) of SARS-CoV-2 genomes, and map them on a Bayesian model to predict fitness. This approach can be complementary to our unsupervised model, which is focused on *predictions*, that is, through the spike protein, if a new genome carries a novel, unseen VOC/VOI. The work of Obermeyer *et al*, on the other hand, focuses on supervised *interpretation* of mutation important for the virus fitness, considering the whole genome, thus providing mechanistic insight. Future steps in our analysis can be inspired by this approach, for example, extracting k-mers (or k-mer modules) from the whole genome instead of only focusing on spike proteins, or using a supervised, white box approach to extract key features marking the making of novel VOC/VOI.

Conclusion

We have implemented an automatic variant surveillance system that exploits One Class classification to detect new potential VOC/VOI SARS-CoV-2 variants by evaluating the spike protein sequence. We evaluated the system ability to recognise a VOC/VOI as outlier before the official recognition by authorities. The classifier was able to detect a VOC/VOI with a median 10 weeks before, thus showing the potential utility of data-driven approaches to virus variant detection.

Contributors GN carried on the experimental study and drafted the paper. SM contributed to the design and implementation of the experimental study and to the paper drafting. MS discussed the main ideas behind the research work and revised the manuscript. RB coordinated the research, contributed to the design of the experimental study and revised the manuscript. SM acceptes full responsibility for the work and had access to the data and controlled the decision to publish.

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Competing interests GN is a full employee of Engenome s.r.l. RB is shareholder of Engenome s.r.l. and Biomeris s.r.l.

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Data availability statement Data are available in a public, open access repository. Data are available in the GISAID repository: https://gisaid.org/.

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Twenty-first century house calls: a survey of ambulatory care providers to inform organisational telehealth strategy

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ABSTRACT

Objectives While patient interest in telehealth increases, clinicians' perspectives may influence longer-term adoption. We sought to identify facilitators and barriers to continued clinician incorporation of telehealth into practice.

Methods A cross-sectional 24-item web-based survey was emailed to 491 providers with ≥50 video visits (VVs) within an academic health system between 1 March 2020 and 31 December 2020. We quantitatively summarised the characteristics and perceptions of respondents by using descriptive and test statistics. We used systematic content analysis to qualitatively code open-ended responses, double coding at least 25%.

Results 247 providers (50.3%) responded to the survey. Seventy-nine per cent were confident in their ability to deliver excellent clinical care through VV. In comparison, 48% were confident in their ability to troubleshoot technical issues. Most clinicians (87%) expressed various concerns about VV. Providers across specialties generally agreed that VV reduced infection risk (71%) and transportation barriers (71%). Three overarching themes in the qualitative data included infrastructure and training, usefulness and expectation setting for patients and providers.

Discussion As healthcare systems plan for future delivery directions, they must address the tension between patients' and providers' expectations of care within the digital space. Telehealth creates new friction, one where the healthcare system must fit into the patient's life rather than the usual dynamic of the patient fitting into the healthcare system.

Conclusion Telehealth infrastructure and patient and clinician technological acumen continue to evolve. Clinicians in this survey offered valuable insights into the directions healthcare organisations can take to right-size this healthcare delivery modality.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The delivery of telehealthcare rose exponentially during the COVID-19 pandemic. However, providers' preparedness to deliver telehealthcare was uneven.

WHAT THIS STUDY ADDS

⇒ We identified variations in the experience and expectations of video visits of cross-specialty providers along with three main themes from qualitative analysis: infrastructure and training, usefulness and expectations.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ These findings have implications for how healthcare systems, clinicians and patients can best move forward with organising and delivering care augmented by technology.

BACKGROUND

Despite the exponential growth in telehealth services and surge in telehealth research during the public health emergency (PHE) related to the COVID-19 pandemic, the challenges of telehealth persist, limiting its adoption into routine care.[1] A recent industry report[2] highlighted an enthusiasm gap between patients and clinicians concerning ongoing telehealth usage, with patients reporting higher convenience, satisfaction and desire for continued telehealth usage than physicians.[2 3] Patients are also more interested in expanding virtual care to include more digital-first healthcare services.[4] Cost savings, ease of use and previsit training were top drivers of patients' satisfaction with telehealth.[4 5]

When surveyed, specialty clinicians' perceptions of telehealth are mixed concerning clinical efficacy, patient satisfaction, access to care and financial sustainability.[6 7] While previous literature recognises important considerations for the future of telehealth, including specifying appropriate services, identifying needed operational changes and technical infrastructure,[1 4 8] few studies have

incorporated cross-specialty clinicians' perspectives for moving forward in telehealth services.[9]

Like others,[10] our health system rapidly implemented telehealth capabilities in 2020 out of necessity for providing care. Clinicians received instruction through prerecorded videos walking through workflows and ti sheets. The failure rate for video visits (VVs), defined by either a shift to audio-only phone calls or a same-day cancellation, was tracked, and additional technical options and support were provided. Towards the end of 2020, platform stability had improved, and workflows matured, having both an electronic health record (EHR)-connected option (patient self-arrives through the patient portal) and an EHR-agnostic option (medical assistant calls patient for virtual rooming, and a text link is sent to the patient to join the visit) that clinics could opt to use.[11] Access to care from a health equity lens was monitored, and audio-only visits were scheduled with those patients unable to access the video.[12]

This study aimed to assess ambulatory care clinicians' perspectives of telehealth services in a health network during the COVID-19 pandemic to understand what factors led to relative success with adopting telehealth. We sought to understand clinicians' preferences, self-assessed capabilities and concerns and to identify salient themes of the clinician experience for future improvement work.

METHODS

Design, setting and study participants

We conducted a mixed-method deductive simultaneously designed study[13] using data from the survey combined with provider credentialling information. Qualitative survey data contextualised these quantitative data to understand clinicians' insights into telehealth's unique benefits and challenges and forecast the future of telehealth. Telehealth (ie, video-based and audio-based) visits were introduced at the academic-community health network in 2018. The network provides 1.5 million ambulatory visits and cares for 55 000 hospitalised patients annually. The health network operates 45 clinic locations in the southeastern Wisconsin. During the PHE (approximately 1 March 2020), video-based visits expanded quickly to all specialties, clinics and providers. VVs were encouraged as the primary means; audio visits occurred if patients had a strong preference or could not access VV. During the rapid expansion of telehealth visits, providers experienced a wide variation in VV's success and failure rates.[11] After stay-at-home orders were lifted in June 2020, patients and clinicians scheduled VVs at their mutual discretion.

For this analysis, we recruited via email practising providers (physicians, physician assistants, and advanced practice registered nurses) who performed ≥50 telehealth encounters (93% of the eligible clinicians), including medical and counselling services, from 1 January 2019 to 31 December 2020. Up to three reminders were sent to non-respondents. Clinician responses were linked to their provider record and then deidentified to analyse how clinicians' characteristics (eg, age, gender and specialty) influenced perspectives. There was a lottery for a nominal gift card, approximately 1/10, for a maximum of $50.

Survey

We developed a 24-item web-based survey assessing provider characteristics and sociotechnical aspects of healthcare delivery through telehealth. The survey was derived from the Consolidated Framework for Implementation Research (CFIR).[14] CFIR provides a practical guide for systematically assessing constructs associated with effective implementation.[14] We assessed the domains of intervention characteristics, outer setting, inner setting and individual characteristics using multiple choice, multiple selections and open-ended text responses (online supplemental material).

Statistical methods and data analysis

We summarised respondents' demographic and clinical characteristics using descriptive statistics and Fisher's exact test for categorical variables because more than 20% of the cell expected numbers were less than 5. The proportion of missing data was small enough (0.4%) that we analysed complete data only. We completed a systematic content analysis[12] to code open-ended survey responses qualitatively to enhance quantitative findings. Trained research team members (JMH, RC, NM and NW) independently coded the qualitative data with at least 25% double coding. The research team frequently met to create the codebook, ensure coding agreement, discuss discrepancies and reach a group consensus on final themes.

RESULTS

Eligible providers (n=491) were contacted by email to participate; 247 (50.3% response rate) completed the electronic survey. Most respondents were female (59%, n=136), non-Hispanic (96%, n=215) and white (81%, n=186), with an average age of 46 years (SD=10, range: 21–90; see table 1).

Quantitative results

Seventy-six per cent of respondents were at least moderately confident in their clinical ability to perform VV. However, less than half (48%) were at least moderately confident in their skills to troubleshoot technical VV challenges. Confidence in troubleshooting technical challenges varied by age, with younger clinicians (28–39 years) being more confident in troubleshooting technical challenges than older clinicians (60–78) (63% vs 41%, p=0.044).

While 90.1% of respondents expressed concerns about VV, the concerns varied by specialty. For example, internal medicine and primary care providers' top concern was the inability to complete a physical exam,

Table 1 Characteristics of respondents (total N=247)*

Characteristics	N (%)
Age (years)	
28–39	63 (26)
40–49	77 (31)
50–59	46 (19)
60–78	27 (11)
Unknown	34 (14)
Race	
White	186 (75)
Asian	23 (9.3)
Black/African–American	5 (2.0)
Other	18 (7.3)
Unknown	15 (6.1%)
Gender	
Female	136 (55)
Male	84 (34)
Other	12 (4.9)
Unknown	15 (6.1)
Provider role	
DO/MD/DPM	169 (68)
APNP/PA/PA-C	78 (32)
Provider specialty	
Anaesthesia and pain management	4 (1.6)
Behavioural health	17 (6.9)
Dermatology	4 (1.6)
Gynaecology	15 (6.1)
Internal medicine subspecialty	80 (33)
Neurology	15 (6.1)
Primary care	48 (20)
Radiology	2 (0.8)
Rehabilitation	3 (1.2)
Surgery	58 (24)
Unknown	1 (0.4)*

*1 missing observation.
APNP, Advanced Practice Nurse Prescriber; DO, Doctor of Osteopathic Medicine; DPM, Doctor of Podiatric Medicine; MD, Doctor of Medicine; PA, Physician's Assistant-Certified; PA, Physician's Assistant.

whereas behavioural health providers' chief concern was reimbursement. The top three concerns across specialties were the inability to complete a physical exam, failure to diagnose and fitting telehealth visits into the workflow (figure 1).

Ninety-six per cent of clinicians agreed that training offered by the organisation was useful, with a tip sheet being the highest endorsed learning tool (38%). Fifty-six per cent of respondents estimated that they could effectively care for up to 39% of their panel via VV. This varied

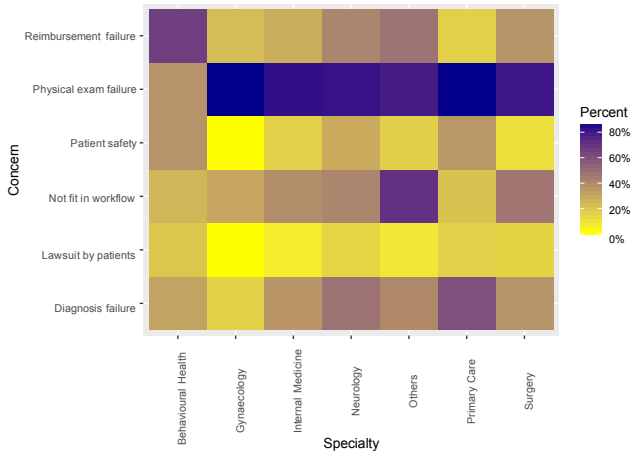

Figure 1.
Heatmap of Video Visit Concerns by Specialty

Figure 1 Heatmap of VV concerns by specialty in response to the survey question 'What concerns do you have regarding VVs? Check all that apply' (unable to complete a physical exam, malpractice lawsuit, patient safety, state liability, failure to diagnose, reimbursement, fitting into workflow, other (open text response), I do not have any concerns). Most (90.1%) respondents expressed concerns about VVs; the concerns varied by specialty. The purple colour represents a higher percentage of respondents that expressed a particular concern by specialty. The yellow colour represents a lower percentage of respondents that expressed a specific concern by specialty. For example, most specialty providers' top concern was the inability to complete a physical exam (81.5%), except for behavioural health providers whose chief concern was reimbursement (65%). The top three concerns across all specialties were the inability to complete a physical exam (74.9%), failure to diagnose (36.7%) and fitting telehealth visits into the workflow (37.6%). VV, video visit.

by specialty (p<0.001), with 71% of behavioural health clinicians endorsing that they can effectively care for 60%–100%. Clinicians across specialties generally agreed on the benefits of VV, including reducing infection risk (71%), travel time (70%), travel distance (78%) and transportation barriers (71%) (see table 2).

Qualitative results

Of the 247 respondents, 218 provided responses to at least one of the 11 open-ended response options. We inductively developed 55 unique codes, which were used 1512 times. Different themes emerged based on the question, with three significant themes overarching the qualitative data, including (1) infrastructure and training, (2) usefulness, and (3) expectation setting for patients and providers. We matched each quote to the respondent's primary department affiliation (see table 3).

Infrastructure and training

The qualitative data aligned with the connection challenges that clinicians reported quantitatively, such as 'having to troubleshoot on both sides and not connecting, which takes up over half of the visit' (primary care). Respondents offered solutions to this frequent problem,

Table 2 Clinician survey responses by specialty

Characteristics*	Primary care n=48	Internal medicine subspecialty n=80	Behavioural health n=17	Surgery n=58	Gynaecology n=15	Neurology n=15	Others n=13	P value*
Confidence caring for patients via VV, n (%)								0.156
≥Moderately confident	33 (70)†	63 (79)	16 (94)	40 (74)	14 (93)	12 (80)	10 (77)	
Confidence troubleshooting technical challenges, n (%)								0.155
≥Moderately confident	19 (40)	38 (48)	8 (47)	27 (47)	12 (80)	8 (53)	4 (31)	
Percentage of encounters effective via VV, n (%)								0.005
0%–19%	15 (31)	24 (30)	0 (0)	6 (46)	10 (67)	3 (20)	18 (31)	
20%–59%	28 (58)	37 (46)	5 (29)	30 (52)	5 (33)	7 (47)	4 (31)	
60%–100%	5 (10)	19 (24)	12 (71)	10 (17)	0 (0)	5 (33)	3 (23)	
Percentage of encounters effective via audio visit, n (%)								0.093
0%–19%	37 (77)	50 (62)	8 (47)	31 (53)	12 (80)	10 (67)	8 (62)	
20%–59%	8 (17)	24 (30)	6 (35)	25 (43)	3 (20)	3 (20)	3 (23)	
60%–100%	3 (6.2)	6 (7.5)	3 (18)	2 (3.4)	0 (0)	2 (13)	2 (15)	
Desire more VV training, n (%)								NA‡
Any training	43 (90)	76 (95)	17 (100)	51 (88)	15 (100	13 (87)	13 (100)	
Troubleshooting	32 (67)	53 (66)	11 (65)	38 (66)	9 (60)	6 (40)	9 (69)	
Web etiquette	6 (12)	12 (15)	6 (35)	8 (14)	4 (27)	3 (20)	2 (15)	
EHR navigation	6 (12)	3 (3.8)	6 (35)	5 (8.6)	1 (6.7)	1 (6.7)	1 (7.7)	
VV clinical practice	13 (27)	11 (14)	3 (18)	7 (12)	2 (13)	3 (20)	6 (46)	

*Fisher's exact test.[31 32]
†n (%).
‡Note that the response was multiple choice.
NA, not available; VV, video visit.

suggesting that 'patients need some sort of practice environment to try out the visit prior to the visit' (internal medicine subspecialty). Clinicians also cited the impact of network connectivity. An internal medicine subspecialist stated that 'WiFi signal's somewhat spotty in my clinic space, choppy audio at times, and videos would sometimes freeze'. However, clinicians from other specialties shared alternative experiences that 'having access to reliable internet, my practice, actually helping some people follow-up regularly' (behavioural health).

Clinicians also remarked on discrepancies and gaps in the telehealth workflow versus in-person visits. For example, one clinician commented that their clinic lacked a 'clear role of nursing and support staff in virtual visits' (internal medicine subspecialty). Another clinician extended their recommendation to the previsit space, expressing, 'We need more effective clinic support including pre-visit effort to confirm technology and update information' (internal medicine subspecialty).

Usefulness

Clinicians endorsed various uses of telehealth in the quantitative portion of the survey that was supported and contextualised by the qualitative data. A clinician offered, 'Patients love the flexibility and convenience of VV. While we bring them in for particular needs, we can accommodate many follow-up visits of diagnostic testing review virtually' (surgery). They also valued the patient's support system, remarking, 'VV have made it possible to include family/relatives into visits that may have been unable to attend otherwise' (gynaecology). One clinician noted the resolution of scepticism about the usability of telehealth, stating, 'Overall, the experience has been good. I have learnt that many of my patient visits can be done effectively over video' (internal medicine subspecialty).

Clinicians across specialties shared examples of their VV that they deemed appropriate. For example, VVs are 'wonderful for follow-up of patients on a stable medication regimen who live far away and just need a check-in periodically to review treatment' (primary care). A clinician from an internal medicine subspecialty suggested 'establishing new patients (which always requires a lot of talking), then being able to set up labs and have them come back for part two physical exam and follow up. [The] second in-person visit goes much more efficiently'.

Table 3 Representative quotes for qualitative analysis

Infrastructure and training	
What was the most difficult part of implementing virtual care (telephone or video)?	Please share your best experience with VVs.
► Lack of support from staff/IT when problems arise. I do not believe clinicians should have to do more than basic troubleshooting. (Primary are) ► Patient familiarity and ability to use technology. (Internal medicine subspecialty) ► Schedulers not being sure when to offer a virtual visit to established patients. (Surgery)	► Clear video and audio. [VV are] more efficient visit than in a clinic [visit]. (Primary care) ► Honestly when technology works on both sides without any troubleshooting. (Primary care) ► Talking to a 72-year-old [patient] through to getting on [the platform] and the joy of him talking with me (via video). (Internal medicine subspecialty)
Usefulness	
What was the most difficult part of implementing virtual care (telephone or video)?	Please share your best experience with VVs.
► It is exhausting to maintain alliances and interpersonal connections virtually. (Behavioural health) ► A limited number of issues are to be addressed without an office visit. (Primary care) ► We know that we are missing something in not having in-person contact. (Behavioural health)	► [Telehealth] allowed me to connect with patients in different ways than when they come to the clinic: seeing their pets, their homes, and other family members. They also saw me in a different light, more human, more approachable, and facing the same challenges. The video visit levels the playing field in terms of hierarchy compared to a clinic visit. (Internal medicine subspecialty) ► During a VV for obesity the patient was checking out at a grocery store and I asked to see what was in his cart. (Surgery)
Expectation setting for providers and patients	
Please share your worst experience with VVs.	Please share your best experience with VVs.
► Typically, when patients don't respect the visit as an actual doctor's visit. I've had patients driving, in Walmart, at the barber. In all of those instances, we had to reschedule the visits. (Surgery) ► Patients need help with setting up virtual visits and virtual visit etiquette, for example, choosing the proper location, lighting, etc. (Internal medicine subspecialty) ► Somehow get patients to understand and accept that a video visit cannot be conducted while other competing activities are going on at the same time. (Primary care)	► Often patients are "pleasantly surprised" with the ease of a VV visit and happy with the care/outcome of the visit. (Surgery) ► Multiple patients who initially expressed skepticism at the efficacy of a virtual visit commented that it met their needs at end of the visit. (Primary care) ► The feedback I receive from patients is that it's so convenient and my satisfaction with working from home when I have back-to-back virtual visits. (Surgery)

VV, video visit.

Changes in the model of care delivery also benefited patients, 'by far, in dermatology, this has streamlined acne, rosacea, chronic med visits when physical exam doesn't rely on magnified exam of particular lesions' (dermatology). Clinicians also reported excellent patient satisfaction especially around the elimination of travel and transportation, 'patients are satisfied by not having to come to the hospital, especially those with transportation or mobility issues' (internal medicine subspecialty).

Clinicians' qualitative comments aligned with the concerns they endorsed in the quantitative portion of the survey, often citing that the inability to complete a physical exam hindered care. One clinician remarked, 'inappropriate patients being scheduled for VV when (they) needed an exam in-clinic to diagnose [the] condition' (surgery). Another shared how virtual care lacks elements of their values as a provider, 'I still believe the "touch and feel" is very important in caring for patients in most situations' (primary care).

Expectation setting for patients and providers

Clinicians identified examples of the types of inappropriate visits to conduct virtually. Several clinicians asked for organisational guidance regarding suitable visit types: exemplars include 'clear guidelines of appropriate patient type to use Virtual Care' (primary care); 'specific diagnoses [and] complaints allowed or disallowed for VV' (dermatology); and 'notify the patients what situations, VV would not be appropriate" (primary care).

A subset of clinicians expressed frustration with how patients engaged during VVs, noting the incongruent expectations of patients and providers. A clinician remarked, 'patients driving during the visit and when asked to pull over or get to a secure position due to risk of distracted driving, [the] patient became enraged. This was

on more than one occasion' (surgery). Another clinician expressed concern regarding the 'decreased control over environment and boundaries such as trying to connect with an elderly patient while a husband with dementia calling out loudly in the background and daughters interrupting every few minutes' (internal medicine subspecialty). However, some clinicians offered suggestions to improve patient–provider expectations as an example there should be 'standard messaging about safe practice during video visits - that is, no driving, need to be in a private space' (surgery).

DISCUSSION

In this survey-based study of 247 providers who had used telehealth in 2020, we identified variations in the experience and expectations of VV along with three main themes from qualitative analysis: infrastructure and training, usefulness and expectations. These findings could have implications for how healthcare systems, clinicians and patients can best move forward with organising and delivering care augmented by technology. A key question also emerges: if patients desire the convenience of virtual care but there are drawbacks, how should those decisions be adjudicated? We reflect on patient-centred care, how care may be organised differently and infrastructure changes encouraged by clinicians. Lastly, we briefly reflect on how our clinical organisation is moving forward with embracing virtual care while enabling clinical departments to determine how best to proceed.

Patient-centred care

Overall, clinicians generally felt comfortable with telehealth, signalling more could be done virtually with the appropriate and proper support. Clinical confidence was high among respondents, and 56% noted that they could see 39% of their patients virtually. This supports the growing trend of new modalities of care to continue to be built around the patient, wherever they are. However, not all clinicians agreed with the usability of telehealth and the ability to use technology to accomplish visits with effectiveness, efficiency and satisfaction in a care context. Undoubtedly, context is critical; facilitating the selection of the ideal medium of a visit—either in-person or mediated by technology—for patients and providers alike will ultimately be a key factor in integrating technology. The nuanced data indicate that organisations must take a customised approach to deploy telehealth across ambulatory care. Not all patients, clinical departments or diagnoses are appropriate for telehealth. For example, telehealth may be inappropriate for encounters when a hands-on physical examination is necessary to manage care.[15] Deciphering optimal telehealthcare will depend on the specialty,[16–18] making a one-size-fits-all approach untenable.

Clinicians lauded the insight gained via telehealth into a patient's life circumstances. Prior work[19] highlighted similar insights that previously *invisible* patient contextual factors came to light during telehealth visits. This was, however, at times uncomfortable. Clinicians reported patients taking telehealth visits in inappropriate settings (eg, while driving, in public) and at times citing that patients do not respect a VV as much as a doctor's in-person visit. Some ended the VV when patients refused to stop driving or were shopping. While this may be prudent for safety and privacy reasons, we reflect on the patient perspective. Patients may perceive the convenience of having a visit while completing other tasks as appealing, though we acknowledge that privacy within shared spaces may limit what can be shared. Telehealth creates new friction, one where the healthcare system must fit into the patient's life, rather than the usual dynamic of the patient fitting into the physician's office. Therefore, telehealth is pushing the boundaries of patient-centred care, and new improved measures of education on safety and training of practitioners to handle those non-traditional situations will be important.

Clinical care organisation

Telehealth creates several opportunities to change the care model. For example, clinicians identified how initial encounters, mostly history-taking and data review, could be done virtually and then shift to gaining objective data in subsequent in-person visits. Patient needs may be more effectively triaged using video, ensuring that patients present to the most appropriate level of care. Pharmacists, nurses and other care team members may leverage video to better relate to patients, reconcile medications and identify additional needs. Clinical organisations could optimise the unique benefits of telehealth to further their value-based care work or more appropriately use in-person care in fee-for-service contracts where access to providers is limited.

Respondents highly endorsed other important benefits of reducing infection risk, eliminating travel time and removing transportation challenges which can be very limiting for patients and providers.[20 21] Removing transportation as a critical step to seeing the provider may reduce health inequities by granting individuals access to the healthcare system regardless of their ability to commute.[22]

We identified through the survey areas where telehealth has opportunities to improve the work–life balance of clinicians. About half of our survey respondents identified that having clinic blocks where they could work from home was extremely important. Healthcare systems should find ways to organise care blocks to support flexibility, especially in current challenges facing healthcare workforce shortage,[23] and ensure that clinicians are adequately compensated for the telehealthcare they provide regardless of payment changes.

Infrastructure, workflow and training requirements

Telehealth infrastructure and patient and clinician technological acumen continue to evolve. Respondents noted technological hurdles (eg, unreliable platform and lack

of tech support) diminished the efficiency and effectiveness of care. In particular, clinicians had difficulties logging onto the VV platform and related technological issues. Many of the recent telehealth studies report similar technology-based challenges.[16 19]

Future directions of telehealth should focus on improving the user experience and reliability of the telehealth platforms,[24] developing a consistent workflow tailored by specialty and creating training, support and knowledge resources. Visit experience will be improved if patients are screened for reliable connectivity, access to devices, expectations of telehealth and ability to navigate the telehealth platform, with the option to switch to other modalities if any issue arises.[25 26] Other organisations have been using medical assistants and community health workers to conduct a previsit assessment before the first VV with a clinician to screen for digital literacy and subsequently improve the success of their VV.[25 27]

Clinicians in our study and elsewhere[9 17 19] reported they could benefit from additional telehealth training to understand what care works best in a virtual delivery format. Clinicians are used to being supported in the clinical setting by a multidisciplinary team (eg, medical assistants, nurses and social workers) but often lack such support in the virtual setting. The adjustments caused frustration among clinicians citing inefficiencies in the digital prearrival, check-in and rooming processes. Healthcare systems must create clinic protocols that incorporate a team to be effective and efficient in the virtual space.[28] Supporting patients capable of self-check-in may create inefficiencies and waste resources, however. Instead, there needs to be an adaptive process that enables patients to complete a self-check-in while 'catching' patients who need help getting connected.

Future directions

In our healthcare system, these data and the qualitative analysis have informed our planning, goal setting and investments in telehealth. For infrastructure, we have invested in redesigning the experience of VV to enable patients to complete the prearrival process independently when possible, making it more efficient for clinicians to conduct visits without needing an assistant. However, a core requirement was the ability to send a patient a direct link by text message for patients who need extra support. Workflows were redesigned to support these use cases.

We have set a practice target to increase our VV to meet patient expectations at the department level. A practice committee developed a playbook for departments to review and determine how they may best use telehealth. Importantly, we committed within the practice that if the reimbursement landscape changes, strategies and targets would be adjusted accordingly.

Limitations

Although this study provided telehealth insights from clinicians across ambulatory care specialties, limitations exist. We asked clinicians to reflect on their perceptions and experiences with virtual visits during the PHE. They may have recall bias,[29] where respondents' memories deteriorated and their ability to recall their perceptions and experiences diminished. The clinician population recruited was limited to one academic-community health network in the Midwest. However, the network includes clinicians practising in academic and community settings and rural and urban locations. Furthermore, most respondents identified as middle-aged white women, limiting the generalisability to more diverse clinician populations. In addition, the survey had a 50% response rate, which is at or better than typical clinician surveys;[30] however, we could not discern the characteristics of the non-respondents to evaluate for differences between them and the respondents. Moreover, the quantitative findings are unweighted frequencies which may introduce response bias. Additionally, the survey was not validated as part of this study, although the questions were derived from a well-established implementation science framework.[14] Finally, the clinicians' insights reflect interactions with patients who accessed telehealthcare. We acknowledge that this is a subset of the patient population.[12]

CONCLUSIONS

Telehealth reached a new level of prominence during the PHE. It is a delivery model that has tremendous benefits for patients.[4 7 18] However, there continue to be infrastructure, usefulness and patient–provider expectation friction points that require a more sophisticated design of the digital care experience. Clinicians in this survey offered valuable insights into the directions healthcare organisations can take to right-size this healthcare delivery modality.

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