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Technology-Enabled Non-Invasive Examinations Augment Primary Care: An Observational Study

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ABSTRACT

Objectives: Significance and efficacy of advanced technology-enabled non-invasive diagnostic screening (TES) using smartphones and other point-of-care medical devices vs. conventional vital sign examinations is unevaluated for primary care screening of patients.

Design, Settings and Participants: Dental conditions, cardiac ECG arrhythmias, tympanic membrane disorders, blood oxygenation levels, optic nerve disorders, and neurological fitness of 455 consenting 18 to 90 years adults were evaluated using FDA approved advanced smartphone powered technologies with vital signs at a primary care center during the 2015 Kumbh Mela in India. A novel remote web platform was developed to allow expert physicians to examine TES data and compare efficacy with conventional vital sign screening methods.

Main outcome measures and Results: TES and vital sign screenings identified unique clinical conditions in distinct patients. Intraoral fluorescent imaging classified 63% of the population with dental caries and periodontal diseases. An association between poor oral health and cardiovascular illnesses was also identified. Tympanic membrane imaging detected eardrum abnormalities in 13% of the population, several with self-reported hearing difficulties. Gait and coordination issues were discovered in eight subjects and one subject had arrhythmia. Cross-correlations were observed between low oxygen saturation and low BMI with smokers (p = 0.0087 and p= 0.0122, respectively), and association of high BMI with elevated blood pressure in middle-aged subjects were found.

Interpretation: TES synergistically identified clinically significant abnormalities in several subjects who otherwise presented normal vital sign measurements. Physicians validated TES findings and utilized vital sign data and medical history responses for comprehensive diagnoses for at-risk patients. TES identified high prevalence of oral diseases, hypertension, obesity and ophthalmic conditions among the middle-aged and elderly Indian population, calling for public health interventions.

Ethics approval: MGVKBHDC/15-16/571 protocol was approved for clinical work, and the data was transferred and analyzed according to MIT COUHES protocol 1512338971

What is already known about this subject: We searched PubMed for studies involving either the proposal or evaluation of imaging technologies for diagnosing medical conditions, with a focus on literature from the past twenty years. Many studies have proposed or evaluated individual types of TES in isolation with relatively few subjects. However there is a lack of comparison to traditional and established vital sign measurements that are commonly deployed in healthcare screenings to determine the effectiveness of TES approaches as a whole.

What are the new findings: This study is the first to combine multiple types of TES and to compare their results to more traditional diagnostic methods. We show a distinct difference in diagnoses of patients using traditional vital signs monitoring and TES, indicating a synergistic role for TES when used for primary health screening.

Impact on clinical practice: Detailed TES imaging and diagnostic approaches outlined by us will allow for increased and earlier monitoring of previously undiagnosed conditions, leading to increased quality of care for patients. In addition to finding high prevalence of obesity, oral conditions, and elevated blood pressure, we foresee two improvements in public health outcomes from our study. Historically marginalized individuals in resource-limited settings can be identified and included to the primary care continuum.

INTRODUCTION

Providing good healthcare in low and middle-income countries (LMIC) paradoxically requires expensive equipment for health monitoring and assessment which may not be easily available because of resource-limitations[1]. Cardiovascular diseases, preventable blindness, oral cancer and treatable neurological conditions constitute more than 50% of the disease burden in LMIC and result in significantly morbidity and mortality[2, 3]. India, with a population in excess of 1.2 billion individuals, is one of the largest countries in the world[4]. India has significant disparity in access to basic healthcare and diagnostic screenings due to its geographically fragmented medical infrastructure[5]. Consequently, significant portions of the population may exist either as undiagnosed, diagnosed but unaware or misdiagnosed for several high-risk diseases at the primary care level.

Inexpensive device-based imaging and first-level analysis (e.g., smartphones capable of pulse oximetry, blood pressure, ECG recording and analysis or image segmentation) either operated by human experts, by operators with basic training using algorithms or clinical decision support systems are examples of affordable and potentially scalable technology-enabled screening[6, 7]. Previous reports from our group have demonstrated the utility of smartphones, modular devices and imaging technologies for sleep apnea[8] and refractometry screenings[9], at-home monitoring of diabetic retinopathy[10] and detecting melanomas[11]. Using smartphones with low-cost adapters, other researchers have also performed oral and cervical cancer[12], diabetic retinopathy [13], and malaria[14] assessments. Mobile smartphones equipped with imaging adapters, high-resolution cameras, light emitting diodes, fast processors and lightweight apps can thus be used for targeted diagnostic screenings at modest expense[15, 16].

Clinical studies measuring the effectiveness of technology-enabled screening (TES) methods in identifying at-risk and sick patients are, however, limited[17]. The majority of previous studies using newer TES approaches have been performed in silos concentrating on individual devices or specific anatomical sites, often precluding more comprehensive assessment of patient health[18-24]. Interpretation of TES data has also been limited by risk of bias, differences between study groups and lack of comparison to traditional and established vital sign measurements that are otherwise commonly deployed in primary care screenings. Due to these reasons, a lack of consensus exists about the usefulness of TES in augmenting vital-sign-monitoring-based primary health screenings in LMIC. Therefore, there is a pressing need for cost-effective, reliable screening protocols and deployable technologies to empower LMIC medical professionals and healthcare providers to identify patients and add them to the continuum of care.

88 The 2015 Kumbh Mela mass gathering[25] presented a unique opportunity for deployment and side-by-side evaluation of TES and traditional vital sign examinations. Multiple TES devices and methods and a remote clinical examination system to facilitate examination of findings were utilized to evaluate their collective use for comprehensive diagnoses of consenting adults. This study assesses whether low-cost, portable and non-invasive examinations using TES can augment conventional vital-sign-centered physiological measurements by detecting additional anatomical, structural or biomarker-driven disease pathologies. We report that TES for dental, optic nerve, tympanic membrane, cardiac rhythm and neurologic abnormalities identified several subjects scored as normal by vital sign assessments. We therefore conclude that TES synergistically augments standard vital sign examinations, and is a promising approach for providing comprehensive and timely care to at-risk and sick individuals using the methods described in this manuscript.

METHODS

Study design: 494 consenting adults between the ages of 18 and 90 years were screened by multiple tests in the order outlined in **Fig 1** at the Mahatma Gandhi Vidyamandir Karmaveer Bhausaheb Hiray Dental College & Hospital (MGVKBHDC) in Nashik, India, during the 2015 Sinhast Kumbh Mela (14 July-25 September). MGVKBHDC/15-16/571 protocol was approved for clinical work, and the data was transferred and analyzed according to MIT COUHES protocol 1512338971. **Table 1** shows the number of subjects who completed each test. Inclusion criteria, ethical consideration, and consent procedure are described in the supplementary appendix.

Medical history and vital sign measurements: Subjects self-reported to a detailed computerized questionnaire that included geographic, demographic as well as questions about past medical history and current illnesses. Height, weight, systolic and diastolic blood pressure, resting heart rate, and temperature were also measured.

Technology-enabled screening: FDA-approved devices were used to image patients, CellScope Oto (CellScope Inc. USA) for the tympanic membrane, D-EYE Direct Ophthalmoscopy Adapter (D-EYE Srl, USA) for the optic nerve head, and SOPROCARE (SOPRO Acteon Imaging, France) for dental health. Microsoft Kinect (Microsoft Corporation, USA) was used to record subjects performing gait and coordination tests. AliveCor Mobile ECG (AliveCor Inc, USA) was used to capture and analyze a 30-second rhythm strip. A CMS 50-DL Pulse Oximeter (Contec Medical Systems, USA) was used to measure blood oxygen saturation levels of hemoglobin. All devices have been previously described elsewhere [20-22, 25]. The supplementary appendix details specific procedures for each device.

Data analyses: Expert physicians conducted diagnostic feature annotation of de-identified images and videos collected by TES via a web-based examination portal. This password-protected secure interface displayed an image or video for one patient at a time for a given examination. Physicians were able to mark specific features in the videos by drawing boxes around them that paused that specific frame, assign an overall score of 1 (best) to 5 (worst) for the entire video, and to write clinical features that were present for specific frames or the entire video (**Supplementary Fig 2**). A panel of at least three physicians for each type of examination was assembled who remotely and independently annotated the data facilitated by the web interface. The majority ratings for each subject were then calculated for all TES tests. For subjects with no majority rating, the lesser of the tied ratings was chosen to not overstate the prevalence of diagnosed illnesses. Results from each test were analyzed for cross-correlations with self-reported medical history responses, age and sex.

RESULTS

Medical history and vital signs: Self-reported medical history responses are shown in **Supplementary Tables 2, 3, and 4**. Results of vital sign measurements are shown in **Table 1** with obesity (40%) and elevated blood pressure (19%) identified as most prevalent among the screened population. In comparing our data to the latest release of the National Family and Health Survey, we detected higher prevalence of high BMI and elevated blood pressure for both females and males but a similar prevalence of low BMI (**Supplementary Table 6**) [26].

Population demographic analysis: It took an average of approximately 35 minutes for each patient to complete the medical questionnaire, vital sign measurements and TES screening. Subjects unable to stay for the entire duration could exit the study at their convenience. There were more male than female participants which is likely at least in part the consequence of the fact that there are generally more male pilgrims at outdoor Indian religious festivals, including the Kumbh Mela. The gender breakdown for nearly all tests was 60% males and 40% females, though gait analysis had an equal percent of both (**Supplementary Fig 3**). Adolescents (18 and 19 years of age) and old adults (65-90 years of age) were approximately 30% of the total population (**Supplementary Fig 4**). The remaining 70% of the population comprised approximately 31% of young adults (20-39 years) and 39% middle age (40-64 years) subjects (**Supplementary Fig 4**). Three-fold more female than male adolescents and four-fold more old-aged males than old-aged females participated in the study, whereas other age groups had roughly equal numbers of males and females (**Supplementary Table 1**)

Self-reported medical history responses: Dental issues, swollen joints, leg cramps and hearing difficulties were each experienced by 18-26% of the population (**Supplementary Table 2**). Several respondents reported history of diabetes, blood pressure and cardiovascular diseases in their families. 9% of total respondents reported that they have been diagnosed with high blood pressure, and 6% were being treated for the disease (**Supplementary Table 2**). Subjects diagnosed with a certain clinical condition and/or undergoing treatment for it may not be the same individuals. Roughly 55% out of 494 respondents reported they wear glasses, indicating that they have refractive error vision problems. (**Supplementary Table 2**). Roughly equal numbers of both sexes responded yes to the majority of questions, with the exception of tobacco addiction, which was reported almost exclusively by males (**Supplementary Table 2**). **Supplementary Table 3** shows the age-cohort distribution of percentage of the people who said yes to a particular question (e.g. 17% of the 98 subjects who said they had family history of diabetes were 18-19 year olds). Barring family history of diabetes, high blood pressure, and thyroid and cardiovascular diseases; higher percentages of middle- and older-aged adults said yes to the majority of all other questions (**Supplementary Table 3**). Additionally, higher percentages of individuals in the middle and old age groups vs. adolescents and young adults answered yes to medical history questions (e.g. 35% of the 65 subjects in the 18-19 age group said they had a vision problem vs. 67% and 75% of 40-64 and 65-90-year-olds) (**Supplementary Table 4**).

Prevalence of obesity and hypertension in males and low BMI in young females: Vital sign measurements showed that approximately 19% of 455 subjects in the study had elevated blood pressure, and 1% had lower than normal blood pressure (**Table 1**). 22% of the 276 tested males of all age groups had elevated blood pressure measurements compared to 15% of the 179 tested females (**Table 2**). High BMI was measured in approximately 40% of the tested population (**Table 1**). Middle age adults (40-64 years) had statistically significantly higher BMI than young adults (20-39 years) and old age subjects (65-90 years) (**Supplementary Table 7**). Middle and old age subjects also had statistically significantly higher BP than adolescents and adult participants in the study (**Supplementary Table 7**). Approximately 18% of the tested population was underweight (**Table 2**). More females in the 18-19 and 20-39 age groups and more males in the 40-64 and 65-90 age groups had lower BMI than subjects in other age groups (**Supplementary Table 5**). Overall, more males aged 20-39 were found to be obese compared to females of that age group (p=0.0375) who in fact were scored as underweight by statistical significance. Forty-two subjects, the majority in the 40-64 age group, suffered from hypertension and had high BMI. Underweight males and females between the ages of 40-64 also found to be at higher risk for elevated blood pressure (n=9).

Comparisons between self-reported medical history and results from vital sign measurements: Adults aged 40 years and older of both sexes who were classified as abnormal in any vital sign measurement were the largest group of subjects correspondingly reporting family history, being diagnosed with, or receiving treatment for several diseases on the questionnaire. **Supplementary Table 8** lists p-values and percentages for cross-correlations between self-reported medical histories and results from vital sign measurements. Statistically significant correlations between obesity and subjects who wore glasses (59%), reported high blood pressure (13%) or had a family history of diabetes (25%) or hypertension (21%) were identified (p = 0.0024, p = 0.0091, p = 0.0384, p = 0.0173, respectively) (**Supplementary Table 8**). Interestingly, overweight subjects were more statistically significantly likely to be non-smokers; conversely, underweight subjects were more likely to be either addicted to tobacco and/or self-reported smokers (p = 0.0406, p = 0.0122, respectively). Occurrences of high blood pressure cross-correlated with several groups of individuals' self-reporting swollen joints, difficulty walking and diabetes (p = 0.0425, p = 0.0483, p = 0.0004, respectively). Subjects reporting either history of hypertension (n=7) or undergoing hypertension treatment (n=14) were statistically significantly more likely (*p* = 0.0006, *p* = 0.0002) to be measured with high blood pressure during our screening (**Supplementary Table 8**).

Identification of clinical conditions using TES: **Fig 2** shows representative diagnostic images and associated clinical findings captured by TES. Intraoral fluorescent (63%), tympanic membrane (13%) and oxygen saturation (4%) imaging examinations identified the largest percentage of unhealthy subjects (**Table 1**). Approximately 38% of subjects had dental caries and 28% had one or more teeth missing. Periodontal diseases were found in 15% of the population (**Supplementary Table 11**). Previously undiagnosed subjects with abnormalities in their ECG rhythm strip (n=1), optic nerve imaging (n=9), gait analysis (n=5) and finger-nose coordination (n=3) test results were identified (**Table 1**). The expert physicians annotated all nine subjects identified with abnormal optic nerve heads with a cup-to-disc ratio more than 0.3. All subjects who completed the hand tremor and finger-count tests were found to be normal.

A slightly larger percentage of tested female participants compared to males were determined to be unhealthy across the majority of TES tests, although the differences were not statistically significant with the exception of middle-aged females who were statistically more likely to have poor dental health than middle-aged males (*p*=0.0266). Middle-aged (n=120) and older (n=66) adults of both sexes encompassed more than 70% of all subjects with abnormal oral TES results (**Supplementary table 10**). Statistically higher prevalence of dental diseases was measured in 65-90-year-olds and 40-64-year-olds compared to 18-19-year-olds and 20-39-year-olds (*p*<0.0001 in all four cases). Low blood oxygen saturation and abnormal tympanic membranes were found in 13 and 26 subjects, respectively, who also had dental issues (**Supplementary table 12**). One subject each had low blood oxygen, tympanic membrane problems and unsatisfactory performance in the gait test. Adults aged 40 and above of both sexes were the majority of the subjects who failed two TES tests.

Identification of subjects with abnormal vital sign measurements and TES results: Numbers of subjects who were scored not normal in one test each from TES and vital sign measurement are shown in **Supplementary Table 13**. High and low BMI followed by elevated blood pressure measurements were most prevalent in subjects with abnormal TES results. Underweight individuals made up 18% of the population (**Table 1**), and 42% of these individuals also had low blood oxygen saturation (*p*=0.0110) (**Supplementary Table 13**). Similarly, approximately one third of the individuals with tympanic membrane abnormalities also had low BMI. Abnormal optic disc diameters were measured in four overweight participants (**Supplementary Table 13**). Dental screening identified the largest numbers of unhealthy subjects from the population who were measured with either high BMI, low BMI or elevated blood pressure, but these cross-correlations were not statistically significant due to extensive prevalence poor oral health in the community. Overall, high BMI (39%) and elevated blood pressure (19%) and poor dental health (58%) were widespread in middle-aged and older adults of the population (**Table 1, Supplementary tables 5 and 10**).

Comparisons between self-reported medical history and results from TES: Table 2 shows percentages of subjects who were scored as not normal in a particular TES test and responded yes to a medical history question. Individuals with swollen joints, hearing, and walking issues were found to be more likely to be scored as abnormal in TES tests compared to other groups. Four subjects (21%) measured with low oxygen saturation were self-reported smokers and this correlation was statistically significant (**Supplementary table 14**). 40% of the subjects for whom we identified tympanic membrane abnormalities reported hearing issues (p=0.0053). (**Supplementary table 14**). Presence of dental caries, gingivitis and or periodontal diseases was correlated with more statistically significant incidences of various clinical conditions reported in the medical history. High percentages of subjects scored as not normal in the finger-nose (n=3) and or gait tests (n=5) had reported hearing issues (**Table 2**). Similar to results in vital signs screenings, individuals aged 40 years and older of both sexes were the largest group of subjects who gave affirmative responses to the questionnaire and abnormal TES results, although this was not statistically significant.

TES synergistically identifies unique subset of abnormal individuals in conjunction with vital sign measurements: Data from subjects who completed medical history questionnaire, all vital signs measurements and all TES tests (n=111) allowed comparative analyses (**Supplementary Tables 16, 17**). Vital sign measurements identified 32 as normal and 79 as abnormal from these 111 subjects, compared to 41 normal and 70 abnormal subjects classified by TES (**Supplementary Table 15**). Our data indicates that similar percentage of these 111 subjects benefitted from diagnosis offered by TES vs. those screened by vital sign measurements. **Table 3** shows the age and gender profiles for 111 subjects and the differential diagnoses between the two screening methods.

Overall, we found abnormal BMI measurements and poor dentition led to the majority of the abnormalities in these 111. Tympanic membrane and BP abnormalities were the second-most widespread in this cohort. Self-reported questionnaire responses and TES screening results from these 111 subjects illustrate another use case with value for augmented screening. Several self-reported healthy individuals were found to have either abnormal vital signs (n=12) or TES results (n=7) or both (n=6). Dental and ear issues were the most common TES abnormalities associated with self-reported healthy subjects. Importantly, all seven self-reported healthy subjects identified as abnormal by TES (dental, n=5; optic nerve, n=1; tympanic membrane, n=1) had no previous diagnoses of these conditions and were different from the 12 individuals with abnormal vital signs. These results indicate the unique and synergistic value of TES in providing comprehensive care in conjunction with vital-sign based screenings.

DISCUSSION

Many of the subjects identified by TES did not have any abnormal vital signs, indicating that TES can play a role in identifying subjects who need care but would not be identified by vital signs measurements alone. Each TES test identified distinctive abnormities in different patients and played a distinct role in identifying at-risk or sick individuals. Because the TES tests screen for much different conditions than the vital signs measurements, our results indicate mutually independent but not entirely exclusive performances of both in identifying at-risk or sick subjects. We examined several potential moderators and old age was a statistically significant premonition for abnormal TES results, underscoring the crucial role for augmented screenings in middle-aged and geriatric individuals. Large proportions of subjects identified with abnormalities in oral (65%), tympanic membrane (60%), and retinal (33%) tests, as well as the only subject in the single-lead ECG test, did not report their respective conditions on their medical history questionnaires. This indicates that these subjects were either previously undiagnosed or unaware of their health conditions. TES thus facilitates more thorough and non-invasive primary care screenings and may expedite early interventions as well as improved awareness for undiagnosed patients.

Vital sign measurements provided valuable insights into the rising epidemics of hypertension and obesity in the screened population in our study. Approximately 19% of the screened population in our study was suffering from hypertension. 18% of the screened population in our study was underweight (BMI <18.5) and several of these subjects were hypoxic, with low oxygen saturation, which can be considered a proxy measure for anemia. Pulseoximetry screenings identified 19 subjects with <90% SpO2. Vold et.al, in studies carried out in Norway, have reported high BMI, middle age and smoking as predictors of oxygen saturation[27]. Subjects with low blood oxygen self-reported smoking addiction and asthma. Most of them were middle-aged males, and the majorities were underweight. We also detected optic nerve abnormalities, dental diseases, gait and hearing difficulties in subjects with low blood oxygen, suggesting that a poor overall health status may co-exist with low blood oxygen measurements. Our data suggests the usefulness of deploying pulse oximetry for general health screenings, especially for underweight patients in LMIC.

Inadequate dental hygiene and resulting sequelae can have significant impact on quality of life and increase the risk of cardiovascular diseases[28, 29]. “Remote monitoring” and “Store-forward” approaches for dental examinations, reviewed elsewhere[30], have been used for teledentistry. In patients aged 65-74 years, the prevalence of caries was 70% and multi-centric oral health survey reported the prevalence of carries to be 51-95% [31]. We found 48% of 65-90-year-olds diagnosed with caries or periodontal disease. A high percentage of

45-60-year-old subjects in our study, who usually may not have been detected by traditional methods, were identified with poor dental health and may have been detected due to the more comprehensive evaluation offered by TES. Significant cross-correlations between patients reporting cardiovascular treatment with poor oral health (p=0.0267) was identified, underscoring the importance of routine dental care and calling for urgent attention to the oral disease epidemic in India.

There are approximately 11.2 million persons aged 40 years and older with glaucoma in India[32]. The most common optic nerve abnormalities that were detected in our study were optic nerve cupping as a risk factor for glaucoma, and optic nerve head neovascularization that is a sign of diabetic retinopathy. All nine patients who were scored as abnormal by optic nerve photography in our study had a DDLS scores of three, indicating early onset of glaucoma. The majority of these patients were females aged between 20-64 years whereas two old age males were marked abnormal. Four patients were also obese and high blood pressure was measured in two individuals, highlighting vulnerable status of young and middle aged obese Indian population.

Smartphone-enabled tele-otology has been deemed suitable for both on-site and remote diagnoses of tympanic membrane and Otitis media (OM) previously[33]. Perforated tympanic membranes (48%) and/or effusions (60%) were most prevalent in patients labeled as abnormal by ENT surgeons. These patients may have been suffering from OM infection and or a generalized inflammation. A large segment of these subjects were middle age or older adults and were also the predominant group that failed the gait and coordination test. Physician consensus, imaging data and self-reported hearing issues emphasize the substantial challenges in diagnosing and treating these patients. We did not perform audiology or speeches tests with these subjects and thus are unable to cross correlate the imaging data with functional tests.

Due to acute shortages of trained neurologists, diagnoses of neurological disorders is extremely challenging in LMIC[34]. Three subjects in the finger-nose test were identified with incoordination and dysmetria. Seven out of the eight total subjects failing neurological tests were males older than 40 years, and three were underweight. The majority of subjects failing either the gait and/or finger-nose tests self-reported swollen joints and a few said that they had difficulty in walking (all subjects were able to walk unassisted). It is conceivable that these issues may be unlinked or causal to their performance in the gait test. However, none of these conditions had previously been diagnosed in these individuals reaffirming a need for more aggressive and large-scale screening using TES methods. We are working on generative algorithms for classification of various neurological disorders and hope to incorporate these in future studies.

Physicians using TES devices in our study commented that a brief period of acclimatization was necessary in both use and interpretation of results from the devices before use in the study. Incorporating training for use of mobile technologies for diagnoses during medical school can reduce this learning curve. To our surprise, most of our tele-examination physicians could accurately diagnose presented conditions often with overwhelming consensus between them. Patients enrolled in our study were also pleased to see immediate results from TES and get rapid feedback from physicians. We acknowledge that TES devices may provide only an indication of the clinical pathologies they evaluate instead of a thorough diagnosis. Despite the claims made by device manufacturers, we also recognize that in their current form-factor TES will not replace or completely remove the physician from the loop. We used representative, clinically validated devices in this study, and our diagnoses may be generalizable to findings from similar datasets. The numbers of patients examined by TES and vital sign measurements were not identical, precluding a more comprehensive analysis of their performances. Although this work is one of the largest, if not the largest, studies carried out using a wide array of different TES methods, a larger sample size in follow-up studies may result in more comprehensive identification of patient demographics and the full gamut of clinical conditions. We do, however, emphasize that one goal of this study was to conduct a cross-sectional analysis of both the population and the tests instead of focusing on only one TES method with a large sample size.

While routine vital sign examinations continue to be important in health screenings, this study demonstrates that the emerging techniques of TES can play an important synergistic role in stratifying populations and providing personalized screening and care, especially in LMIC. Multiple TES screening methods and data analyses outlined in this study can help in training and standardization for deployment of augmented, low-cost, non-invasive and portable screening approaches in conjunction with traditional primary healthcare exams, leading to increased clinical interventions, diagnoses and awareness of health conditions for individuals.

Footnotes

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Data sharing*: Anonymized patient level data and or full dataset will be made available following standard MIT COUHES data sharing protocols.*

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Competing interests: *"All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work."*

Author contributions: *OG, MM, and GY organized the data; PS, OG, and GY did data analysis; PS, SVS, GY, and OG performed literature search; PS, GY, SVS and VP interpreted data; GY made figures; PS and GY wrote the manuscript; RM led clinical data collection; PS supervised the research.*

FIGURE LEGENDS

Fig 1. Study design.
(A) Flowchart for overall screening procedure. (B) Subject being screened for rhythm strip abnormalities using AliveCor Mobile ECG.

Fig 2. Representative images of labeled conditions detected in technology-enabled screenings.
(A) Normal images for technology-enabled screenings. Left-to-right, top-to-bottom: dental, periodontal, tympanic membrane, optic nerve, finger-nose.
(B) Labeled conditions for technology-enabled screenings. Left-to-right, top-to-bottom: caries, missing teeth, periodontal disease, perforated eardrum, effusion, width of optic rim 0.01-0.1, abnormal finger-nose.

Table 1. Results of vital signs measurements and technology-enabled screenings.

	Female		Male		Total	
	Abnormal	Tested	Abnormal	Tested	Abnormal	Tested
Vital signs tests						
High BMI	75 (39)	193	121 (40)	301	196 (40)	494
Low BMI	42 (22)	193	47 (16)	301	89 (18)	494
High BP	26 (15)	179	62 (22)	276	88 (19)	455
Low BP	3 (2)	179	1 (0.4)	276	4 (1)	455
Technology-enabled screenings						
Low blood oxygen	5 (3)	179	14 (5)	276	19 (4)	455
Single-lead ECG	0 (0)	168	1 (0.4)	262	1 (0.2)	430
Oral	109 (68)	160	151 (60)	251	260 (63)	411
Retinal	5 (3)	169	4 (2)	235	9 (2)	404
Tympanic membrane	17 (13)	126	25 (13)	198	42 (13)	324
Hand tremor	0 (0)	127	0 (0)	186	0 (0)	313
Finger-nose	0 (0)	123	3 (2)	182	3 (1)	305
Finger-count	0 (0)	122	0 (0)	177	0 (0)	299
Gait	1 (1)	104	4 (4)	110	5 (2)	214

Numbers and percentages (in parentheses) of males and females with conditions identified by vital signs tests and technology-enabled screenings.

Table 2. Number of subjects identified with a clinical condition by a technology-enabled screening test and responded yes to a medical history question.

Abnormality	No. with abnormality	Glasses	Dental	Swollen joints	Hearing	FH diabetes	FH high BP	Tobacco	Difficulty walking	High BP	Diabetes	High BP Rx	Asthma	Smoking	FH cardiac	Cardiac Rx	Cardiovascular	Low BP	FH stroke	FH eye disease	Heart attack	Coronary bypass	Drinking	Eye treatment	Memory loss	Ear treatment	FH ear disease
Hypoxemia	19	7	9	3	5	2	0	3	3	0	0	0	3	4*	0	1	0	0	0	0	0	0	0	0	0	0	0
TM	42	22	14	14	17	7	6	3	5	5	4	4	3	1	2	1	1	0	1	0	0	0	0	0	0	1	0
Retinal	9	6	5	4	4	2	2	0	3*	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Oral	260	145*	82*	85*	72*	41	31**	27	36*	30	23	24*	15	13	7	8*	4	3	2	3	3	3	1	2	2	1	1
Finger-nose	3	1	1	3*	2	0	0	1	3*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gait	5	1	4*	4*	3	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Total populations reflect the number of subjects with the particular condition in that row. Multiple subjects were associated with more than one condition or questionnaire response.
TM: tympanic membrane.
* $p < 0.05$, subjects are more likely to have responded yes to the column's question and have the condition.
** $p < 0.05$, subjects are less likely to have responded yes to the column's question and have the condition.

Table 3. Synergistic role of technology-enabled screening in identifying at-risk or sick individuals.

.		Adolescent (18-19)		Young adult (20-39)		Middle age (40-64)		Old age (65-90)		
Vital signs	TES	Female	Male	Female	Male	Female	Male	Female	Male	Total (n=111)
✓	✓	5	0	3	0	0	2	0	0	10
x	✓	5	0	5	12	2	6	0	1	31
✓	x	4	0	5	4	5	3	0	1	22
x	x	5	0	3	7	9	15	2	7	48
Total in age cohort		19	0	16	23	16	26	2	9	111

Check marks indicate normal status while x indicates abnormalities in a particular screening method.

REFERENCES

1. Rivo, M. 2008 World Health Report emphasizes importance of primary health care. Am Fam Physician. 2009;79(12):1051.
2. Alwan, A, Maclean, DR, Riley, LM, et al. Monitoring and surveillance of chronic non-communicable diseases: progress and capacity in high-burden countries. Lancet. 2010;376(9755):1861-8.
3. Samb, B, Desai, N, Nishtar, S, et al. Prevention and management of chronic disease: a litmus test for health-systems strengthening in low-income and middle-income countries. Lancet. 2010;376(9754):1785-97.
4. Thakur, J. Key recommendations of high-level expert group report on universal health coverage for India. Indian J Community Med. 2011;36(Suppl 1):S84-5.
5. Shi, L. The impact of primary care: a focused review. Scientifica (Cairo). 2012;2012:432892.
6. Dhawan, AP, Heetderks, WJ, Pavel, M, et al. Current and Future Challenges in Point-of-Care Technologies: A Paradigm-Shift in Affordable Global Healthcare With Personalized and Preventive Medicine. IEEE J Transl Eng Health Med. 2015;3:2800110.
7. Topol, EJ. Transforming medicine via digital innovation. Sci Transl Med. 2010;2(16):16cm4.
8. Puri, RS, Athanassiadis, AG, Gill, N, et al. Design and preliminary evaluation of a wearable device for mass-screening of sleep apnea. Annual International Conference of the IEEE Engineering in Medicine and Biology Society 2016;38th
9. Pamplona, VF, Mohan, A, Oliveira, MM, Raskar, R. NETRA: Interactive Display for Estimating Refractive Errors and Focal Range. Acm T Graphic. 2010;29(4).
10. Swedish, T, Roesch, K, Lee, IH, et al. eyeSelfie: Self Directed Eye Alignment using Reciprocal Eye Box Imaging. Acm T Graphic. 2015;34(4).
11. Das, A, Swedish, T, Wahi, A, et al. Mobile phone based mini-spectrometer for rapid screening of skin cancer. Proc Spie. 2015;9482.
12. Giller, G. Using a Smartphone to Detect Cancer. Sci Am. 2014;310(5):28-.
13. Creuzot-Garcher, C, Martin-Phipps, T, Beynat, J, et al. Effectiveness of a Mobile Diabetic Retinopathy Screening Campaign to Encourage Diabetics to Undergo Regular Ophthalmic Follow-Up. Ophthalmic Res. 2014;52(4):206-11.
14. Pirnstill, CW, Cote, GL. Malaria Diagnosis Using a Mobile Phone Polarized Microscope. Sci Rep-Uk. 2015;5.
15. Granot, Y, Ivorra, A, Rubinsky, B. A new concept for medical imaging centered on cellular phone technology. PLoS One. 2008;3(4):e2075.
16. Jani, IV, Quevedo, JI, Tobaiwa, O, et al. Use of mobile phone technology to improve the quality of point-of-care testing in a low-resource setting. AIDS. 2016;30(1):159-61.
17. Topol, E. Digital medicine: empowering both patients and clinicians. Lancet. 2016;388(10046):740-1.
18. Muhlestein, JB, Le, V, Albert, D, et al. Smartphone ECG for evaluation of STEMI: results of the ST LEUIS Pilot Study. J Electrocardiol. 2015;48(2):249-59.
19. Rechmann, P, Liou, SW, Rechmann, BM, Featherstone, JD. Performance of a light fluorescence device for the detection of microbial plaque and gingival inflammation. Clin Oral Investig. 2016;20(1):151-9.
20. Gabel, M, Gilad-Bachrach, R, Renshaw, E, Schuster, A. Full Body Gait Analysis with Kinect. Ieee Eng Med Bio. 2012:1960-7.
21. Richards, JR, Gaylor, KA, Pilgrim, AJ. Comparison of traditional otoscope to iPhone otoscope in the pediatric ED. Am J Emerg Med. 2015;33(8):1089-92.
22. Eikelboom, RH, Mbao, MN, Coates, HL, Atlas, MD, Gallop, MA. Validation of tele-otology to diagnose ear disease in children. Int J Pediatr Otorhi. 2005;69(6):739-44.
23. Kopycka-Kedzierawski, DT, Bell, CH, Billings, RJ. Prevalence of dental caries in Early Head Start children as diagnosed using teledentistry. Pediatr Dent. 2008;30(4):329-33.
24. Russo, A, Morescalchi, F, Costagliola, C, Delcassi, L, Semeraro, F. A Novel Device to Exploit the Smartphone Camera for Fundus Photography. J Ophthalmol. 2015;2015:823139.

25. Baranwal, A, Anand, A, Singh, R, et al. Managing the Earth's Biggest Mass Gathering Event and WASH Conditions: Maha Kumbh Mela (India). PLoS Curr. 2015;7.
26. Kumar, A, Kalra, S, Unnikrishnan, AG. Metabolic state of the nation: Results of the national family health survey-4. Indian J Endocrinol Metab. 2016;20(4):429-31.
27. Vold, ML, Aasebo, U, Melbye, H. Low FEV1, smoking history, and obesity are factors associated with oxygen saturation decrease in an adult population cohort. Int J Chron Obstruct Pulmon Dis. 2014;9:1225-33.
28. DeStefano, F, Anda, RF, Kahn, HS, Williamson, DF, Russell, CM. Dental disease and risk of coronary heart disease and mortality. BMJ. 1993;306(6879):688-91.
29. Mendez, MV, Scott, T, LaMorte, W, et al. An association between periodontal disease and peripheral vascular disease. Am J Surg. 1998;176(2):153-7.
30. Jampani, ND, Nutalapati, R, Dontula, BS, Boyapati, R. Applications of teledentistry: A literature review and update. J Int Soc Prev Community Dent. 2011;1(2):37-44.
31. Veerasamy, A, Kirk, R, Gage, J. Epidemiology of dental caries among adolescents in Tamil Nadu, India. Int Dent J. 2016;66(3):169-77.
32. George, R, Ve, RS, Vijaya, L. Glaucoma in India: estimated burden of disease. J Glaucoma. 2010;19(6):391-7.
33. Mbao, MN, Eikelboom, RH, Atlas, MD, Gallop, MA. Evaluation of video-otoscopes suitable for tele-otology. Telemed J E-Health. 2003;9(4):325-30.
34. Gourie-Devi, M. Epidemiology of neurological disorders in India: review of background, prevalence and incidence of epilepsy, stroke, Parkinson's disease and tremors. Neurol India. 2014;62(6):588-98.

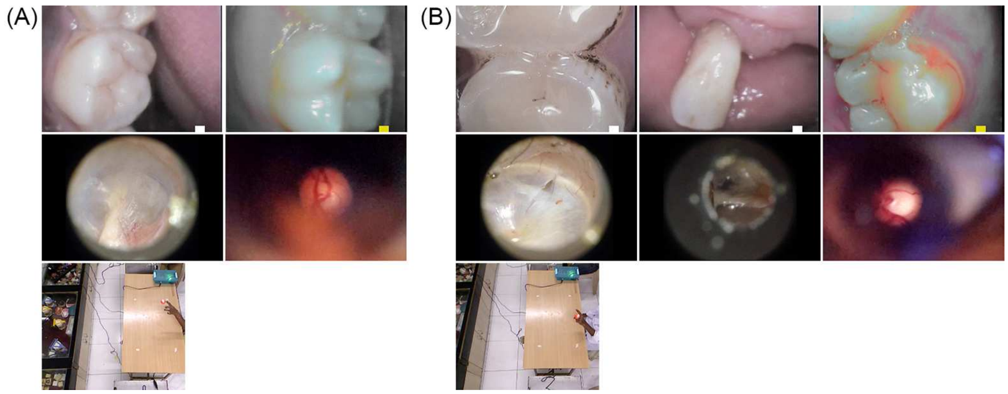
STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

Page(s)		Item No	Recommendation
1	**Title and abstract**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
2			(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
	Introduction		
4	Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
5	Objectives	3	State specific objectives, including any prespecified hypotheses
	Methods		
6	Study design	4	Present key elements of study design early in the paper
6	Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
6, 22	Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up
n/a			(*b*) For matched studies, give matching criteria and number of exposed and unexposed
6, 22, 23	Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
6, 22, 23	Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
22, 27	Bias	9	Describe any efforts to address potential sources of bias
22	Study size	10	Explain how the study size was arrived at
23	Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
23, 24	Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
23, 24			(*b*) Describe any methods used to examine subgroups and interactions
11			(*c*) Explain how missing data were addressed
n/a			(*d*) If applicable, explain how loss to follow-up was addressed
n/a			(*e*) Describe any sensitivity analyses
	Results		
17, 27	Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
22			(b) Give reasons for non-participation at each stage
38			(c) Consider use of a flow diagram

26, 28	Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
17			(b) Indicate number of participants with missing data for each variable of interest
n/a			(c) Summarise follow-up time (eg, average and total amount)
n/a	Outcome data	15*	Report numbers of outcome events or summary measures over time
7-11, 18	Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
23			(*b*) Report category boundaries when continuous variables were categorized
n/a			(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
7-11	Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
	Discussion		
12	Key results	18	Summarise key results with reference to study objectives
14	Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
12, 14	Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
14	Generalisability	21	Discuss the generalisability (external validity) of the study results
	Other information		
15	Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.



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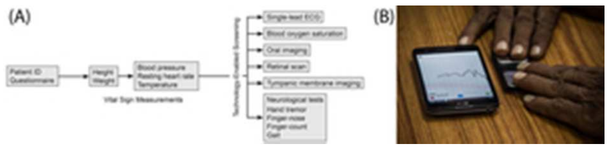

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Supplementary Appendix

Contents

Supplementary Methods

Criteria, ethical considerations and consent procedure: Mahatma Gandhi Vidyamandir Karmaveer Bhausaheb Hiray Dental College & Hospital (MGVKBHDC) in Nashik was designated as one of the primary health provision and disaster management centers for the 2015 Sinhast Kumbh Mela (14 July-25 September). The hospital has an outpatient facility where pilgrims and local people were provided care, information and a resting area throughout the event. Indians between the ages of 18 years and 90 years of all ethnicities, races and genders were included in the study. Subjects younger than 18 years or older than 90 years were excluded from participation. 494 consenting adults were seen in the week that MGVKBHDC was soliciting volunteers. We anticipated pilgrims and out-of-state consenting adults would be the largest group to volunteer to be enrolled in this study, allowing us to examine inhabitants from all over the county, but local Indians were also allowed to participate. MGVKBHDC institutional human subjects review committee approved our consent procedure, clinical data collection and the plan for communication of testing results with the subjects (Protocol number: MGVKBHDC/15-16/571). Bilingual physicians from MGVKBHDC explained the scope of the study and consent forms (in English or Hindi) to subjects who were interested in participating. Subjects were asked to sign the consent forms and then remain in a waiting area before active participation in the study. Participants were free to leave at any point during their screenings. MGVKBHDC primary care physicians, dentists, ophthalmologists, otolaryngologists and neurologists performed the health screenings in the order outlined in **Fig 1**, communicated the results to subjects and provided appropriate referrals to patients needing additional medical care. De-identified data was transferred to the Massachusetts Institute of Technology (MIT) investigators for analysis after approval of the protocol by the MIT Committee on the Use of Humans as Experimental Subjects (MIT COUHES protocol number: 1512338971).

Data collection: A unique registration number (1-494) linked to each subject was used to store and annotate data from screening kiosks.

Medical history and vital signs: Self-reported responses of subjects to a detailed computerized questionnaire that included geographic and demographic questions, questions about past medical history and current illnesses. A bilingual physician recorded the medications and symptoms reported by the subjects as well as their reports of family medical history. An Omron 10 series wireless upper arm monitor with cuff (Model: BP786N) was used to collect systolic and diastolic blood pressure following the manufacturer's instructions (Omron Electronics, USA). Temperatures were measured using a digital thermometer. Height and body weight were measured using a digital scale and were recorded for all subjects.

Technology-enabled screening devices:

Blood oxygen saturation: A CMS 50-DL Pulse Oximeter (Contec Medical Systems, USA) was used to measure blood oxygen saturation levels of hemoglobin based on photoplethysmographic pulses and pulse rate from subjects' right index fingertips [34].

ECG: The AliveCor Mobile ECG (AliveCor Inc, USA) is a single-channel cardiac event recorder consisting of a device and smartphone app that can record and review ECGs [20]. a 30-second rhythm strip (lead I) recording was uploaded wirelessly for interpretation via the AliveCor algorithm, and an ECG analysis that indicated heart rate and presence of possible atrial fibrillation was displayed on the mobile phone. Before each use, a physician cleaned the two electrodes with alcohol-based sanitizer and launched the app on the smartphone (Nexus5, LG, South Korea).

Tympanic membrane imaging: Inspection of the external ear canal and eardrum was performed using the iPhone5 LEDs and camera with the CellScope Oto phone adapter (CellScope Inc. USA) [24]. A disposable ear tip attached to the device canula was used for imaging each subject.

Oral imaging: A commercially available FDA-approved intraoral camera with software, SOPROCARE (SOPRO Acteon Imaging, France), that automatically segments and displays images of plaque, caries and periodontal diseases was used [21]. Panning 30-second videos of the buccal surfaces of the upper first molars (16, 26), the buccal surface of the upper laterals (12, 22), the buccal surface of first lower molars (36, 46), as well as incisal, buccal and lingual surfaces of all accessible teeth were collected. The housing of the camera stick was covered in a clear disposable plastic sheath (U-line, USA) and sterile disposable camera bag. Subjects and clinicians wore UV protective eyewear during oral imaging. Images and video were collected by each of the following modes: (A) only 405nm LEDs powered, (B) only 450nm LEDs powered, (C) only white LEDs powered. A HP 620 Notebook (Hewlett Packard, USA), Windows 7, (Microsoft Corporation, USA) with preloaded

SOPROCARE software was used to store images and videos. A specialized scale for assigning patient scores vs. conventional DMFT (number of decayed, missing and filled teeth in an individual and in a population) or the Russell's periodontal indices [35] was used by dentist examining the data. The camera system uses standard white light and three blue LEDS that emit non-ionizing light at 450 nm wavelengths. Inflamed gingiva can be scored due to fluorescence from porphyrins in blood. Illumination of microbial plaque with blue light induces fluorescence due to the bacteria and porphyrin content of the plaque.

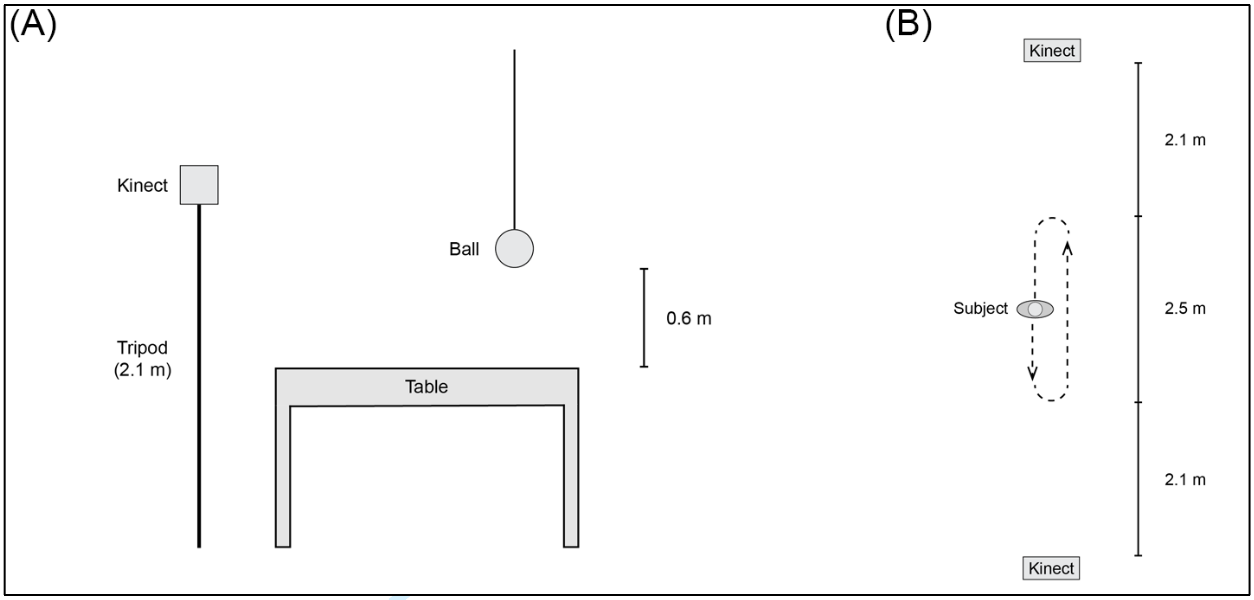
Optic nerve head photography: Non-mydriatic digital retinal imaging using the D-EYE (D-EYE Srl, USA) direct ophthalmoscopy adapter [31] attached to iPhone5s camera was performed to capture video and still images of optic nerves of subjects.

Gait and coordination analyses: The Microsoft Kinect (Microsoft Corporation, USA) sensor has an RGB camera, depth sensor and multi-array microphone, which provide full-body 3D motion capture, facial and voice recognition capabilities [22]. A 2D, depth and skeleton motion dataset of motor skills, hand-eye coordination, depth perception, neuromuscular stability of individual subjects was captured by the following protocol: a) finger-nose test with index finger touching a ball suspended from the ceiling two feet in front and then the nose: to identify tremors, incoordination, and dysmetria [36]; b) finger-count dexterity test to count to five using thumb touching fingertips: to detect slowness, tremors, and incoordination [37]; c) holding out hands steadily with palms facing down: to detect tremors and arm drift (upward, downward and lateral) [37], d) walking a distance of 2.5 meters in a straight line, turning around and walking back: to identify subjects who have posture abnormalities, tremors, imbalance (left/right), a penguin gait, or an asymmetric gait while walking [38]. Kinect sensors placed in front of and behind subjects were used to capture the walking in straight-line actions (**Supplementary Fig 1B**). For all other tests, one Kinect sensor was placed unobtrusively to the left or right of the subjects (**Supplementary Fig 1A**).

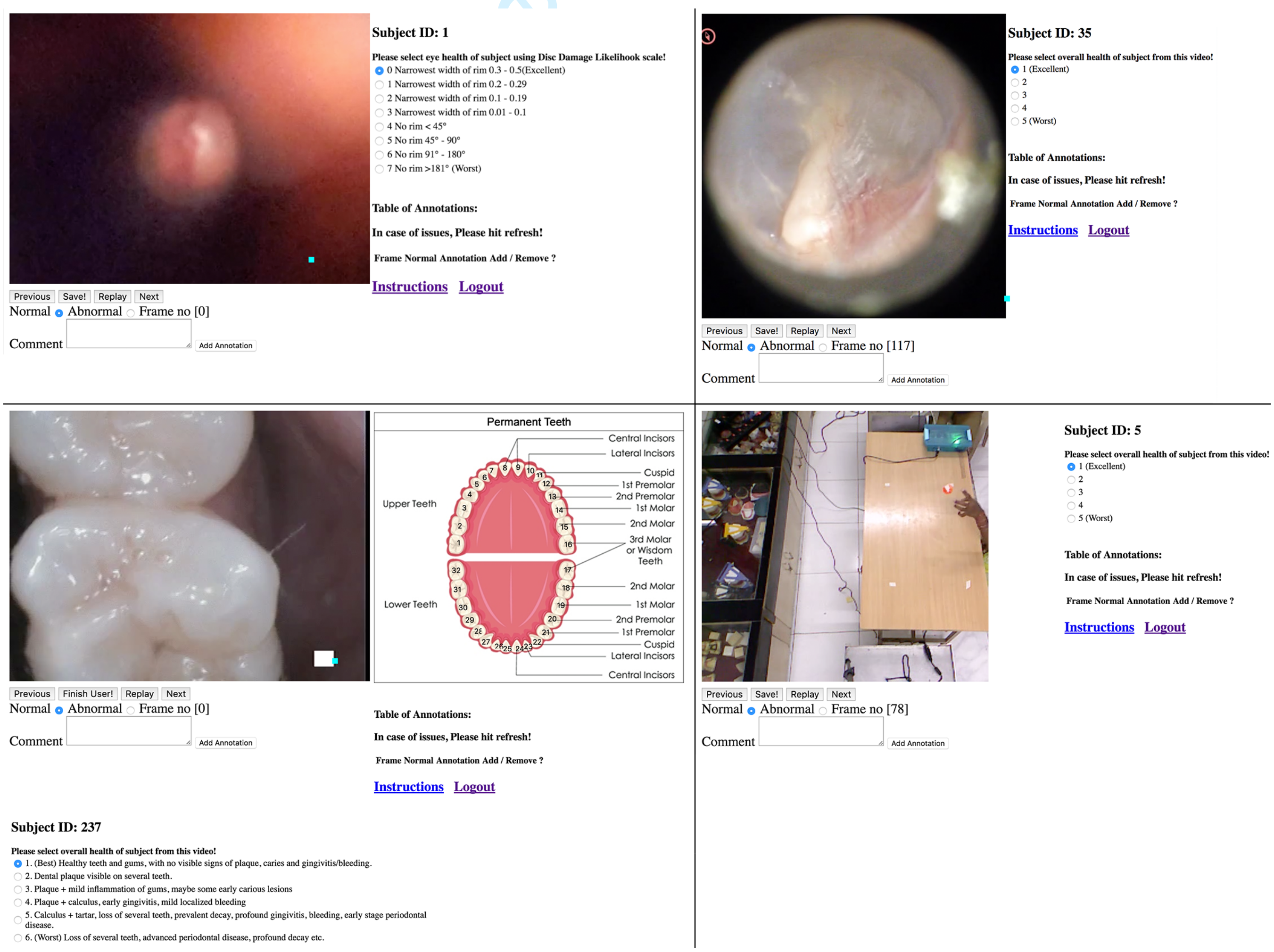
Data analyses: De-identified data assigned to unique subject IDs was split into five separate pools consisting of optic nerve, tympanic membrane, ear, oral and neurological videos for all study participants. BMI, blood pressure, resting heart rate and body temperature are routinely measured without sophisticated TES by most primary care providers and have been collectively annotated as "vital signs" throughout this study. Other imaging and smartphone-based tests have been designated as TES methods. Vital signs and responses to medical questionnaires were grouped together for computational analyses. Resting heart rate and temperature have clinically well-defined normal, high and low ranges. For BMI, numbers less than 19 were labeled low, between 19 and 25 were characterized as normal, and 25 and above were considered high. For blood pressure, systolic pressure below 90 mmHg or diastolic pressure below 60 mmHg was considered low, systolic pressure between 90 and 140 mmHg and diastolic pressure between 60 and 90 mmHg was labeled normal, and systolic pressure above 140 mmHg or diastolic pressure above 90 mmHg was labeled high. Blood oxygen levels of 90% or less were annotated low. The outputs from the AliveCor mobile app were readily used as annotations for ECG tests because they were labeled 'Normal' or 'Possible atrial fibrillation'.

Expert physicians via a web-based examination portal conducted diagnostic feature annotation of de-identified images and videos collected by TES. This password-protected secure interface displayed an image or video for one patient at a time for a given examination. Annotators were able to mark specific features in the videos by drawing boxes around them that paused that specific frame, assign an overall score of 1 (best) to 5 (worst) for the entire video, and to write clinical features that were present for specific frames or the entire video (**Supplementary Fig 2**). A panel of at least three physicians for each type of examination was assembled and independently of each other remotely annotated the data facilitated by the web interface. Due to the greater quantity of Microsoft Kinect videos, three physician-trained raters annotated all the videos, and then an expert physician ratified their labels. The interface for optic nerve videos used a previously described Disc Damage Likelihood Scale (DDLS) scale for glaucoma screening [39]. The majority ratings for each subject were computed for all TES tests. For subjects with no majority rating, the lesser of the tied ratings was chosen to not overstate the prevalence of diagnosed illnesses. Results from each test were analyzed for cross-correlations with self-reported medical history responses, age and sex. Clinical findings for individuals who were tested at all six screening kiosks were also analyzed to generate population health profiles. Efficacy of Vital Sign measurements vs. TES to identify at-risk or sick individuals examined during the study is discussed in the manuscript.

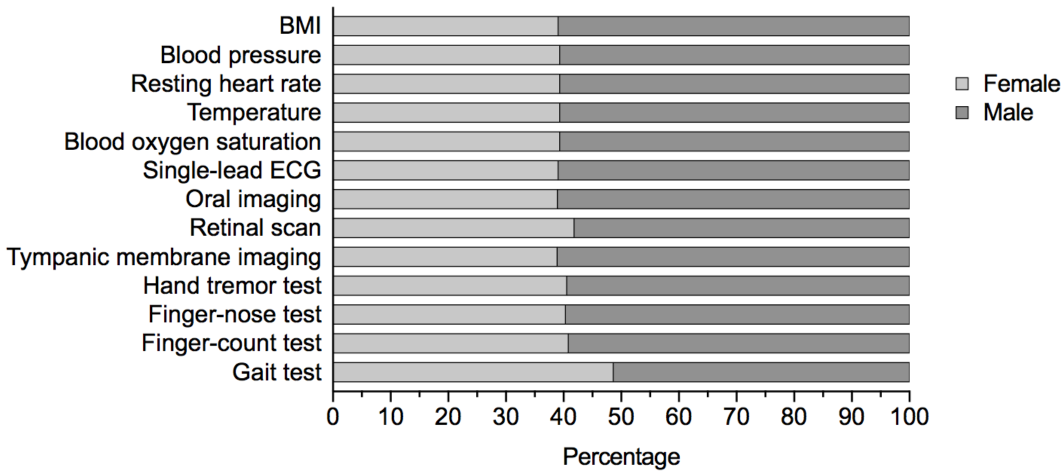
Statistical methods: Fisher's exact test was used to determine statistically significant correlations between diagnoses using TES or vital sign measurements and number, age, sex and questionnaire responses of participating subjects. The significance threshold was set at $p < 0.05$. To determine in **Supplementary Table 7** whether high BMI was statistically more prevalent in one particular age cohort (out of a total of four age groups), we calculated four proportions representing the number of subjects in a specific age cohort who had high BMI compared to the total number of subjects in that age cohort. Each proportion was compared pairwise using Fisher's exact test, which reported p-values of 0.0014 and 0.0052 when comparing the proportion from the middle age cohort to the proportions from the young adult and old age cohorts, respectively. In **Supplementary Table 8** to determine that there is a statistically significant correlation between a subject being measured for high BMI and responding that they wear glasses, we calculated two proportions: 1) the number of subjects who had high BMI and said they wear glasses (115) compared to the total number of subjects with high BMI (196), and 2) the number of subjects who did not have high BMI and said they wear glasses (132) compared to the number of subjects who did not have high BMI regardless of whether they wear glasses (298). Fisher's exact test reported a p-value of 0.0024 when comparing these proportions, so we conclude that the correlation between high BMI and wearing glasses is significant. Analyses were performed on groups of subjects who completed each individual test to avoid considering subjects who did not have that test performed.



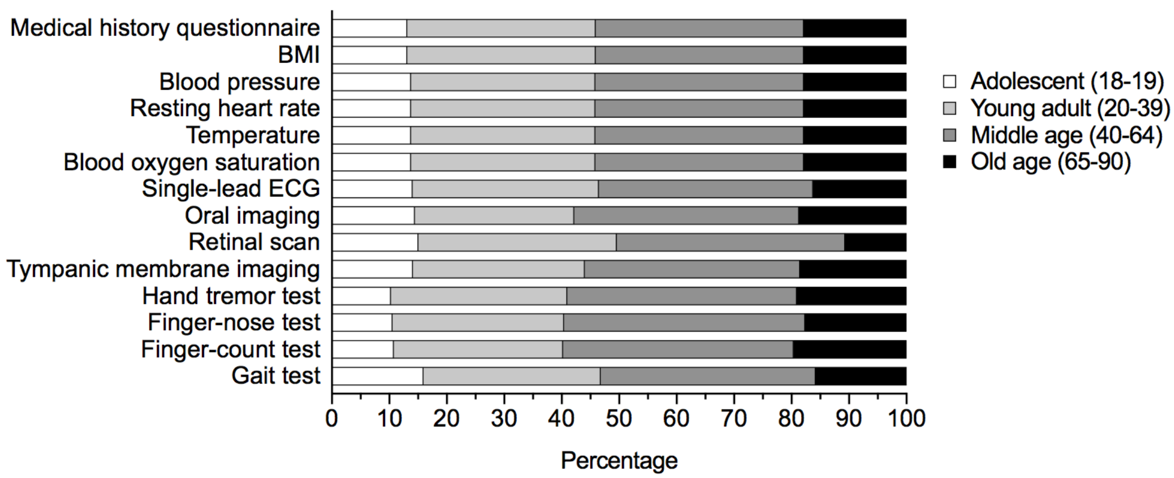
Supplementary Fig 1. Diagram of Microsoft Kinect placement for gait and coordination screening tests.
(A) Finger-nose test, from the side. Both the Kinect and ball are centered over the table with the patient facing the ball and the Kinect.
(B) Gait test, top-down. Both Kinects are 1 m off the ground and the subject walks in a straight line between them.



Supplementary Fig 2. Web interfaces for remote annotation used by physician experts for clinical evaluations.
Clockwise from top left: retinal scan, tympanic membrane imaging, gait and coordination tests, oral imaging



Supplementary Fig 3. Percentage of test populations of each gender.



Supplementary Fig 4. Percentage of test populations in each age cohort. Age ranges for each cohort are in parentheses.

Supplementary Table 1. Test populations divided by gender and age cohorts.

	Adolescent (18-19)			Young adult (20-39)			Middle age (40-64)			Old age (65-90)		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
Medical history	39	26	65	64	88	152	73	115	188	17	72	89
Body mass index	39	26	65	64	88	152	73	115	188	17	72	89
Blood pressure	38	25	63	56	81	137	69	104	173	16	66	82
Resting heart rate	38	25	63	56	81	137	69	104	173	16	66	82
Temperature	38	25	63	56	81	137	69	104	173	16	66	82
Blood oxygen saturation	38	25	63	56	81	137	69	104	173	16	66	82
Single-lead electrocardiogram	36	25	61	58	81	139	60	100	160	14	56	70
Oral imaging	37	22	59	43	71	114	65	96	161	15	62	77
Retinal scan	37	23	60	61	79	140	63	97	160	8	36	44
Tympanic membrane imaging	30	9	39	35	52	87	49	80	129	12	57	69
Hand tremor test	24	8	32	41	55	96	50	75	125	12	48	60
Finger-nose test	24	8	32	37	54	91	50	78	128	12	42	54
Finger-count test	24	8	32	36	52	88	49	71	120	13	46	59
Gait test	30	4	34	33	33	66	34	46	80	7	27	34

Age ranges in years for each age cohort are in parentheses.

Supplementary Table 2. Gender breakdown of self-reported medical history.

	Female (n=193)	Male (n=301)	Total (n=494)
Glasses	55	47	50
Dental	21	29	26
Swollen joints	25	25	25
Hearing	17	25	22
Family history of diabetes	22	18	20
Leg cramps	20	18	19
Family history of high blood pressure	21	13	16
Fatigue	16	16	16
Acidity	20	11	15
Tiredness	13	15	14
Tobacco addiction	2	18	11
Surgery	10	10	10
Difficulty walking	10	10	10
High blood pressure	10	8	9
Diabetes	7	9	8
Snore Loudly	5	9	7
High blood pressure treatment	7	6	6
Environmental allergies	8	4	6
Sleepiness	5	6	5
Medication allergies	6	5	5
Asthma	5	5	5
Smoking addiction	0	8	5
Family history of cardiac diseases	3	3	3
Family history of asthma	3	3	3
Thyroid	6	1	3
Self-medication	1	4	3
Jewelry allergies	6	0	2
Past skin infection	3	2	2
Family history of thyroid disease	2	2	2
Cardiac treatment	1	3	2
Stop breathing during sleep	1	2	2
Oral infection	2	2	2
Kidney disorder	2	1	2
Skin problem	1	2	2
Skin infection	0.5	2	1
Food allergies	2	1	1
Hyperactivity	2	1	1
Cardiovascular	0.5	2	1
Migraine	2	1	1
Low blood pressure	3	0.3	1
Family history of stroke	2	0.3	1
Past ear infection	0.5	1	0.8
Family history of eye disease	0.5	1	0.8
Heart attack	0	1	0.8
Material allergies	1	1	0.8
Anxiety	0.5	1	0.8
Injury in past 6 months	1	1	0.8
Family history of depression	1	0.3	0.6
Coronary bypass surgery	0	1	0.6
Attention deficit disorder	1	0	0.6
Drinking addiction	0	1	0.6
Eye treatment	0.5	0.3	0.4
Family history of skin disease	0.5	0.3	0.4
Memory loss	1	0	0.4
Ear treatment	0.5	0.3	0.4
Lung diseases	0.5	0.3	0.4
Family history of ear disease	0	0.7	0.4
Cancer	0.5	0	0.2
Sexually transmitted disease	0	0.3	0.2
Liver disease	0.5	0	0.2
Skin treatment	0.5	0	0.2
Past gastric infection	0	0.3	0.2
Depression	0	0	0
Sleep disorder treatment	0	0	0
Heart murmur	0	0	0
Past lung infection	0	0	0

Percentage of total population by gender who answered yes to each medical history question.

Supplementary Table 3. Age cohort breakdown of self-reported medical history.

	Adolescent (18-19)	Young adult (20-39)	Middle age (40-64)	Old age (65-90)
Glasses	11	21	47	21
Dental	3	22	53	22
Swollen joints	0	10	51	38
Hearing	1	7	50	42
Family history of diabetes	17	44	34	5
Leg cramps	0	15	47	38
Family history of high blood pressure	18	46	33	4
Fatigue	1	21	55	23
Acidity	5	30	47	18
Tiredness	3	21	53	23
Tobacco addiction	0	18	46	36
Surgery	8	18	37	37
Difficulty walking	0	2	49	49
High blood pressure	0	9	57	34
Diabetes	0	15	64	21
Snore Loudly	0	27	65	8
High blood pressure treatment	0	6	55	39
Environmental allergies	17	41	34	7
Sleepiness	4	7	63	26
Medication allergies	15	15	54	15
Asthma	0	4	67	29
Smoking addiction	0	9	52	39
Family history of cardiac diseases	6	38	38	19
Family history of asthma	13	13	67	7
Thyroid	0	14	64	21
Self-medication	0	29	50	21
Jewelry allergies	0	33	67	0
Past skin infection	8	25	50	17
Family history of thyroid disease	18	55	9	18
Cardiac treatment	0	20	40	40
Stop breathing during sleep	0	33	33	33
Oral infection	0	11	67	22
Kidney disorder	13	13	50	25
Skin problem	0	0	50	50
Skin infection	0	29	57	14
Food allergies	0	29	57	14
Hyperactivity	14	29	57	0
Cardiovascular	0	33	67	0
Migraine	17	83	0	0
Low blood pressure	17	17	67	0
Family history of stroke	20	60	20	0
Past ear infection	0	75	0	25
Family history of eye disease	0	75	25	0
Heart attack	0	25	25	50
Material allergies	0	75	25	0
Anxiety	0	50	50	0
Injury in past 6 months	25	0	75	0
Family history of depression	33	67	0	0
Coronary bypass surgery	0	0	33	67
Attention deficit disorder	0	0	100	0
Drinking addiction	0	0	67	33
Eye treatment	0	0	0	100
Family history of skin disease	0	50	50	0
Memory loss	0	0	50	50
Ear treatment	0	0	100	0
Lung diseases	0	0	50	50
Family history of ear disease	0	50	0	50
Cancer	0	0	100	0
Sexually transmitted disease	0	100	0	0
Liver disease	0	0	100	0
Skin treatment	0	100	0	0
Past gastric infection	0	0	100	0
Depression	0	0	0	0
Sleep disorder treatment	0	0	0	0
Heart murmur	0	0	0	0
Past lung infection	0	0	0	0

Distribution of subjects, in percentages, who responded yes to a medical history question across age cohorts. Age ranges in years for each age cohort are in parentheses.

Supplementary Table 4. **Percentage of subjects in each age cohort who responded yes to a medical history question.**

	Adolescent (18-19)	Young adult (20-39)	Middle age (40-64)	Old age (65-90)
Glasses	43	34	62	57
Dental	6	18	36	33
Swollen joints	0	9	34	54
Hearing	2	5	29	51
Family history of diabetes	26	28	18	6
Leg cramps	0	9	23	39
Family history of high blood pressure	22	24	14	3
Fatigue	2	11	22	20
Acidity	6	14	18	15
Tiredness	3	10	20	18
Tobacco addiction	0	7	14	22
Surgery	6	6	10	20
Difficulty walking	0	1	13	27
High blood pressure	0	3	13	17
Diabetes	0	4	13	9
Snore Loudly	0	7	13	3
High blood pressure treatment	0	1	9	13
Environmental allergies	8	8	5	2
Sleepiness	2	1	9	8
Medication allergies	6	3	7	4
Asthma	0	1	9	8
Smoking addiction	0	1	6	10
Family history of cardiac diseases	2	4	3	3
Family history of asthma	3	1	5	1
Thyroid	0	1	5	3
Self-medication	0	3	4	3
Jewelry allergies	0	3	4	0
Past skin infection	2	2	3	2
Family history of thyroid disease	3	4	1	2
Cardiac treatment	0	1	2	4
Stop breathing during sleep	0	2	2	3
Oral infection	0	1	3	2
Kidney disorder	2	1	2	2
Skin problem	0	0	2	4
Skin infection	0	1	2	1
Food allergies	0	1	2	1
Hyperactivity	2	1	2	0
Cardiovascular	0	1	2	0
Migraine	2	3	0	0
Low blood pressure	2	0.7	2	0
Family history of stroke	2	2	1	0
Past ear infection	0	2	0	1
Family history of eye disease	0	2	0.5	0
Heart attack	0	0.7	0.5	2
Material allergies	0	2	0.5	0
Anxiety	0	1	1	0
Injury in past 6 months	2	0	2	0
Family history of depression	2	1	0	0
Coronary bypass surgery	0	0	0.5	2
Attention deficit disorder	0	0	2	0
Drinking addiction	0	0	1	1
Eye treatment	0	0	0	2
Family history of skin disease	0	0.7	0.5	0
Memory loss	0	0	0.5	1
Ear treatment	0	0	1	0
Lung diseases	0	0	0.5	1
Family history of ear disease	0	0.7	0	1
Cancer	0	0	0.5	0
Sexually transmitted disease	0	0.7	0	0
Liver disease	0	0	0.5	0
Skin treatment	0	0.7	0	0
Past gastric infection	0	0	0.5	0
Depression	0	0	0	0
Sleep disorder treatment	0	0	0	0
Heart murmur	0	0	0	0
Past lung infection	0	0	0	0

Age ranges in years for each age cohort are in parentheses.

Supplementary Table 5. Numbers of subjects in each age cohort identified by vital sign tests.

	Adolescent (18-19)			Young adult (20-39)			Middle age (40-64)			Old age (65-90)		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
High BMI	10	11	21	15	35	50	43	57	100	7	18	25
Low BMI	11	6	17	19	9	28	7	13	20	5	19	24
High BP	0	1	1	4	12	16	15	30	45	7	19	26
Low BP	1	0	1	2	0	2	0	1	1	0	0	0

Age ranges in years for each age cohort are in parentheses.

Supplementary Table 6. Percentages of subjects with each condition in our study and in each encompassing region from the National Family and Health Survey 4 (NFHS4).

	High BMI		Low BMI		High BP	
	Female	Male	Female	Male	Female	Male
Our study	39%	40%	22%	16%	15%	22%
NFHS4 India	20.7%	18.6%	22.9%	20.2%	8.8%	13.6%
NFHS4 Maharashtra	23.4%	23.8%	23.5%	19.1%	9.1%	15.9%
NFHS4 Nashik	22.9%	23.7%	25.8%	16.8%	5.7%	11%

Supplementary Table 7. Statistically significant prevalence of clinical conditions identified by vital sign measurements across age cohorts.

				More prevalent cohort		Less prevalent cohort	
Condition	More prevalent in	Than in	*p*-value	No. with condition (percentage)	No. in cohort	No. with condition (percentage)	No. in cohort
High BMI	Middle age	Young adult	0.0014	100 (60)	168	50 (33)	152
High BMI	Middle age	Old age	0.0052	100 (60)	168	25 (28)	89
High BP	Young adult	Adolescent	0.0147	16 (12)	135	1 (2)	65
High BP	Middle age	Adolescent	<0.0001	45 (26)	172	1 (2)	65
High BP	Middle age	Young adult	0.0023	45 (26)	172	16 (11)	152
High BP	Old age	Adolescent	<0.0001	26 (32)	82	1 (2)	65
High BP	Old age	Young adult	0.0006	52 (67)	82	16 (11)	152

Age ranges in years for each cohort: 18-19 for adolescents, 20-39 for young adults, 40-64 for middle age, and 65-90 for old age.

Supplementary Table 8. Number of subjects with a vital sign condition and responded yes to a medical history question.

Condition	No. with condition	Glasses	Dental	Swollen joints	Hearing	FH diabetes	FH high BP	Tobacco	Difficulty walking	High BP	Diabetes	High BP Rx	Asthma	Smoking	FH cardiac	Cardiac Rx	Cardiovascular	Low BP	FH stroke	FH eye disease	Heart attack	Coronary bypass	Drinking	Eye treatment	Memory loss	Ear treatment	FH ear disease	Cancer
High BMI	196	115*	48	52	38	48*	41*	23	19	26*	18	17	9	3**	5	5	1	1	1	3	2	1	1	0	2	2	1	0
Low BMI	89	39	21	23	25	11	10	16*	12	4	6	4	4	9*	1	1	0	2	1	0	0	0	1	0	0	0	0	0
High BP	88	54	24	30*	25	19	11	11	14*	17*	15*	14*	2	4	4	4	3	0	0	1	2	1	0	1	1	1	1	0
Low BP	4	3	1	1	1	2	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Total populations reflect the number of subjects with the particular condition in that row. Multiple subjects were associated with more than one condition or questionnaire response.

* $p < 0.05$, subjects are more likely to have responded yes to the column's question and have the vital sign abnormality.

** $p < 0.05$, subjects are less likely to have responded yes to the column's question and have the vital sign abnormality.

Supplementary Table 9. Statistically significant correlations between vital sign conditions and self-reported medical history.

			Subjects with vital sign condition		Subjects without vital sign condition	
Condition	Medical History	*p*-value	No. responded yes (percentage)	No. with condition	No. responded yes (percentage)	No. without condition
High BMI	Glasses	0.0024	115 (59)	196	132 (44)	298
High BMI	FH diabetes	0.0384	48 (24)	196	50 (17)	298
High BMI	FH High BP	0.0173	41 (21)	196	38 (13)	298
Low BMI	Tobacco addiction	0.0406	16 (18)	89	40 (10)	405
High BMI	High BP	0.0091	26 (13)	196	18 (6)	298
Low BMI	Smoking	0.0122	9 (10)	89	14 (3)	405
High BMI	Smoking	0.0077	3 (2)	196	20 (7)	298
High BP	Glasses	0.0251	60 (68)	88	179 (49)	367
High BP	Swollen joints	0.0425	30 (34)	88	89 (24)	367
High BP	Difficulty walking	0.0483	14 (16)	88	33 (9)	367
High BP	High BP	0.0006	17 (19)	88	24 (7)	367
High BP	Diabetes	0.0004	15 (17)	88	22 (6)	367
High BP	High BP Rx	0.0002	14 (16)	88	17 (5)	367

Supplementary Table 10. Numbers of subjects in each age cohort identified by technology-enabled screenings.

	Adolescent (18-19)			Young adult (20-39)			Middle age (40-64)			Old age (65-90)		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
Blood oxygen saturation	0	2	2	2	2	4	3	5	8	0	5	5
Single-lead ECG	0	1	1	0	0	0	0	0	0	0	0	0
Oral	17	5	22	22	30	52	55	65	120	15	51	66
Retinal	2	1	3	2	7	9	9	8	17	4	9	13
Tympanic membrane	0	0	0	1	2	3	4	0	4	0	2	2
Hand tremor test	0	0	0	0	0	0	0	0	0	0	0	0
Finger-nose test	0	0	0	0	0	0	0	2	2	0	1	1
Finger-count test	0	0	0	0	0	0	0	0	0	0	0	0
Gait test	0	0	0	0	1	1	0	1	1	1	2	3

Age ranges in years for each age cohort are in parentheses.

Supplementary Table 11. Distribution of unhealthy subjects by clinical condition identified in each technology-enabled screening test.

Test	Condition	No. with condition (percent)	No. screened by test
Oral	Carious	156 (38)	411
Oral	Missing tooth	115 (28)	411
Oral	Edentulous	35 (9)	411
Oral	Periodontal disease	61 (15)	411
Retinal	Width of rim 0.01-0.1	9 (2)	404
Tympanic membrane	Perforated eardrum	25 (8)	324
Tympanic membrane	Effusion	20 (6)	324
Finger-nose	Abnormal	3 (1)	305
Gait	Abnormal	5 (2)	214

Supplementary Table 12. Number of subjects identified with clinical conditions in two technology-enabled screening tests.

	Tympanic membrane	Retinal	Oral	Finger-nose	Gait
Low blood oxygen	1	1	13	0	1
Tympanic membrane		0	26	2	2
Retinal			8	0	0
Oral				2	4
Finger-nose					0

Supplementary Table 13. Percentages of subjects identified with a clinical condition by a technology-enabled screening test and a vital sign abnormality.

Abnormality	High BMI	Low BMI	High BP	Low BP
Low blood oxygen	21	42*	11	5
Tympanic Membrane	31	31	32	0
Retinal	44	11	11	0
Oral	40	17	21	1
Finger-nose	0	33	0	0
Gait	20	40	20	0

* $p < 0.05$, subjects are more likely to have the vital sign abnormality if they have the technology-enabled screening condition.

Supplementary Table 14. Statistically significant correlations between conditions identified by a technology-enabled screening test and self-reported medical history.

			Subjects with condition		Subjects without condition	
Abnormality	Medical History	*p*-value	No. responded yes (percentage)	No. with condition	No. responded yes (percentage)	No. without condition
Low blood oxygen	Smoking	0.0087	4 (21)	19	15 (3)	436
Tympanic Membrane	Hearing difficulty	0.0053	17 (40)	42	65 (23)	282
Retinal	Hearing difficulty	0.0500	4 (44)	9	65 (16)	395
Retinal	Difficulty walking	0.0298	3 (33)	9	30 (8)	395
Oral	Glasses	0.0195	145 (57)	255	70 (45)	156
Oral	Dental problems	0.0043	82 (32)	255	30 (19)	156
Oral	Swollen joints	0.0002	85 (33)	255	26 (17)	156
Oral	Hearing difficulty	0.0017	72 (28)	255	23 (15)	156
Oral	FH high BP	0.0172*	31 (12)	255	33 (21)	156
Oral	Difficulty walking	0.0089	36 (14)	255	9 (6)	156
Oral	High BP	0.0339	30 (12)	255	8 (5)	156
Oral	High BP Rx	0.0490	24 (9)	255	6 (4)	156
Oral	Cardiac Rx	0.0267	8 (3)	255	0 (0)	156
Finger-nose	Difficulty walking	0.0009	3 (100)	3	27 (9)	302
Finger-nose	Swollen joints	0.0159	3 (100)	3	80 (26)	302
Gait	Teeth problems	0.0179	4 (80)	5	53 (25)	209
Gait	Swollen joints	0.0159	4 (80)	5	45 (22)	209

Supplementary Table 15. Age cohort and gender of subjects identified with any vital sign condition or any technology-enabled screening abnormality.

	Adolescent (18-19)		Young adult (20-39)		Middle age (40-64)		Old age (65-90)		
	Female	Male	Female	Male	Female	Male	Female	Male	Total (n=111)
Vital sign condition	10	0	8	19	11	21	2	8	79
Technology-enabled screening abnormality	9	0	8	11	14	18	2	8	70
Total in age cohort	19	0	16	23	16	26	2	9	

y Table 16. Detailed results of technology-enabled screenings and vital sign measurements of the 111 subjects who completed all tests.

der	Questionnaire	High BMI	Low BMI	High BP	Low BP	ECG	Hypoxemia	TM	Retinal	Oral	Finger-nose	Gait
	x											
	x											
	x											
	x											
		x										
		x										
			x									
		x										
		x										
		x										
				x								
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	x	x										
	x	x										
	x	x										
	x		x									
	x		x									
		x		x								
		x			x							
	x	x										
	x	x										
	x	x										
	x		x									
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	x	x										
		x		x								
	x		x									
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	x	x		x								
	x	x		x								
	x	x		x								
	x	x		x								
										x		
										x		
								x				
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	x									x		
	x								x			
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	x									x		
	x									x		
	x									x		
	x									x		
	x									x		
	x									x		
	x									x		

y Table 17. **Detailed results of technology-enabled screenings and vital sign measurements of the 111 subjects who completed all tests.**

ler	Questionnaire	High BMI	Low BMI	High BP	Low BP	ECG	Hypoxemia	TM	Retinal	Oral	Finger-nose	Gait
			x							x		
			x							x		
		x		x				x				
	x			x						x		
	x	x						x				
	x	x					x					
			x					x		x		
	x	x								x		
	x	x								x		
			x					x		x		
	x	x								x		
			x					x		x		
	x			x						x		
	x	x								x		
	x			x						x		
	x			x						x		
	x	x								x		
	x	x								x		
	x		x							x		
	x			x						x		
	x	x								x		
	x	x								x		
	x	x								x		
	x			x						x		
	x		x					x				
	x	x						x				
	x	x								x		
	x		x							x		
	x	x								x		
	x		x							x		
	x		x							x		
	x	x		x						x		
	x	x						x		x		
	x			x				x		x		
	x	x						x		x		
	x	x							x	x		
	x	x							x	x		
	x	x		x						x		
	x	x						x		x		
	x	x							x	x		
	x	x		x						x		
	x	x		x						x		
	x		x	x						x		
	x	x		x						x		
	x		x							x		x
	x		x				x			x		x
	x		x	x				x		x		
	x	x		x				x		x		x

hat the subject was marked as abnormal in that row's test.
membrane

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Evaluation of technology-enabled examinations of cardiac rhythm, optic nerve, oral health, tympanic membrane, gait and coordination jointly with routine health screenings: An observational study

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Evaluation of technology-enabled examinations of cardiac rhythm, optic nerve, oral health, tympanic membrane, gait and coordination jointly with routine health screenings: An observational study

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ABSTRACT

Objectives: Technology-enabled non-invasive diagnostic screening (TES) using smartphones and other point-of-care medical devices was evaluated in conjunction with conventional routine health screenings for the primary care screening of patients.

Design: Dental conditions, cardiac ECG arrhythmias, tympanic membrane disorders, blood oxygenation levels, optic nerve disorders, and neurological fitness were evaluated using FDA-approved advanced smartphone powered technologies. Routine health screenings were also conducted. A novel remote web platform was developed to allow expert physicians to examine TES data and compare efficacy with routine health screenings.

Setting: The study was conducted at a primary care center during the 2015 Kumbh Mela in Maharashtra, India.

Participants: 455 consenting 18 to 90 years adults attending the 2015 Kumbh Mela were tested.

Results: TES and routine health screenings identified unique clinical conditions in distinct patients. Intraoral fluorescent imaging classified 63.3% of the population with dental caries and periodontal diseases. An association between poor oral health and cardiovascular illnesses was also identified. Tympanic membrane imaging detected eardrum abnormalities in 13.0% of the population, several with a medical history of hearing difficulties. Gait and coordination issues were discovered in eight subjects and one subject had arrhythmia. Cross-correlations were observed between low oxygen saturation and low BMI with smokers (p = 0.0087 and p= 0.0122, respectively), and association of high BMI with elevated blood pressure in middle-aged subjects were found.

Conclusions: TES synergistically identified clinically significant abnormalities in several subjects who otherwise presented as normal in routine health screenings. Physicians validated TES findings and utilized routine health screening data and medical history responses for comprehensive diagnoses for at-risk patients. TES identified high prevalence of oral diseases, hypertension, obesity and ophthalmic conditions among the middle-aged and elderly Indian population, calling for public health interventions.

Ethics approval: MGVKBHDC/15-16/571 protocol was approved for clinical work, and the data was transferred and analyzed according to MIT COUHES protocol 1512338971

47 Strengths and limitations of this study:

48 • This is one of the first studies to investigate using technology-enabled screenings to augment routine health examinations

50 • A remote examination platform was developed to facilitate diagnoses of health conditions by multiple physicians.

52 • The overall study size is large, but some organ-specific tests will benefit from larger studies.

53 • Sample sizes for each test were different with respect to number of subjects and gender distribution.

54 • The study is cross-sectional.

INTRODUCTION

Providing good healthcare in low and middle-income countries (LMIC) paradoxically requires expensive equipment for health monitoring and assessment which may not be easily available because of resource-limitations[1]. Cardiovascular diseases, preventable blindness, oral cancer and treatable neurological conditions constitute more than half of the disease burden in LMIC and result in significantly morbidity and mortality[2, 3]. India, with a population in excess of 1.2 billion individuals, is one of the largest countries in the world[4]. India has significant disparity in access to basic healthcare and diagnostic screenings due to its geographically fragmented medical infrastructure[5]. Consequently, significant portions of the population may exist either as undiagnosed, diagnosed but unaware or misdiagnosed for several high-risk diseases at the primary care level.

Inexpensive device-based imaging and first-level analysis (e.g., smartphones capable of pulse oximetry, blood pressure, ECG recording and analysis or image segmentation) either operated by human experts, by operators with basic training using algorithms or clinical decision support systems are examples of affordable and potentially scalable technology-enabled screening[6, 7]. Previous reports from our group have demonstrated the utility of smartphones, modular devices and imaging technologies for sleep apnea[8] and refractometry screenings[9], at-home monitoring of diabetic retinopathy[10] and detecting melanomas[11]. Using smartphones with low-cost adapters, other researchers have also performed oral and cervical cancer[12], diabetic retinopathy [13], and malaria[14] assessments. Mobile smartphones equipped with imaging adapters, high-resolution cameras, light emitting diodes, fast processors and lightweight apps can thus be used for targeted diagnostic screenings at modest expense[15, 16].

The majority of previous studies using newer TES approaches have been performed in silos concentrating on individual devices or specific anatomical sites, often precluding more comprehensive assessment of patient health[17-23]. Interpretation of TES data has also been limited by risk of bias, differences between study groups and lack of comparison to established routine health screenings that are otherwise commonly deployed in primary care screenings. Due to these reasons, a lack of consensus exists about the usefulness of TES in augmenting primary health screenings in LMIC. Therefore, there is a pressing need for cost-effective, reliable screening protocols and deployable technologies to empower LMIC medical professionals and healthcare providers to identify patients and add them to the continuum of care.

The 2015 Kumbh Mela mass gathering[24] presented a unique opportunity for deployment and side-by-side evaluation of TES and routine health screenings. Multiple TES devices and methods and a remote clinical examination system to facilitate examination of findings were utilized to evaluate their collective use for comprehensive diagnoses of consenting adults. This study assesses whether low-cost, portable and non-invasive examinations using TES can augment conventional routine health screenings by detecting additional anatomical, structural or biomarker-driven disease pathologies.

METHODS

Study design: 494 consenting adults between the ages of 18 and 90 years were screened by multiple tests in the order outlined in **Fig 1** at the Mahatma Gandhi Vidyamandir Karmaveer Bhausaheb Hiray Dental College & Hospital (MGVKBHDC) in Nashik, India, during the 2015 Sinhast Kumbh Mela (14 July-25 September). MGVKBHDC/15-16/571 protocol was approved for clinical work, and the data was transferred and analyzed according to MIT COUHES protocol 1512338971. **Table 1** shows the number of subjects who completed each test. Subjects could exit the study at their convenience, and the study design allowed for different numbers of subjects for each test (**Table 1**). Inclusion criteria, ethical consideration, and consent procedure are described in the supplementary appendix.

Medical questionnaire and routine health screenings: A designated physician administered a medical questionnaire, where subjects provided verbal answers and the physician was responsible for entering their answers into a computerized interface. The detailed questionnaire included geographic and demographic questions as well as questions about past medical history and current illnesses but did not capture data from past healthcare records. Height, weight, systolic and diastolic blood pressure, resting heart rate, and temperature were also each measured, separately by a different physician.

Technology-enabled screening: FDA-approved devices were used to image patients, CellScope Oto (CellScope Inc. USA) for the tympanic membrane, D-EYE Direct Ophthalmoscopy Adapter (D-EYE Srl, USA) for the optic nerve head, and SOPROCARE (SOPRO Acteon Imaging, France) for dental health. Microsoft Kinect (Microsoft Corporation, USA) was used to record subjects performing gait and coordination tests (**Supplementary Fig 1**). AliveCor Mobile ECG (AliveCor Inc, USA) was used to capture and analyze a 30-second rhythm strip. A CMS 50-DL Pulse Oximeter (Contec Medical Systems, USA) was used to measure blood oxygen saturation levels of hemoglobin. All devices and clinical evaluations have been previously described elsewhere [17-20, 23, 25-29]. The supplementary appendix details specific procedures for each device and the principles by which each operates.

Data analyses: Expert physicians conducted diagnostic feature annotation of de-identified images and videos collected by TES via a web-based examination portal in order to maximize time in the field for screening additional subjects **(Supplementary Methods)**. This password-protected secure interface displayed an image or video for one patient at a time for a given examination. Physicians were able to mark specific features in the videos by drawing boxes around them that paused that specific frame, assign an overall score of 1 (best) to 5 (worst) for the entire video, and to write clinical features that were present for specific frames or the entire video

(**Supplementary Fig 2**). A panel of at least three physicians for each type of examination was assembled who remotely and independently annotated the data facilitated by the web interface. The majority ratings for each subject were then calculated for all TES tests. For subjects with no majority rating, the lesser of the tied ratings was chosen to not overstate the prevalence of diagnosed illnesses. On average, each physician spent tens of seconds to approximately a minute annotating each per video. Results from each test were analyzed for cross-correlations with medical questionnaire responses, age and sex. Analyses of results from specific tests include data from all subjects who completed that test.

RESULTS

Medical history and routine health screenings: Results of routine health screenings are shown in **Table 1**, with gender and age range breakdowns in **Supplementary Table 1.** Medical questionnaire responses are shown in **Supplementary Tables 2, 3, and 4**. Accepted clinical ranges for each condition identified by routine health screenings through consultation with physicians and were applied automatically to the routine health screening data without requiring physicians to annotate the data on a per-patient basis (**Supplementary Methods**) [25, 30, 31]. Obesity (39.7%) and elevated blood pressure (19.3%) were identified as most prevalent among the screened population. In comparing our data to the latest release of the National Family and Health Survey, we detected higher prevalence of high BMI and elevated blood pressure for both females and males but a similar prevalence of low BMI (**Supplementary Tables 5, 6**) [32].

Population demographic analysis: It took an average of approximately 35 minutes for each patient to complete the medical questionnaire, routine health screenings and TES screening. Overall, there were more male than female participants which is likely at least in part the consequence of the fact that there are generally more male pilgrims at outdoor Indian religious festivals, including the Kumbh Mela. The gender breakdown for nearly all tests was approximately 60% males and 40% females, though gait analysis had an equal percent of both because the subjects who stayed long enough to complete that screening happened by chance to be split equally among males and females (**Supplementary Fig 3**). Adolescents (18 and 19 years of age) and old adults (65-90 years of age) were approximately 30% of the total population (**Supplementary Fig 4**). The remaining 70% of the population comprised approximately 31% of young adults (20-39 years) and approximately 39% middle age (40-64 years) subjects (**Supplementary Fig 4**). Three-fold more female than male adolescents and four-fold more old-aged males than old-aged females participated in the study, whereas other age groups had roughly equal numbers of males and females (**Supplementary Table 1**)

Medical questionnaire responses: Medical histories of dental issues, swollen joints, hearing difficulties, and leg cramps were each reported by 26.1%, 25.3%, 21.9%, 18.6% of the population, respectively (**Supplementary Table 2**). Several respondents reported a history of diabetes, blood pressure and cardiovascular diseases in their families. 8.9% of total respondents reported that they had been diagnosed with high blood pressure, and 6.3% were being treated for the disease (**Supplementary Table 2**). Subjects diagnosed with a certain clinical condition and/or undergoing treatment for it may not be the same individuals. 50.0% out of 494 respondents reported they wear glasses, indicating that they have refractive error vision problems. (**Supplementary Table 2**). Roughly equal numbers of both sexes responded yes to the majority of questions, with the exception of tobacco addiction, which was reported almost exclusively by males (**Supplementary Table 2**). **Supplementary Table 3** shows the age-cohort distribution of percentage of the people who said yes to a particular question (e.g. approximately 17% of the 98 subjects who said they had family history of diabetes were 18-19 year olds). Barring family history of diabetes, high blood pressure, and thyroid and cardiovascular diseases; higher percentages of middle- and older-aged adults said yes to the majority of all other questions (**Supplementary Table 3**). Additionally, higher percentages of individuals in the middle and old age groups vs. adolescents and young adults answered yes to medical history questions (e.g. approximately 35% of the 65 subjects in the 18-19 age group said they had a vision problem vs. approximately 67% and approximately 75% of 40-64 and 65-90-year-olds) (**Supplementary Table 4**). **Supplementary Tables 2, 3, and 4** each show the full list of questions asked in the medical questionnaire.

Prevalence of obesity and hypertension in males and low BMI in young females: Routine health screenings showed that approximately 19.3% of 455 subjects in the study had elevated blood pressure, and 0.9% had lower than normal blood pressure (**Table 1**). 22.5% of the 276 tested males of all age groups had elevated blood pressure measurements compared to 14.5% of the 179 tested females (**Table 2**). High BMI was measured in 39.7% of the tested population (**Table 1**). Middle age adults (40-64 years) had statistically significantly higher BMI than young adults (20-39 years) and old age subjects (65-90 years) (**Supplementary Table 7**). Middle and old age subjects also had statistically significantly higher BP than adolescents and adult participants in the study (**Supplementary Table 7**). Approximately 18.0% of the tested population was underweight (**Table 2**). More females in the 18-19 and 20-39 age groups and more males in the 40-64 and 65-90 age groups had lower BMI than subjects in other age groups (**Supplementary Table 5**). Overall, more males aged 20-39 were found to be obese compared to females of that age group (p=0.0375) who in fact were scored as underweight by statistical significance. Forty-two subjects, the majority in the 40-64 age group, suffered from hypertension and had high BMI. Underweight males and females between the ages of 40-64 also found to be at higher risk for elevated blood pressure (n=9).

Comparisons between medical questionnaire and results from routine health screenings: Adults aged 40 years and older of both sexes who were classified as abnormal in any routine health screening were the largest group of subjects correspondingly reporting family history, being diagnosed with, or receiving treatment for several diseases on the questionnaire. **Supplementary Table 8** lists p-values and percentages for cross-correlations between medical histories and results from routine health screenings. Statistically significant correlations between obesity and subjects who wore glasses (58.7%), reported high blood pressure (13.3%) or had a family history of diabetes (24.5%) or hypertension (20.9%) were identified (*p* = 0.0024, *p* = 0.0091, *p* = 0.0384, *p* = 0.0173, respectively) (**Supplementary Table 8**). Interestingly, overweight subjects were more statistically significantly likely to be non-smokers; conversely, underweight subjects were more likely to be either addicted to tobacco and/or smokers (*p* = 0.0406, *p* = 0.0122, respectively). Occurrences of high blood pressure cross-correlated with several groups of individuals' with a medical history of swollen joints, difficulty walking and diabetes (*p* = 0.0425, *p* = 0.0483, *p* = 0.0004, respectively). Subjects reporting either history of hypertension (n=7) or undergoing hypertension treatment (n=14) were statistically significantly more likely (*p* = 0.0006, *p* = 0.0002) to be measured with high blood pressure during our screening (**Supplementary Table 8**). High BMI and high blood pressure were additionally found to be correlated with many conditions on the medical questionnaire (**Supplementary Table 9**).

Identification of clinical conditions using TES: Fig 2 shows representative diagnostic images and associated diagnoses captured using TES. Intraoral fluorescent (63.3%), tympanic membrane (13.0%) and oxygen saturation (4.2%) imaging examinations identified the largest percentage of unhealthy subjects (**Table 1**). **Supplementary Table 10** shows the breakdown of abnormal results by gender and age range. Approximately 38.0% of subjects had dental caries and 28.0% had one or more teeth missing. Periodontal diseases were found in 14.8% of the population (**Supplementary Table 11**). Previously undiagnosed subjects with abnormalities in their ECG rhythm strip (n=1), optic nerve imaging (n=9), gait analysis (n=5) and finger-nose coordination (n=3) test results were identified (**Table 1**). The expert physicians annotated all nine subjects identified with abnormal optic nerve heads with a cup-to-disc ratio more than 0.3. All subjects who completed the hand tremor and finger-count tests were found to be normal.

A slightly larger percentage of tested female participants compared to males were determined to be unhealthy across the majority of TES tests, although the differences were not statistically significant with the exception of middle-aged females who were statistically more likely to have poor dental health than middle-aged males (*p*=0.0266). Middle-aged (n=120) and older (n=66) adults of both sexes encompassed 70.7% of all subjects with abnormal oral TES results (**Supplementary table 10**). Statistically higher prevalence of dental diseases was measured in 65-90-year-olds and 40-64-year-olds compared to 18-19-year-olds and 20-39-year-olds (*p*<0.0001 in all four cases). Low blood oxygen saturation and abnormal tympanic membranes were found in 13 and 26 subjects, respectively, who also had dental issues (**Supplementary table 12**). One subject each had low blood oxygen, tympanic membrane problems and unsatisfactory performance in the gait test. Adults aged 40 and above of both sexes were the majority of the subjects who failed two TES tests.

Identification of subjects with abnormal routine health screenings and TES results: Numbers of subjects who were scored not normal in one test each from TES and routine health screening are shown in **Supplementary Table 13**. High and low BMI followed by elevated blood pressure measurements were most prevalent in subjects with abnormal TES results. Underweight individuals made up 18.0% of the population (**Table 1**), and 42.1% of these individuals also had low blood oxygen saturation (p=0.0110) (**Supplementary Table 13**). Similarly, approximately one third of the individuals with tympanic membrane abnormalities also had low BMI. Abnormal optic disc diameters were measured in four overweight participants (**Supplementary Table 13**). Dental screening identified the largest numbers of unhealthy subjects from the population who were measured with either high BMI, low BMI or elevated blood pressure, but these cross-correlations were not statistically significant due to extensive prevalence poor oral health in the community. Overall, high BMI (39.7%) and elevated blood pressure (19.3%) and poor dental health (63.3%) were widespread in middle-aged and older adults of the population (**Table 1, Supplementary tables 5 and 10**).

Comparisons between medical questionnaire and results from TES: Table 2 shows percentages of subjects who were scored as not normal in a particular TES test and responded yes to a medical history question. Individuals with swollen joints, hearing, and walking issues were found to be more likely to be scored as abnormal in TES tests compared to other groups. Four subjects (21.1%) measured with low oxygen saturation had a medical history of being smokers and this correlation was statistically significant (**Supplementary table 14**). 40.5% of the subjects for whom we identified tympanic membrane abnormalities reported hearing issues (p=0.0053). (**Supplementary table 14**). Presence of dental caries, gingivitis and or periodontal diseases was correlated with more statistically significant incidences of various clinical conditions reported in the medical questionnaire. High percentages of subjects scored as not normal in the finger-nose (n=3) and or gait tests (n=5) had reported hearing issues (**Table 2**). Similar to results in routine health screenings, individuals aged 40 years and older of both sexes were the largest group of subjects who gave affirmative responses to the questionnaire and abnormal TES results, although this was not statistically significant.

TES synergistically identifies unique subset of abnormal individuals in conjunction with routine health screenings: Data from subjects who completed the medical questionnaire, all routine health screenings and all TES tests (n=111) allowed comprehensive analyses. Subjects who exited the study before completing all routine health screenings and TES tests were not considered in these analyses. Routine health screenings identified 32 as normal and 79 as abnormal from these 111 subjects, compared to 41 normal and 70 abnormal subjects classified by TES (**Supplementary Table 15**). **Supplementary Tables 16 and 17** show the data for each of the

111 subjects. Our data indicates that a similar percentage of these 111 subjects benefitted from diagnosis offered by TES as those screened by routine health screenings. **Table 3** shows the age and gender profiles for 111 subjects and the differential diagnoses between the two screening methods.

Overall, we found abnormal BMI measurements and poor dentition led to the majority of the abnormalities in these 111. Tympanic membrane and BP abnormalities were the second-most widespread in this cohort. Medical questionnaire responses and TES screening results from these 111 subjects illustrate another use case with value for augmented screening. Several individuals with healthy medical histories were found to have either abnormal routine health screenings (n=12) or TES results (n=7) or both (n=6). Dental and ear issues were the most common TES abnormalities associated with these subjects with healthy medical histories. Importantly, all seven subjects with a healthy medical questionnaire identified as abnormal by TES (dental, n=5; optic nerve, n=1; tympanic membrane, n=1) had no previous diagnoses of these conditions and were different from the 12 individuals with abnormal routine health screenings. These results indicate the unique and synergistic value of TES in providing comprehensive care in conjunction with routine health screenings.

DISCUSSION

Many of the subjects identified by TES did not have any abnormal routine health screenings, indicating that TES can play a role in identifying subjects who need care but would not be identified by routine health screenings alone. Each TES test identified distinctive abnormities in different patients and played a distinct role in identifying at-risk or sick individuals. Because the TES tests screen for much different conditions than the routine health screenings, our results indicate mutually independent but not entirely mutually exclusive performances of both in identifying at-risk or sick subjects. We examined several potential moderators and old age was a statistically significant premonition for abnormal TES results, underscoring the crucial role for augmented screenings in middle-aged and geriatric individuals. Large proportions of subjects identified with abnormalities in oral (69.1%), tympanic membrane (59.5%), and retinal (33.3%) tests, as well as the only subject in the single-lead ECG test, did not report their respective conditions on their medical questionnaires. TES thus facilitates more thorough and non-invasive primary care screenings and may expedite early interventions for conditions not identified by routine health screenings.

Routine health screenings provided valuable insights into the rising epidemics of hypertension and obesity in the screened population in our study. Approximately 19.3% of the screened population in our study was suffering from hypertension. 18.0% of the screened population in our study was underweight (BMI <18.5) and several of these subjects were hypoxic, with low oxygen saturation, which can be considered a proxy measure for anemia. Pulseoximetry screenings identified 19 subjects with <90% SpO2. Vold et.al, in studies carried out in Norway, have reported high BMI, middle age and smoking as predictors of oxygen saturation[33]. Subjects with low blood oxygen had medical histories of smoking addiction and asthma. Most of them were middle-aged males, and the majorities were underweight. We also detected optic nerve abnormalities, dental diseases, gait and hearing difficulties in subjects with low blood oxygen, suggesting that a poor overall health status may co-exist with low blood oxygen measurements. Our data suggests the usefulness of deploying pulse oximetry for general health screenings, especially for underweight patients in LMIC.

Inadequate dental hygiene and resulting sequelae can have significant impact on quality of life and increase the risk of cardiovascular diseases[34, 35]. “Remote monitoring” and “Store-forward” approaches for dental examinations, reviewed elsewhere[36], have been used for teledentistry. In patients aged 65-74 years, the prevalence of caries was approximately 70% and multi-centric oral health survey reported the prevalence of carries to be 51-95% [37]. We found approximately 48% of 65-90-year-olds diagnosed with caries or periodontal disease. A high percentage of 45-60-year-old subjects in our study, who usually may not have been detected by traditional methods, were identified with poor dental health and may have been detected due to the more comprehensive evaluation offered by TES. Significant cross-correlations between patients reporting cardiovascular treatment with poor oral health (p=0.0267) was identified, underscoring the importance of routine dental care and calling for urgent attention to the oral disease epidemic in India.

There are approximately 11.2 million persons aged 40 years and older with glaucoma in India[38]. The most common optic nerve abnormalities that were detected in our study were optic nerve cupping as a risk factor for glaucoma, and optic nerve head neovascularization that is a sign of diabetic retinopathy. All nine patients who were scored as abnormal by optic nerve photography in our study had a DDLS scores of three, indicating early onset of glaucoma. The majority of these patients were females aged between 20-64 years whereas two old age males were marked abnormal. Four patients were also obese and high blood pressure was measured in two individuals, highlighting vulnerable status of young and middle aged obese Indian population.

Smartphone-enabled tele-otology has been deemed suitable for both on-site and remote diagnoses of tympanic membrane and Otitis media (OM) previously[39]. Perforated tympanic membranes (59.2%) and/or effusions (47.6%) were most prevalent in patients labeled as abnormal by ENT surgeons. These patients may have been suffering from OM infection and or a generalized inflammation. A large segment of these subjects were middle age or older adults and were also the predominant group that failed the gait and coordination test. Physician consensus, imaging data and a history of hearing issues emphasize the substantial challenges in diagnosing and treating these patients. We did not perform audiology or speeches tests with these subjects and thus are unable to cross correlate the imaging data with functional tests.

Due to acute shortages of trained neurologists, diagnoses of neurological disorders is extremely challenging in LMIC[40]. Three subjects in the finger-nose test were identified with incoordination and dysmetria. Seven out of the eight total subjects failing neurological tests were males older than 40 years, and three were underweight. The majority of subjects failing either the gait and/or finger-nose tests a medical history of swollen joints and a few said that they had difficulty in walking (all subjects were able to walk unassisted). It is conceivable that these issues may be unlinked or causal to their performance in the gait test. However, none of these conditions had previously been diagnosed in these individuals reaffirming a need for more aggressive and large-scale screening using TES methods. We are working on generative algorithms for classification of various neurological disorders and hope to incorporate these in future studies.

Physicians using TES devices in our study commented that a brief period of acclimatization was necessary in both use and interpretation of results from the devices before use in the study. Incorporating training for use of mobile technologies for diagnoses during medical school can reduce this learning curve. To our surprise, most of our tele-examination physicians could accurately diagnose presented conditions often with overwhelming consensus between them. Patients enrolled in our study were also pleased to see immediate results from TES and get rapid feedback from physicians. We acknowledge that TES devices may provide only an indication of the clinical pathologies they evaluate instead of a thorough diagnosis. Despite the claims made by device manufacturers, we also recognize that in their current form-factor TES will not replace or completely remove the physician from the loop. We used representative, clinically validated devices in this study, and our diagnoses may be generalizable to findings from similar datasets. Due to some subjects leaving the study early, the numbers of patients examined by each TES test and routine health screening were not identical, restricting more comprehensive analyses to the 111 subjects who completed all tests. Although this work is one of the largest, if not the largest, studies carried out using a wide array of different TES methods, a larger sample size in follow-up studies may result in more comprehensive identification of patient demographics and the full gamut of clinical conditions. We do, however, emphasize that one goal of this study was to conduct a cross-sectional analysis of both the population and the tests instead of focusing on only one TES method with a large sample size.

While routine health screenings continue to be important, this study demonstrates that the emerging techniques of TES can play an important synergistic role in stratifying populations and providing personalized screening and care, especially in LMIC. Multiple TES screening methods and data analyses outlined in this study can help in training and standardization for deployment of augmented, low-cost, non-invasive and portable screening approaches in conjunction with traditional primary healthcare exams, leading to increased clinical interventions, diagnoses and awareness of health conditions for individuals.

Footnotes

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Data sharing*: Anonymized patient level data and or full dataset will be made available following standard MIT COUHES data sharing protocols.*

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Competing interests: *"All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work."*

Author contributions: *Otkrist Gupta, Mrinal Mohit, and Gregory Yauney organized the data received from collaborating institution by pooling various test data for each patient, Otkrist Gupta created a web analysis platform for remote examinations; Pratik Shah, Otkrist Gupta, SV Subramanian, Vincent Patalano and Gregory Yauney analyzed and interpreted data labeled by expert physicians; Pratik Shah, Gregory Yauney, and Otkrist Gupta performed literature search; Gregory Yauney made figures; Pratik Shah and Gregory Yauney wrote the manuscript; Rikin Merchant led clinical data collection and coordinated transfer to MIT; Pratik Shah supervised the research and directed the study at MIT.*

FIGURE LEGENDS

Fig 1. Study design. Flowchart for overall screening procedure.

Fig 2. Representative images of labeled conditions detected in technology-enabled screenings.
(A) Normal images for technology-enabled screenings. Left-to-right, top-to-bottom: dental, periodontal, tympanic membrane, optic nerve.
(B) Labeled conditions for technology-enabled screenings. Left-to-right, top-to-bottom: caries, missing teeth, periodontal disease, perforated eardrum, effusion, width of optic rim 0.01-0.1.

416 **Table 1. Results of routine health screenings and technology-enabled screenings.**

	Female		Male		Total	
	Abnormal	Tested	Abnormal	Tested	Abnormal	Tested
Routine health screenings						
High BMI	75 (38.9)	193	121 (40.2)	301	196 (39.7)	494
Low BMI	42 (21.8)	193	47 (15.6)	301	89 (18.0)	494
High BP	26 (14.5)	179	62 (22.5)	276	88 (19.3)	455
Low BP	3 (1.7)	179	1 (0.4)	276	4 (0.9)	455
Technology-enabled screenings						
Low blood oxygen	5 (2.8)	179	14 (5.1)	276	19 (4.2)	455
Single-lead ECG	0 (0.0)	168	1 (0.4)	262	1 (0.2)	430
Oral	109 (68.1)	160	151 (60.2)	251	260 (63.3)	411
Retinal	5 (3.0)	169	4 (1.7)	235	9 (2.2)	404
Tympanic membrane	17 (13.5)	126	25 (12.6)	198	42 (13.0)	324
Hand tremor	0 (0.0)	127	0 (0.0)	186	0 (0.0)	313
Finger-nose	0 (0.0)	123	3 (1.6)	182	3 (1.0)	305
Finger-count	0 (0.0)	122	0 (0.0)	177	0 (0.0)	299
Gait	1 (1.0)	104	4 (3.6)	110	5 (2.3)	214

417 Numbers and percentages (in parentheses) of males and females with conditions identified by routine health screenings and technology-
418 enabled screenings.
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Table 2. Number of subjects identified with a clinical condition by a technology-enabled screening test and responded yes to a medical history question.

Abnormality	No. with abnormality	Glasses	Dental	Swollen joints	Hearing	FH diabetes	FH high BP	Tobacco	Difficulty walking	High BP	Diabetes	High BP Rx	Asthma	Smoking	FH cardiac	Cardiac Rx	Cardiovascular	Low BP	FH stroke	FH eye disease	Heart attack	Coronary bypass	Drinking	Eye treatment	Memory loss	Ear treatment	FH ear disease
Hypoxemia	19	7	9	3	5	2	0	3	3	0	0	0	3	4*	0	1	0	0	0	0	0	0	0	0	0	0	0
TM	42	22	14	14	17	7	6	3	5	5	4	4	3	1	2	1	1	0	1	0	0	0	0	0	0	1	0
Retinal	9	6	5	4	4	2	2	0	3*	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Oral	260	145*	82*	85*	72*	41	31**	27	36*	30	23	24*	15	13	7	8*	4	3	2	3	3	3	1	2	2	1	1
Finger-nose	3	1	1	3*	2	0	0	1	3*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gait	5	1	4*	4*	3	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Total populations reflect the number of subjects with the particular condition in that row. Multiple subjects were associated with more than one condition or questionnaire response.
TM: tympanic membrane.
* $p < 0.05$, subjects are more likely to have responded yes to the column's question and have the condition.
** $p < 0.05$, subjects are less likely to have responded yes to the column's question and have the condition.

Table 3. Synergistic role of technology-enabled screening in identifying at-risk or sick individuals.

Routine health screenings	TES	Adolescent (18-19) Female	Adolescent (18-19) Male	Young adult (20-39) Female	Young adult (20-39) Male	Middle age (40-64) Female	Middle age (40-64) Male	Old age (65-90) Female	Old age (65-90) Male	Total (n=111)
✓	✓	5	0	3	0	0	2	0	0	10
x	✓	5	0	5	12	2	6	0	1	31
✓	x	4	0	5	4	5	3	0	1	22
x	x	5	0	3	7	9	15	2	7	48
Total in age cohort		19	0	16	23	16	26	2	9	111

Check marks indicate normal status while x indicates abnormalities in a particular screening method.

REFERENCES

1. Rivo, M. 2008 World Health Report emphasizes importance of primary health care. Am Fam Physician. 2009;79(12):1051.
2. Alwan, A, Maclean, DR, Riley, LM, et al. Monitoring and surveillance of chronic non-communicable diseases: progress and capacity in high-burden countries. Lancet. 2010;376(9755):1861-8.
3. Samb, B, Desai, N, Nishtar, S, et al. Prevention and management of chronic disease: a litmus test for health-systems strengthening in low-income and middle-income countries. Lancet. 2010;376(9754):1785-97.
4. Thakur, J. Key recommendations of high-level expert group report on universal health coverage for India. Indian J Community Med. 2011;36(Suppl 1):S84-5.
5. Shi, L. The impact of primary care: a focused review. Scientifica (Cairo). 2012;2012:432892.
6. Dhawan, AP, Heetderks, WJ, Pavel, M, et al. Current and Future Challenges in Point-of-Care Technologies: A Paradigm-Shift in Affordable Global Healthcare With Personalized and Preventive Medicine. IEEE J Transl Eng Health Med. 2015;3:2800110.
7. Topol, EJ. Transforming medicine via digital innovation. Sci Transl Med. 2010;2(16):16cm4.
8. Puri, RS, Athanassiadis, AG, Gill, N, et al. Design and preliminary evaluation of a wearable device for mass-screening of sleep apnea. Annual International Conference of the IEEE Engineering in Medicine and Biology Society 2016;38th
9. Pamplona, VF, Mohan, A, Oliveira, MM, Raskar, R. NETRA: Interactive Display for Estimating Refractive Errors and Focal Range. Acm T Graphic. 2010;29(4).
10. Swedish, T, Roesch, K, Lee, IH, et al. eyeSelfie: Self Directed Eye Alignment using Reciprocal Eye Box Imaging. Acm T Graphic. 2015;34(4).
11. Das, A, Swedish, T, Wahi, A, et al. Mobile phone based mini-spectrometer for rapid screening of skin cancer. Proc Spie. 2015;9482.
12. Giller, G. Using a Smartphone to Detect Cancer. Sci Am. 2014;310(5):28-.
13. Creuzot-Garcher, C, Martin-Phipps, T, Beynat, J, et al. Effectiveness of a Mobile Diabetic Retinopathy Screening Campaign to Encourage Diabetics to Undergo Regular Ophthalmic Follow-Up. Ophthalmic Res. 2014;52(4):206-11.
14. Pirnstill, CW, Cote, GL. Malaria Diagnosis Using a Mobile Phone Polarized Microscope. Sci Rep-Uk. 2015;5.
15. Granot, Y, Ivorra, A, Rubinsky, B. A new concept for medical imaging centered on cellular phone technology. PLoS One. 2008;3(4):e2075.
16. Jani, IV, Quevedo, JI, Tobaiwa, O, et al. Use of mobile phone technology to improve the quality of point-of-care testing in a low-resource setting. AIDS. 2016;30(1):159-61.
17. Muhlestein, JB, Le, V, Albert, D, et al. Smartphone ECG for evaluation of STEMI: results of the ST LEUIS Pilot Study. J Electrocardiol. 2015;48(2):249-59.
18. Rechmann, P, Liou, SW, Rechmann, BM, Featherstone, JD. Performance of a light fluorescence device for the detection of microbial plaque and gingival inflammation. Clin Oral Investig. 2016;20(1):151-9.
19. Gabel, M, Gilad-Bachrach, R, Renshaw, E, Schuster, A. Full Body Gait Analysis with Kinect. Ieee Eng Med Bio. 2012:1960-7.
20. Richards, JR, Gaylor, KA, Pilgrim, AJ. Comparison of traditional otoscope to iPhone otoscope in the pediatric ED. Am J Emerg Med. 2015;33(8):1089-92.
21. Eikelboom, RH, Mbao, MN, Coates, HL, Atlas, MD, Gallop, MA. Validation of tele-otology to diagnose ear disease in children. Int J Pediatr Otorhi. 2005;69(6):739-44.
22. Kopycka-Kedzierawski, DT, Bell, CH, Billings, RJ. Prevalence of dental caries in Early Head Start children as diagnosed using teledentistry. Pediatr Dent. 2008;30(4):329-33.
23. Russo, A, Morescalchi, F, Costagliola, C, Delcassi, L, Semeraro, F. A Novel Device to Exploit the Smartphone Camera for Fundus Photography. J Ophthalmol. 2015;2015:823139.
24. Baranwal, A, Anand, A, Singh, R, et al. Managing the Earth's Biggest Mass Gathering Event and WASH Conditions: Maha Kumbh Mela (India). PLoS Curr. 2015;7.

25. Nitzan, M, Romem, A, Koppel, R. Pulse oximetry: fundamentals and technology update. Med Devices (Auckl). 2014;7:231-9.
26. Gagnon, C, Mathieu, J, Desrosiers, J. Standardized finger-nose test validity for coordination assessment in an ataxic disorder. Can J Neurol Sci. 2004;31(4):484-9.
27. Norman, KE, Heroux, ME. Measures of fine motor skills in people with tremor disorders: appraisal and interpretation. Front Neurol. 2013;4:50.
28. Salzman, B. Gait and balance disorders in older adults. Am Fam Physician. 2010;82(1):61-8.
29. Spaeth, GL, Henderer, J, Liu, C, et al. The disc damage likelihood scale: reproducibility of a new method of estimating the amount of optic nerve damage caused by glaucoma. Trans Am Ophthalmol Soc. 2002;100:181-5; discussion 5-6.
30. Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults--The Evidence Report. National Institutes of Health. Obes Res. 1998;6 Suppl 2:51S-209S.
31. Pickering, TG, Hall, JE, Appel, LJ, et al. Recommendations for blood pressure measurement in humans and experimental animals: part 1: blood pressure measurement in humans: a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. Circulation. 2005;111(5):697-716.
32. Kumar, A, Kalra, S, Unnikrishnan, AG. Metabolic state of the nation: Results of the national family health survey-4. Indian J Endocrinol Metab. 2016;20(4):429-31.
33. Vold, ML, Aasebo, U, Melbye, H. Low FEV1, smoking history, and obesity are factors associated with oxygen saturation decrease in an adult population cohort. Int J Chron Obstruct Pulmon Dis. 2014;9:1225-33.
34. DeStefano, F, Anda, RF, Kahn, HS, Williamson, DF, Russell, CM. Dental disease and risk of coronary heart disease and mortality. BMJ. 1993;306(6879):688-91.
35. Mendez, MV, Scott, T, LaMorte, W, et al. An association between periodontal disease and peripheral vascular disease. Am J Surg. 1998;176(2):153-7.
36. Jampani, ND, Nutalapati, R, Dontula, BS, Boyapati, R. Applications of teledentistry: A literature review and update. J Int Soc Prev Community Dent. 2011;1(2):37-44.
37. Veerasamy, A, Kirk, R, Gage, J. Epidemiology of dental caries among adolescents in Tamil Nadu, India. Int Dent J. 2016;66(3):169-77.
38. George, R, Ve, RS, Vijaya, L. Glaucoma in India: estimated burden of disease. J Glaucoma. 2010;19(6):391-7.
39. Mbao, MN, Eikelboom, RH, Atlas, MD, Gallop, MA. Evaluation of video-otoscopes suitable for tele-otology. Telemed J E-Health. 2003;9(4):325-30.
40. Gourie-Devi, M. Epidemiology of neurological disorders in India: review of background, prevalence and incidence of epilepsy, stroke, Parkinson's disease and tremors. Neurol India. 2014;62(6):588-98.

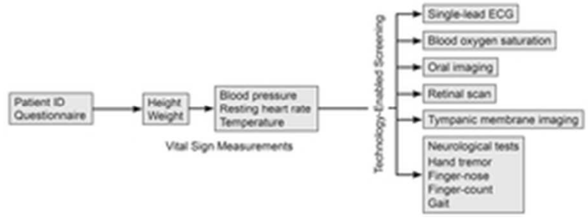

Fig 1. Study design. Flowchart for overall screening procedure.

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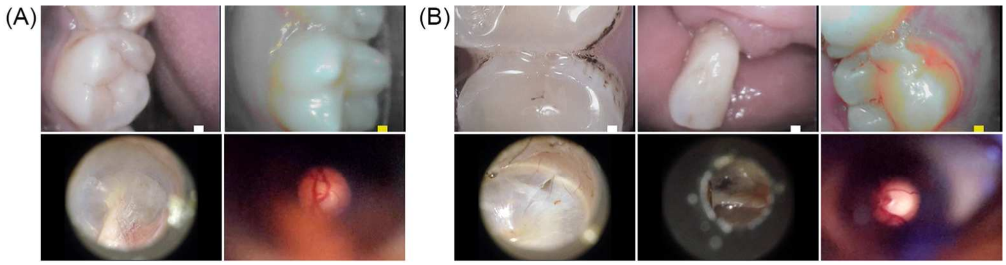


Fig 2. Representative images of labeled conditions detected in technology-enabled screenings.
(A) Normal images for technology-enabled screenings. Left-to-right, top-to-bottom: dental, periodontal, tympanic membrane, optic nerve.
(B) Labeled conditions for technology-enabled screenings. Left-to-right, top-to-bottom: caries, missing teeth, periodontal disease, perforated eardrum, effusion, width of optic rim 0.01-0.1.

149x38mm (300 x 300 DPI)

1 **Supplementary Appendix**

2

3 Contents

Supplementary Methods

Criteria, ethical considerations and consent procedure: Mahatma Gandhi Vidyamandir Karmaveer Bhausaheb Hiray Dental College & Hospital (MGVKBHDC) in Nashik was designated as one of the primary health provision and disaster management centers for the 2015 Sinhast Kumbh Mela (14 July-25 September). The hospital has an outpatient facility where pilgrims and local people were provided care, information and a resting area throughout the event. Indians between the ages of 18 years and 90 years of all ethnicities, races and genders were included in the study. Subjects younger than 18 years or older than 90 years were excluded from participation. 494 consenting adults were seen in the week that MGVKBHDC was soliciting volunteers. We anticipated pilgrims and out-of-state consenting adults would be the largest group to volunteer to be enrolled in this study, allowing us to examine inhabitants from all over the county, but local Indians were also allowed to participate. MGVKBHDC institutional human subjects review committee approved our consent procedure, clinical data collection and the plan for communication of testing results with the subjects (Protocol number: MGVKBHDC/15-16/571). Bilingual physicians from MGVKBHDC explained the scope of the study and consent forms (in English or Hindi) to subjects who were interested in participating. Subjects were asked to sign the consent forms and then remain in a waiting area before active participation in the study. Participants were free to leave at any point during their screenings. MGVKBHDC primary care physicians, dentists, ophthalmologists, otolaryngologists and neurologists performed the health screenings in the order outlined in **Fig 1**, communicated the results to subjects and provided appropriate referrals to patients needing additional medical care. De-identified data was transferred to the Massachusetts Institute of Technology (MIT) investigators for analysis after approval of the protocol by the MIT Committee on the Use of Humans as Experimental Subjects (MIT COUHES protocol number: 1512338971).

Data collection: A unique registration number (1-494) linked to each subject was used to store and annotate data from screening kiosks.

Medical history and routine health screenings: Self-reported responses of subjects to a detailed computerized questionnaire that included geographic and demographic questions, questions about past medical history and current illnesses. A bilingual physician recorded the medications and symptoms reported by the subjects as well as their reports of family medical history. An Omron 10 series wireless upper arm monitor with cuff (Model: BP786N) was used to collect systolic and diastolic blood pressure following the manufacturer's instructions (Omron Electronics, USA). Temperatures were measured using a digital thermometer. Height and body weight were measured using a digital scale and were recorded for all subjects.

Technology-enabled screening devices:

Blood oxygen saturation: A CMS 50-DL Pulse Oximeter (Contec Medical Systems, USA) was used to measure blood oxygen saturation levels of hemoglobin based on photoplethysmographic pulses and pulse rate from subjects' right index fingertips [25].

ECG: The AliveCor Mobile ECG (AliveCor Inc, USA) is a single-channel cardiac event recorder consisting of a device and smartphone app that can record and review ECGs [17]. a 30-second rhythm strip (lead I) recording was uploaded wirelessly for interpretation via the AliveCor algorithm, and an ECG analysis that indicated heart rate and presence of possible atrial fibrillation was displayed on the mobile phone. Before each use, a physician cleaned the two electrodes with alcohol-based sanitizer and launched the app on the smartphone (Nexus5, LG, South Korea).

Tympanic membrane imaging: Inspection of the external ear canal and eardrum was performed using the iPhone5 LEDs and camera with the CellScope Oto phone adapter (CellScope Inc. USA) [20]. A disposable ear tip attached to the device canula was used for imaging each subject.

Oral imaging: A commercially available FDA-approved intraoral camera with software, SOPROCARE (SOPRO Acteon Imaging, France), that automatically segments and displays images of plaque, caries and periodontal diseases was used [18]. Panning 30-second videos of the buccal surfaces of the upper first molars (16, 26), the buccal surface of the upper laterals (12, 22), the buccal surface of first lower molars (36, 46), as well as incisal, buccal and lingual surfaces of all accessible teeth were collected. The housing of the camera stick was covered in a clear disposable plastic sheath (U-line, USA) and sterile disposable camera bag. Subjects and clinicians wore UV protective eyewear during oral imaging. Images and video were collected by each of the following modes: (A) only 405nm LEDs powered, (B) only 450nm LEDs powered, (C) only white

LEDs powered. A HP 620 Notebook (Hewlett Packard, USA), Windows 7, (Microsoft Corporation, USA) with preloaded SOPROCARE software was used to store images and videos. A specialized scale for assigning patient scores vs. conventional DMFT (number of decayed, missing and filled teeth in an individual and in a population) or the Russell's periodontal indices was used by dentist examining the data. The camera system uses standard white light and three blue LEDS that emit non-ionizing light at 450 nm wavelengths. Inflamed gingiva can be scored due to fluorescence from porphyrins in blood. Illumination of microbial plaque with blue light induces fluorescence due to the bacteria and porphyrin content of the plaque.

Optic nerve head photography: Non-mydriatic digital retinal imaging using the D-EYE (D-EYE Srl, USA) direct ophthalmoscopy adapter attached to iPhone5s camera was performed to capture video and still images of optic nerves of subjects [23].

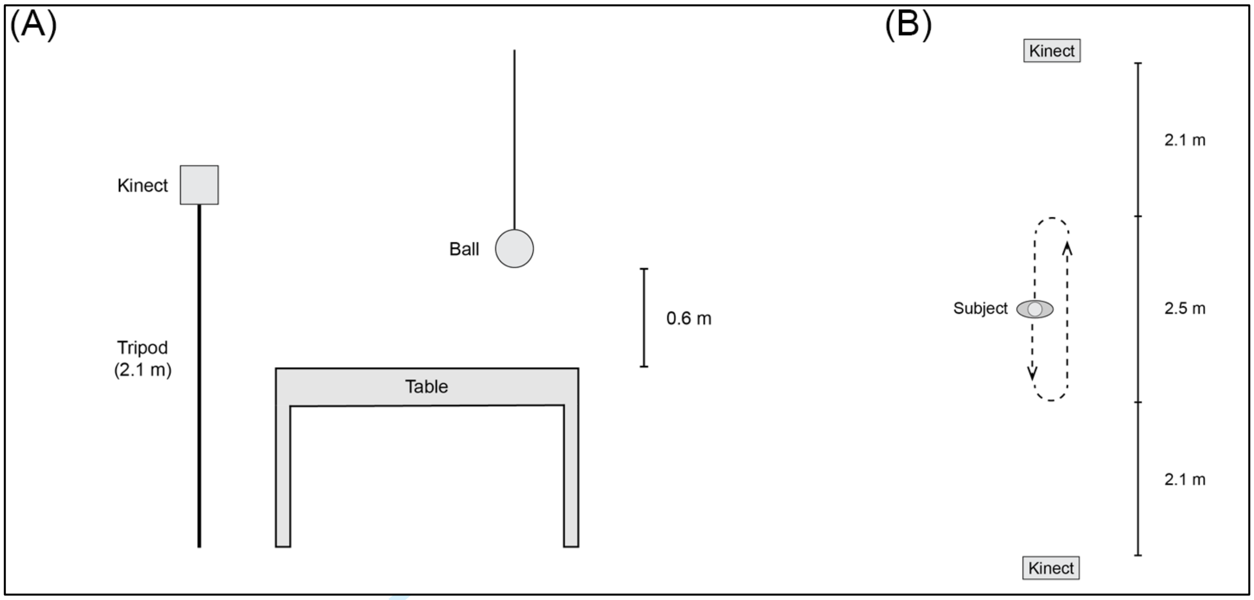
Gait and coordination analyses: The Microsoft Kinect (Microsoft Corporation, USA) sensor has an RGB camera, depth sensor and multi-array microphone, which provide full-body 3D motion capture, facial and voice recognition capabilities [19]. A 2D, depth and skeleton motion dataset of motor skills, hand-eye coordination, depth perception, neuromuscular stability of individual subjects was captured by the following protocol: a) finger-nose test with index finger touching a ball suspended from the ceiling two feet in front and then the nose: to identify tremors, incoordination, and dysmetria [26]; b) finger-count dexterity test to count to five using thumb touching fingertips: to detect slowness, tremors, and incoordination [27]; c) holding out hands steadily with palms facing down: to detect tremors and arm drift (upward, downward and lateral) [27], d) walking a distance of 2.5 meters in a straight line, turning around and walking back: to identify subjects who have posture abnormalities, tremors, imbalance (left/right), a penguin gait, or an asymmetric gait while walking [28]. Kinect sensors placed in front of and behind subjects were used to capture the walking in straight-line actions (**Supplementary Fig 1B**). For all other tests, one Kinect sensor was placed unobtrusively to the left or right of the subjects (**Supplementary Fig 1A**).

Data analyses: De-identified data assigned to unique subject IDs was split into five separate pools consisting of optic nerve, tympanic membrane, ear, oral and neurological videos for all study participants. BMI, blood pressure, resting heart rate and body temperature are routinely measured without sophisticated TES by most primary care providers and have been collectively annotated as "routine health screenings" throughout this study. Other imaging and smartphone-based tests have been designated as TES methods. Routine health screenings and responses to medical questionnaires were grouped together for computational analyses. Resting heart rate and temperature have clinically well-defined normal, high and low ranges. For BMI, numbers less than 19 were labeled low, between 19 and 25 were characterized as normal, and 25 and above were considered high [30]. For blood pressure, systolic pressure below 90 mmHg or diastolic pressure below 60 mmHg was considered low, systolic pressure between 90 and 140 mmHg and diastolic pressure between 60 and 90 mmHg was labeled normal, and systolic pressure above 140 mmHg or diastolic pressure above 90 mmHg was labeled high [31]. Blood oxygen levels of 90% or less were annotated low. The outputs from the AliveCor mobile app were readily used as annotations for ECG tests because they were labeled 'Normal' or 'Possible atrial fibrillation' [25].

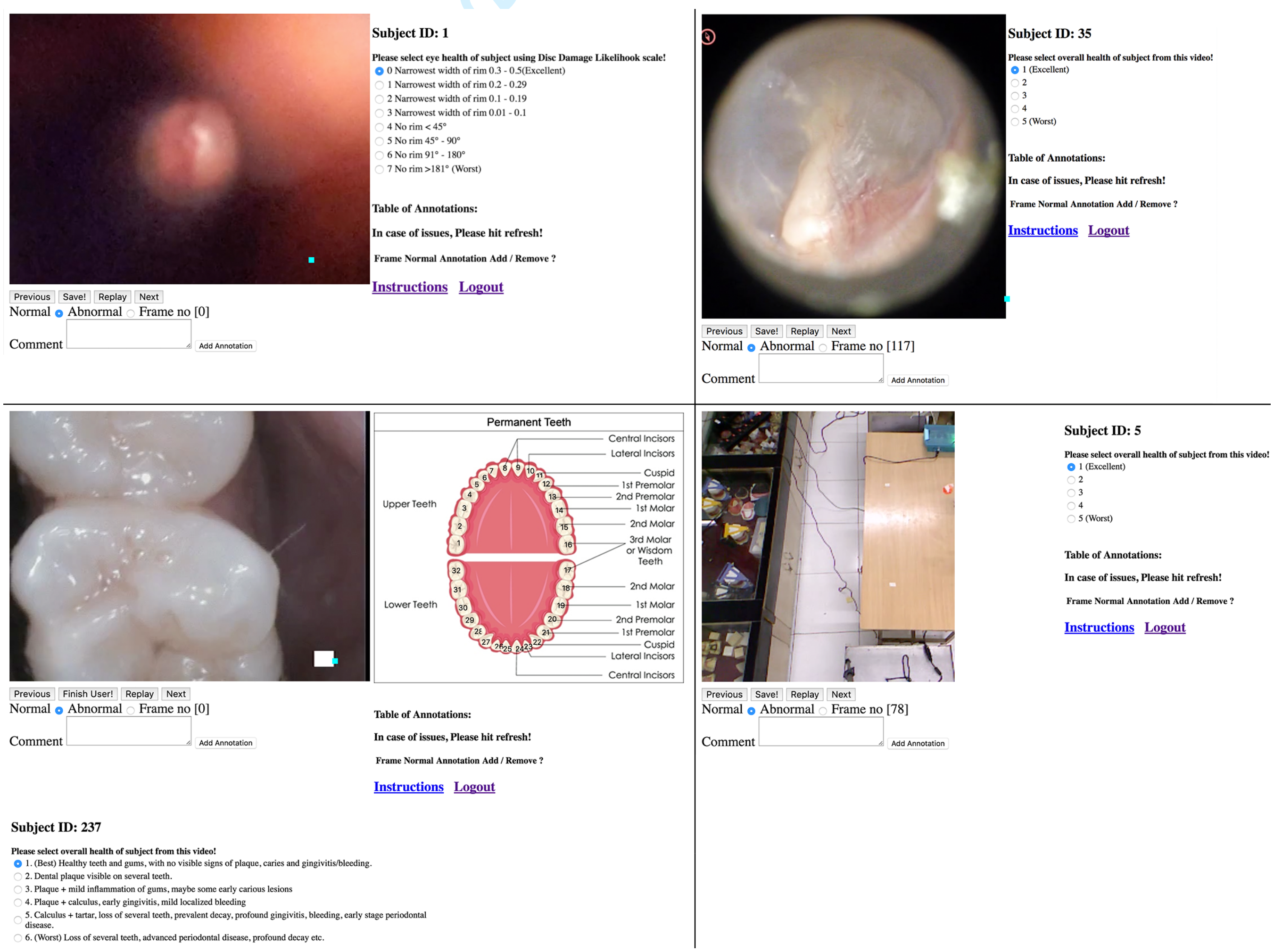
Videos captured by TES devices were categorized by patient ID and TES examination and displayed directly to expert physicians via a web-based examination portal conducted diagnostic feature annotation of de-identified images and videos. This password-protected secure interface was developed using web technologies (HTML, JavaScript, node.js) for this purpose and displayed an image or video for one patient at a time for a given examination. Annotators were able to mark specific features in the videos by drawing boxes around them that paused that specific frame, assign an overall score of 1 (best) to 5 (worst) for the entire video, and to write clinical features that were present for specific frames or the entire video (**Supplementary Fig 2**). A panel of at least three physicians for each type of examination was assembled and independently of each other remotely annotated the data facilitated by the web interface. Due to the greater quantity of Microsoft Kinect videos, three physician-trained raters annotated all the videos, and then an expert physician ratified their labels. The interface for optic nerve videos used a previously described Disc Damage Likelihood Scale (DDLS) scale for glaucoma screening [29]. The majority ratings for each subject were computed for all TES tests. For subjects with no majority rating, the lesser of the tied ratings was chosen to not overstate the prevalence of diagnosed illnesses. Results from each test were analyzed for cross-correlations with self-reported medical history responses, age and sex. Clinical findings for individuals who were tested at all six screening kiosks were also analyzed to generate population health profiles. Efficacy of routine health screenings vs. TES to identify at-risk or sick individuals examined during the study is discussed in the manuscript. Conditions outside the normal range identified by physicians for each TES test are as follows. Oral imaging: caries, missing teeth, periodontal disease;

tympanic membrane imaging: perforated eardrum, effusion; optic nerve head photography: width of optic rim 0.01-0.1; coordination analyses: abnormal finger-nose test.

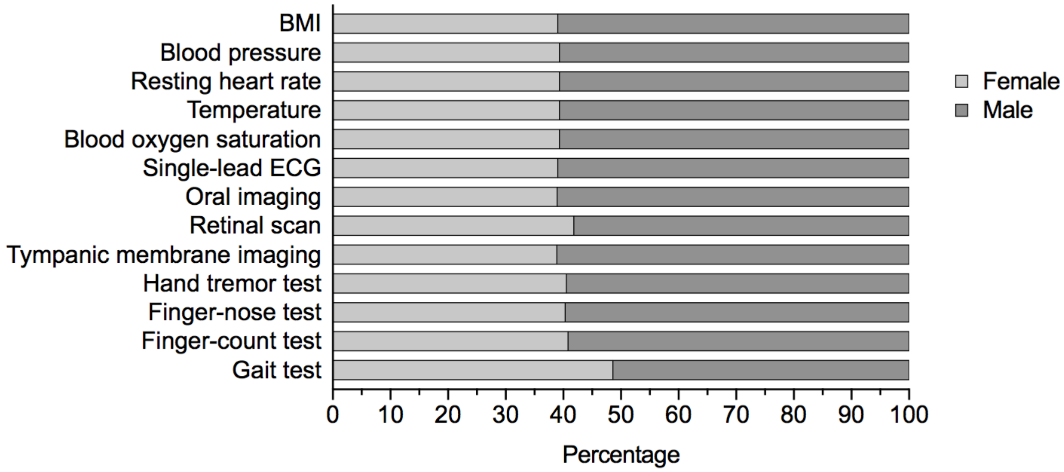
Statistical methods: Fisher's exact test was used to determine statistically significant correlations between diagnoses using TES or routine health screenings and number, age, sex and questionnaire responses of participating subjects. The significance threshold was set at $p < 0.05$. To determine in **Supplementary Table 7** whether high BMI was statistically more prevalent in one particular age cohort (out of a total of four age groups), we calculated four proportions representing the number of subjects in a specific age cohort who had high BMI compared to the total number of subjects in that age cohort. Each proportion was compared pairwise using Fisher's exact test, which reported *p*-values of 0.0014 and 0.0052 when comparing the proportion from the middle age cohort to the proportions from the young adult and old age cohorts, respectively. In **Supplementary Table 8** to determine that there is a statistically significant correlation between a subject being measured for high BMI and responding that they wear glasses, we calculated two proportions: 1) the number of subjects who had high BMI and said they wear glasses (115) compared to the total number of subjects with high BMI (196), and 2) the number of subjects who did not have high BMI and said they wear glasses (132) compared to the number of subjects who did not have high BMI regardless of whether they wear glasses (298). Fisher's exact test reported a p-value of 0.0024 when comparing these proportions, so we conclude that the correlation between high BMI and wearing glasses is significant. Analyses were performed on groups of subjects who completed each individual test to avoid considering subjects who did not have that test performed.



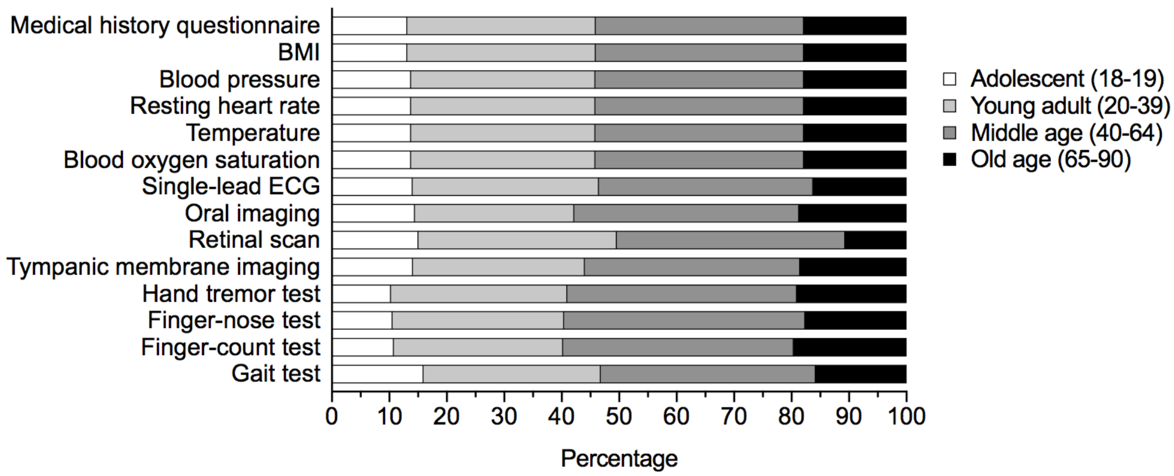
Supplementary Fig 1. Diagram of Microsoft Kinect placement for gait and coordination screening tests.
(A) Finger-nose test, from the side. Both the Kinect and ball are centered over the table with the patient facing the ball and the Kinect.
(B) Gait test, top-down. Both Kinects are 1 m off the ground and the subject walks in a straight line between them.



Supplementary Fig 2. Web interfaces for remote annotation used by physician experts for clinical evaluations.
Clockwise from top left: retinal scan, tympanic membrane imaging, gait and coordination tests, oral imaging



Supplementary Fig 3. Percentage of test populations of each gender.



Supplementary Fig 4. Percentage of test populations in each age cohort.
Age ranges for each cohort are in parentheses.

Supplementary Table 1. Test populations divided by gender and age cohorts.

	Adolescent (18-19)			Young adult (20-39)			Middle age (40-64)			Old age (65-90)		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
Medical history	39	26	65	64	88	152	73	115	188	17	72	89
Body mass index	39	26	65	64	88	152	73	115	188	17	72	89
Blood pressure	38	25	63	56	81	137	69	104	173	16	66	82
Resting heart rate	38	25	63	56	81	137	69	104	173	16	66	82
Temperature	38	25	63	56	81	137	69	104	173	16	66	82
Blood oxygen saturation	38	25	63	56	81	137	69	104	173	16	66	82
Single-lead electrocardiogram	36	25	61	58	81	139	60	100	160	14	56	70
Oral imaging	37	22	59	43	71	114	65	96	161	15	62	77
Retinal scan	37	23	60	61	79	140	63	97	160	8	36	44
Tympanic membrane imaging	30	9	39	35	52	87	49	80	129	12	57	69
Hand tremor test	24	8	32	41	55	96	50	75	125	12	48	60
Finger-nose test	24	8	32	37	54	91	50	78	128	12	42	54
Finger-count test	24	8	32	36	52	88	49	71	120	13	46	59
Gait test	30	4	34	33	33	66	34	46	80	7	27	34

Age ranges in years for each age cohort are in parentheses.

151 **Supplementary Table 2. Gender breakdown of self-reported medical history.**
152

	Female (n=193)	Male (n=301)	Total (n=494)
Glasses	54.9	46.8	50.0
Dental	21.2	29.2	26.1
Swollen joints	25.4	25.2	25.3
Hearing	17.1	24.9	21.9
Family history of diabetes	22.3	18.3	19.8
Leg cramps	19.7	17.9	18.6
Family history of high blood pressure	21.2	12.6	16.0
Fatigue	15.5	15.6	15.6
Acidity	20.2	11.3	14.8
Tiredness	13.0	15.0	14.2
Tobacco addiction	1.6	17.6	11.3
Surgery	9.8	10.0	9.9
Difficulty walking	10.4	9.6	9.9
High blood pressure	10.4	8.0	8.9
Diabetes	6.7	8.6	7.9
Snore Loudly	4.7	9.3	7.5
High blood pressure treatment	7.3	5.6	6.3
Environmental allergies	8.3	4.3	5.9
Sleepiness	5.2	5.6	5.5
Medication allergies	6.2	4.7	5.3
Asthma	4.7	5.0	4.9
Smoking addiction	0.0	7.6	4.7
Family history of cardiac diseases	3.1	3.3	3.2
Family history of asthma	3.1	3.0	3.0
Thyroid	5.7	1.0	2.8
Self-medication	1.0	4.0	2.8
Jewelry allergies	6.2	0.0	2.4
Past skin infection	3.1	2.0	2.4
Family history of thyroid disease	2.1	2.3	2.2
Cardiac treatment	1.0	2.7	2.0
Stop breathing during sleep	1.0	2.3	1.8
Oral infection	1.6	2.0	1.8
Kidney disorder	2.1	1.3	1.6
Skin problem	1.0	2.0	1.6
Skin infection	0.5	2.0	1.4
Food allergies	1.6	1.3	1.4
Hyperactivity	2.1	1.0	1.4
Cardiovascular	0.5	1.7	1.2
Migraine	2.1	0.7	1.2
Low blood pressure	2.6	0.3	1.2
Family history of stroke	2.1	0.3	1.0
Past ear infection	0.5	1.0	0.8
Family history of eye disease	0.5	1.0	0.8
Heart attack	0.0	1.3	0.8
Material allergies	1.0	0.7	0.8
Anxiety	0.5	1.0	0.8
Injury in past 6 months	0.5	1.0	0.8
Family history of depression	1.0	0.3	0.6
Coronary bypass surgery	0.0	1.0	0.6
Attention deficit disorder	1.0	0.3	0.6
Drinking addiction	0.0	1.0	0.6
Eye treatment	0.5	0.3	0.4
Family history of skin disease	0.5	0.3	0.4
Memory loss	1.0	0.0	0.4
Ear treatment	0.5	0.3	0.4
Lung diseases	0.5	0.3	0.4
Family history of ear disease	0.0	0.7	0.4
Cancer	0.5	0.0	0.2
Sexually transmitted disease	0.0	0.3	0.2
Liver disease	0.5	0.0	0.2
Skin treatment	0.5	0.0	0.2
Past gastric infection	0.0	0.3	0.2
Depression	0.0	0.0	0.0
Sleep disorder treatment	0.0	0.0	0.0
Heart murmur	0.0	0.0	0.0
Past lung infection	0.0	0.0	0.0

153
154 Percentage of total population by gender who answered yes to each medical history question.
155

Supplementary Table 3. Age cohort breakdown of self-reported medical history.

	Adolescent (18-19)	Young adult (20-39)	Middle age (40-64)	Old age (65-90)
Glasses	11	21	47	21
Dental	3	22	53	22
Swollen joints	0	10	51	38
Hearing	1	7	50	42
Family history of diabetes	17	44	34	5
Leg cramps	0	15	47	38
Family history of high blood pressure	18	46	33	4
Fatigue	1	21	55	23
Acidity	5	30	47	18
Tiredness	3	21	53	23
Tobacco addiction	0	18	46	36
Surgery	8	18	37	37
Difficulty walking	0	2	49	49
High blood pressure	0	9	57	34
Diabetes	0	15	64	21
Snore Loudly	0	27	65	8
High blood pressure treatment	0	6	55	39
Environmental allergies	17	41	34	7
Sleepiness	4	7	63	26
Medication allergies	15	15	54	15
Asthma	0	4	67	29
Smoking addiction	0	9	52	39
Family history of cardiac diseases	6	38	38	19
Family history of asthma	13	13	67	7
Thyroid	0	14	64	21
Self-medication	0	29	50	21
Jewelry allergies	0	33	67	0
Past skin infection	8	25	50	17
Family history of thyroid disease	18	55	9	18
Cardiac treatment	0	20	40	40
Stop breathing during sleep	0	33	33	33
Oral infection	0	11	67	22
Kidney disorder	13	13	50	25
Skin problem	0	0	50	50
Skin infection	0	29	57	14
Food allergies	0	29	57	14
Hyperactivity	14	29	57	0
Cardiovascular	0	33	67	0
Migraine	17	83	0	0
Low blood pressure	17	17	67	0
Family history of stroke	20	60	20	0
Past ear infection	0	75	0	25
Family history of eye disease	0	75	25	0
Heart attack	0	25	25	50
Material allergies	0	75	25	0
Anxiety	0	50	50	0
Injury in past 6 months	25	0	75	0
Family history of depression	33	67	0	0
Coronary bypass surgery	0	0	33	67
Attention deficit disorder	0	0	100	0
Drinking addiction	0	0	67	33
Eye treatment	0	0	0	100
Family history of skin disease	0	50	50	0
Memory loss	0	0	50	50
Ear treatment	0	0	100	0
Lung diseases	0	0	50	50
Family history of ear disease	0	50	0	50
Cancer	0	0	100	0
Sexually transmitted disease	0	100	0	0
Liver disease	0	0	100	0
Skin treatment	0	100	0	0
Past gastric infection	0	0	100	0
Depression	0	0	0	0
Sleep disorder treatment	0	0	0	0
Heart murmur	0	0	0	0
Past lung infection	0	0	0	0

Distribution of subjects, in percentages, who responded yes to a medical history question across age cohorts. Age ranges in years for each age cohort are in parentheses.

Supplementary Table 4. **Percentage of subjects in each age cohort who responded yes to a medical history question.**

	Adolescent (18-19)	Young adult (20-39)	Middle age (40-64)	Old age (65-90)
Glasses	43	34	62	57
Dental	6	18	36	33
Swollen joints	0	9	34	54
Hearing	2	5	29	51
Family history of diabetes	26	28	18	6
Leg cramps	0	9	23	39
Family history of high blood pressure	22	24	14	3
Fatigue	2	11	22	20
Acidity	6	14	18	15
Tiredness	3	10	20	18
Tobacco addiction	0	7	14	22
Surgery	6	6	10	20
Difficulty walking	0	1	13	27
High blood pressure	0	3	13	17
Diabetes	0	4	13	9
Snore Loudly	0	7	13	3
High blood pressure treatment	0	1	9	13
Environmental allergies	8	8	5	2
Sleepiness	2	1	9	8
Medication allergies	6	3	7	4
Asthma	0	1	9	8
Smoking addiction	0	1	6	10
Family history of cardiac diseases	2	4	3	3
Family history of asthma	3	1	5	1
Thyroid	0	1	5	3
Self-medication	0	3	4	3
Jewelry allergies	0	3	4	0
Past skin infection	2	2	3	2
Family history of thyroid disease	3	4	1	2
Cardiac treatment	0	1	2	4
Stop breathing during sleep	0	2	2	3
Oral infection	0	1	3	2
Kidney disorder	2	1	2	2
Skin problem	0	0	2	4
Skin infection	0	1	2	1
Food allergies	0	1	2	1
Hyperactivity	2	1	2	0
Cardiovascular	0	1	2	0
Migraine	2	3	0	0
Low blood pressure	2	0.7	2	0
Family history of stroke	2	2	1	0
Past ear infection	0	2	0	1
Family history of eye disease	0	2	0.5	0
Heart attack	0	0.7	0.5	2
Material allergies	0	2	0.5	0
Anxiety	0	1	1	0
Injury in past 6 months	2	0	2	0
Family history of depression	2	1	0	0
Coronary bypass surgery	0	0	0.5	2
Attention deficit disorder	0	0	2	0
Drinking addiction	0	0	1	1
Eye treatment	0	0	0	2
Family history of skin disease	0	0.7	0.5	0
Memory loss	0	0	0.5	1
Ear treatment	0	0	1	0
Lung diseases	0	0	0.5	1
Family history of ear disease	0	0.7	0	1
Cancer	0	0	0.5	0
Sexually transmitted disease	0	0.7	0	0
Liver disease	0	0	0.5	0
Skin treatment	0	0.7	0	0
Past gastric infection	0	0	0.5	0
Depression	0	0	0	0
Sleep disorder treatment	0	0	0	0
Heart murmur	0	0	0	0
Past lung infection	0	0	0	0

Age ranges in years for each age cohort are in parentheses.

Supplementary Table 5. Numbers of subjects in each age cohort identified by routine health screenings.

	Adolescent (18-19)			Young adult (20-39)			Middle age (40-64)			Old age (65-90)		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
High BMI	10	11	21	15	35	50	43	57	100	7	18	25
Low BMI	11	6	17	19	9	28	7	13	20	5	19	24
High BP	0	1	1	4	12	16	15	30	45	7	19	26
Low BP	1	0	1	2	0	2	0	1	1	0	0	0

Age ranges in years for each age cohort are in parentheses.

Supplementary Table 6. Percentages of subjects with each condition in our study and in each encompassing region from the National Family and Health Survey 4 (NFHS4).

	High BMI		Low BMI		High BP	
	Female	Male	Female	Male	Female	Male
Our study	38.9%	40.2%	21.8%	15.6%	14.5%	22.5%
NFHS4 India	20.7%	18.6%	22.9%	20.2%	8.8%	13.6%
NFHS4 Maharashtra	23.4%	23.8%	23.5%	19.1%	9.1%	15.9%
NFHS4 Nashik	22.9%	23.7%	25.8%	16.8%	5.7%	11%

Supplementary Table 7. Statistically significant prevalence of clinical conditions identified by routine health screenings across age cohorts.

				More prevalent cohort		Less prevalent cohort	
Condition	More prevalent in	Than in	*p*-value	No. with condition (percentage)	No. in cohort	No. with condition (percentage)	No. in cohort
High BMI	Middle age	Young adult	0.0014	100 (59.5)	168	50 (32.9)	152
High BMI	Middle age	Old age	0.0052	100 (59.5)	168	25 (28.1)	89
High BP	Young adult	Adolescent	0.0147	16 (11.9)	135	1 (1.5)	65
High BP	Middle age	Adolescent	<0.0001	45 (26.2)	172	1 (1.5)	65
High BP	Middle age	Young adult	0.0023	45 (26)	172	16 (10.5)	152
High BP	Old age	Adolescent	<0.0001	26 (31.7)	82	1 (1.5)	65
High BP	Old age	Young adult	0.0006	52 (66.7)	82	16 (10.5)	152

Age ranges in years for each cohort: 18-19 for adolescents, 20-39 for young adults, 40-64 for middle age, and 65-90 for old age.

Supplementary Table 8. Number of subjects with a routine health screening condition and responded yes to a medical history question.

Condition	No. with condition	Glasses	Dental	Swollen joints	Hearing	FH diabetes	FH high BP	Tobacco	Difficulty walking	High BP	Diabetes	High BP Rx	Asthma	Smoking	FH cardiac	Cardiac Rx	Cardiovascular	Low BP	FH stroke	FH eye disease	Heart attack	Coronary bypass	Drinking	Eye treatment	Memory loss	Ear treatment	FH ear disease	Cancer
High BMI	196	115*	48	52	38	48*	41*	23	19	26*	18	17	9	3**	5	5	1	1	1	3	2	1	1	0	2	2	1	0
Low BMI	89	39	21	23	25	11	10	16*	12	4	6	4	4	9*	1	1	0	2	1	0	0	0	1	0	0	0	0	0
High BP	88	54	24	30*	25	19	11	11	14*	17*	15*	14*	2	4	4	4	3	0	0	1	2	1	0	1	1	1	1	0
Low BP	4	3	1	1	1	2	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Total populations reflect the number of subjects with the particular condition in that row. Multiple subjects were associated with more than one condition or questionnaire response.
* $p < 0.05$, subjects are more likely to have responded yes to the column's question and have the routine health screening abnormality.
** $p < 0.05$, subjects are less likely to have responded yes to the column's question and have the routine health screening abnormality.

Supplementary Table 9. Statistically significant correlations between routine health screening conditions and self-reported medical history.

			Subjects with routine screening condition		Subjects without routine screening condition	
Condition	Medical History	*p*-value	No. responded yes (percentage)	No. with condition	No. responded yes (percentage)	No. without condition
High BMI	Glasses	0.0024	115 (58.7)	196	132 (44.3)	298
High BMI	FH diabetes	0.0384	48 (24.5)	196	50 (16.8)	298
High BMI	FH High BP	0.0173	41 (20.9)	196	38 (12.8)	298
Low BMI	Tobacco addiction	0.0406	16 (18.0)	89	40 (9.9)	405
High BMI	High BP	0.0091	26 (13.3)	196	18 (6.0)	298
Low BMI	Smoking	0.0122	9 (10.1)	89	14 (3.5)	405
High BMI	Smoking	0.0077	3 (1.5)	196	20 (6.7)	298
High BP	Glasses	0.0251	60 (68.2)	88	179 (48.8)	367
High BP	Swollen joints	0.0425	30 (34.1)	88	89 (24.3)	367
High BP	Difficulty walking	0.0483	14 (15.9)	88	33 (9.0)	367
High BP	High BP	0.0006	17 (19.3)	88	24 (6.5)	367
High BP	Diabetes	0.0004	15 (17.0)	88	22 (6.0)	367
High BP	High BP Rx	0.0002	14 (15.9)	88	17 (4.6)	367

Supplementary Table 10. Numbers of subjects in each age cohort identified by technology-enabled screenings.

	Adolescent (18-19)			Young adult (20-39)			Middle age (40-64)			Old age (65-90)		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
Blood oxygen saturation	0	2	2	2	2	4	3	5	8	0	5	5
Single-lead ECG	0	1	1	0	0	0	0	0	0	0	0	0
Oral	17	5	22	22	30	52	55	65	120	15	51	66
Retinal	2	1	3	2	7	9	9	8	17	4	9	13
Tympanic membrane	0	0	0	1	2	3	4	0	4	0	2	2
Hand tremor test	0	0	0	0	0	0	0	0	0	0	0	0
Finger-nose test	0	0	0	0	0	0	0	2	2	0	1	1
Finger-count test	0	0	0	0	0	0	0	0	0	0	0	0
Gait test	0	0	0	0	1	1	0	1	1	1	2	3

Age ranges in years for each age cohort are in parentheses.

Supplementary Table 11. Distribution of unhealthy subjects by clinical condition identified in each technology-enabled screening test.

Test	Condition	No. with condition (percent)	No. screened by test
Oral	Carious	156 (38.0)	411
Oral	Missing tooth	115 (28.0)	411
Oral	Edentulous	35 (8.5)	411
Oral	Periodontal disease	61 (14.8)	411
Retinal	Width of rim 0.01-0.1	9 (2.2)	404
Tympanic membrane	Perforated eardrum	25 (7.7)	324
Tympanic membrane	Effusion	20 (6.2)	324
Finger-nose	Abnormal	3 (1.0)	305
Gait	Abnormal	5 (2.3)	214

Supplementary Table 12. Number of subjects identified with clinical conditions in two technology-enabled screening tests.

	Tympanic membrane	Retinal	Oral	Finger-nose	Gait
Low blood oxygen	1	1	13	0	1
Tympanic membrane		0	26	2	2
Retinal			8	0	0
Oral				2	4
Finger-nose					0

Supplementary Table 13. Percentages of subjects identified with a clinical condition by a technology-enabled screening test and a routine health screening abnormality.

Abnormality	High BMI	Low BMI	High BP	Low BP
Low blood oxygen	21.1	42.1*	10.5	5.3
Tympanic Membrane	31.0	31.0	31.7	0.0
Retinal	44.4	11.1	11.1	0.0
Oral	40.4	17.3	20.6	0.8
Finger-nose	0.0	33.3	0.0	0.0
Gait	20.0	40.0	20.0	0.0

* $p < 0.05$, subjects are more likely to have the routine health screening abnormality if they have the technology-enabled screening condition.

Supplementary Table 14. Statistically significant correlations between conditions identified by a technology-enabled screening test and self-reported medical history.

			Subjects with condition		Subjects without condition	
Abnormality	Medical History	*p*-value	No. responded yes (percentage)	No. with condition	No. responded yes (percentage)	No. without condition
Low blood oxygen	Smoking	0.0087	4 (21.1)	19	15 (3.4)	436
Tympanic Membrane	Hearing difficulty	0.0053	17 (40.5)	42	65 (23.0)	282
Retinal	Hearing difficulty	0.0500	4 (44.4)	9	65 (16.5)	395
Retinal	Difficulty walking	0.0298	3 (33.3)	9	30 (7.6)	395
Oral	Glasses	0.0195	145 (56.9)	255	70 (44.9)	156
Oral	Dental problems	0.0043	82 (32.2)	255	30 (19.2)	156
Oral	Swollen joints	0.0002	85 (33.3)	255	26 (16.7)	156
Oral	Hearing difficulty	0.0017	72 (28.2)	255	23 (14.7)	156
Oral	FH high BP	0.0172*	31 (12.2)	255	33 (21.2)	156
Oral	Difficulty walking	0.0089	36 (14.1)	255	9 (5.8)	156
Oral	High BP	0.0339	30 (11.8)	255	8 (5.1)	156
Oral	High BP Rx	0.0490	24 (9.4)	255	6 (3.8)	156
Oral	Cardiac Rx	0.0267	8 (3.1)	255	0 (0)	156
Finger-nose	Difficulty walking	0.0009	3 (100)	3	27 (8.99)	302
Finger-nose	Swollen joints	0.0159	3 (100)	3	80 (26.0)	302
Gait	Teeth problems	0.0179	4 (80.0)	5	53 (25.4)	209
Gait	Swollen joints	0.0159	4 (80.0)	5	45 (21.5)	209

Supplementary Table 15. Age cohort and gender of subjects identified with any routine health screening or any technology-enabled screening abnormality.

	Adolescent (18-19)		Young adult (20-39)		Middle age (40-64)		Old age (65-90)		
	Female	Male	Female	Male	Female	Male	Female	Male	Total (n=111)
Routine health screening condition	10	0	8	19	11	21	2	8	79
Technology-enabled screening abnormality	9	0	8	11	14	18	2	8	70
Total in age cohort	19	0	16	23	16	26	2	9	

Supplementary Table 16. Detailed results of technology-enabled screenings and routine health screenings of the 111 subjects who completed all tests.

	Questionnaire	High BMI	Low BMI	High BP	Low BP	ECG	Hypoxemia	TM	Retinal	Oral	Finger-nose	Gait
Normal routine, Normal TES												
	x											
	x											
	x											
	x											
Routine health screening condition, normal TES		x										
		x										
			x									
		x										
		x										
		x										
				x								
			x									
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	x	x										
	x		x									
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	x	x		x								
	x	x		x								
	x	x		x								
	x	x		x								
	x	x		x								
Normal routine health screening, Abnormal TES										x		
										x		
								x				
										x		
										x		
										x		
	x									x		
	x								x			
	x									x		
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	x									x		
	x									x		
	x									x		
	x							x				
	x									x		x
	x						x		x	x		

Each row corresponds to a different individual whose age and gender have been anonymized
An x indicates that the subject was marked as abnormal in that row's test.
TM: Tympanic membrane.

Supplementary Table 17. **Detailed results of technology-enabled screenings and routine health screening of the 111 subjects who completed all tests.**

	Questionnaire	High BMI	Low BMI	High BP	Low BP	ECG	Hypoxemia	TM	Retinal	Oral	Finger-nose	Gait
Routine health screening condition, Abnormal TES			x							x		
			x							x		
		x		x				x				
	x			x						x		
	x	x						x				
	x	x					x					
			x					x		x		
	x	x								x		
	x	x								x		
			x					x		x		
	x	x								x		
			x					x		x		
	x			x						x		
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	x		x	x						x		
	x	x		x						x		
	x		x							x		x
	x		x				x			x		x
	x		x	x				x		x		
	x	x		x				x		x		x

Each row corresponds to a different individual whose age and gender have been anonymized
An x indicates that the subject was marked as abnormal in that row’s test.
TM: Tympanic membrane

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

Page(s)		Item No	Recommendation
1	**Title and abstract**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
2			(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
	Introduction		
4	Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
4, 5	Objectives	3	State specific objectives, including any prespecified hypotheses
	Methods		
6	Study design	4	Present key elements of study design early in the paper
6	Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
6, S2	Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up
n/a			(*b*) For matched studies, give matching criteria and number of exposed and unexposed
6, 7, S2, S3	Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
6, 7, S2, S3	Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
6, S2, S4	Bias	9	Describe any efforts to address potential sources of bias
6, S2	Study size	10	Explain how the study size was arrived at
6, S3, S4	Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
S3, S4	Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
S3, S4			(*b*) Describe any methods used to examine subgroups and interactions
6, 8, 11, 12			(*c*) Explain how missing data were addressed
n/a			(*d*) If applicable, explain how loss to follow-up was addressed
n/a			(*e*) Describe any sensitivity analyses
	Results		
18, S7	Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
6, S2			(b) Give reasons for non-participation at each stage

Fig 1			(c) Consider use of a flow diagram
S6, S8	Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
18			(b) Indicate number of participants with missing data for each variable of interest
n/a			(c) Summarise follow-up time (eg, average and total amount)
n/a	Outcome data	15*	Report numbers of outcome events or summary measures over time
8-12, 19	Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
S3			(*b*) Report category boundaries when continuous variables were categorized
n/a			(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
8-12	Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
	Discussion		
13	Key results	18	Summarise key results with reference to study objectives
15	Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
13, 15	Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
15	Generalisability	21	Discuss the generalisability (external validity) of the study results
	Other information		
16	Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

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Technology-enabled examinations of cardiac rhythm, optic nerve, oral health, tympanic membrane, gait and coordination evaluated jointly with routine health screenings: An observational study at the 2015 Kumbh Mela in India

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Technology-enabled examinations of cardiac rhythm, optic nerve, oral health, tympanic membrane, gait and coordination evaluated jointly with routine health screenings: An observational study at the 2015 Kumbh Mela in India

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ABSTRACT

Objectives: Technology-enabled non-invasive diagnostic screening (TES) using smartphones and other point-of-care medical devices was evaluated in conjunction with conventional routine health screenings for the primary care screening of patients.

Design: Dental conditions, cardiac ECG arrhythmias, tympanic membrane disorders, blood oxygenation levels, optic nerve disorders, and neurological fitness were evaluated using FDA-approved advanced smartphone powered technologies. Routine health screenings were also conducted. A novel remote web platform was developed to allow expert physicians to examine TES data and compare efficacy with routine health screenings.

Setting: The study was conducted at a primary care center during the 2015 Kumbh Mela in Maharashtra, India.

Participants: 455 consenting 18 to 90 years adults attending the 2015 Kumbh Mela were tested.

Results: TES and routine health screenings identified unique clinical conditions in distinct patients. Intraoral fluorescent imaging classified 63.3% of the population with dental caries and periodontal diseases. An association between poor oral health and cardiovascular illnesses was also identified. Tympanic membrane imaging detected eardrum abnormalities in 13.0% of the population, several with a medical history of hearing difficulties. Gait and coordination issues were discovered in eight subjects and one subject had arrhythmia. Cross-correlations were observed between low oxygen saturation and low BMI with smokers (p = 0.0087 and p= 0.0122, respectively), and association of high BMI with elevated blood pressure in middle-aged subjects were found.

Conclusions: TES synergistically identified clinically significant abnormalities in several subjects who otherwise presented as normal in routine health screenings. Physicians validated TES findings and utilized routine health screening data and medical history responses for comprehensive diagnoses for at-risk patients. TES identified high prevalence of oral diseases, hypertension, obesity and ophthalmic conditions among the middle-aged and elderly Indian population, calling for public health interventions.

Ethics approval: The Mahatma Gandhi Vidyamandir Karmaveer Bhausaheb Hiray Dental College & Hospital institutional ethics committee reviewed and approved protocol MGVKBHDC/15-16/571 for clinical data collection in Nashik, India. Deidentified data was transferred and analyzed at Massachusetts Institute of Technology (MIT) in Cambridge, MA, according to MIT Committee on the Use of Humans as Experimental Subjects approval for protocol 1512338971.

Strengths and limitations of this study:

- The strength of this work is that it is one of the first studies to investigate using technology-enabled mobile health screenings to augment routine health examinations.
- The study describes development and successful use of web examination platforms that enabled multiple physicians to diagnose health conditions remotely.
- A limitation of this study is that sample sizes for each test were different with respect to number of subjects and gender distribution.
- This study is limited to cross-sectional analysis. A future longitudinal study may allow for additional insights into time-varying conditions.

INTRODUCTION

Providing good healthcare in low and middle-income countries (LMIC) paradoxically requires expensive equipment for health monitoring and assessment which may not be easily available because of resource-limitations[1]. Cardiovascular diseases, preventable blindness, oral cancer and treatable neurological conditions constitute more than half of the disease burden in LMIC and result in significantly morbidity and mortality[2, 3]. India, with a population in excess of 1.2 billion individuals, is one of the largest countries in the world[4]. India has significant disparity in access to basic healthcare and diagnostic screenings due to its geographically fragmented medical infrastructure[5]. Consequently, significant portions of the population may exist either as undiagnosed, diagnosed but unaware or misdiagnosed for several high-risk diseases at the primary care level.

Inexpensive device-based imaging and first-level analysis (e.g., smartphones capable of pulse oximetry, blood pressure, ECG recording and analysis or image segmentation) either operated by human experts, by operators with basic training using algorithms or clinical decision support systems are examples of affordable and potentially scalable technology-enabled screening[6, 7]. Previous reports from our group have demonstrated the utility of smartphones, modular devices and imaging technologies for sleep apnea[8] and refractometry screenings[9], at-home monitoring of diabetic retinopathy[10] and detecting melanomas[11]. Using smartphones with low-cost adapters, other researchers have also performed oral and cervical cancer[12], diabetic retinopathy [13], and malaria[14] assessments. Mobile smartphones equipped with imaging adapters, high-resolution cameras, light emitting diodes, fast processors and lightweight apps can thus be used for targeted diagnostic screenings at modest expense[15, 16].

The majority of previous studies using newer TES approaches have been performed in silos concentrating on individual devices or specific anatomical sites, often precluding more comprehensive assessment of patient health[17-23]. Interpretation of TES data has also been limited by risk of bias, differences between study groups and lack of comparison to established routine health screenings that are otherwise commonly deployed in primary care screenings. Due to these reasons, a lack of consensus exists about the usefulness of TES in augmenting primary health screenings in LMIC. Therefore, there is a pressing need for cost-effective, reliable screening protocols and deployable technologies to empower LMIC medical professionals and healthcare providers to identify patients and add them to the continuum of care.

The 2015 Kumbh Mela mass gathering[24] presented a unique opportunity for deployment and side-by-side evaluation of TES and routine health screenings. Multiple TES devices and methods and a remote clinical examination system to facilitate examination of findings were utilized to evaluate their collective use for comprehensive diagnoses of consenting adults. This study assesses whether low-cost, portable and non-invasive examinations using TES can augment conventional routine health screenings by detecting additional anatomical, structural or biomarker-driven disease pathologies.

METHODS

Study design: 494 consenting adults between the ages of 18 and 90 years were screened by multiple tests in the order outlined in **Fig 1** at the Mahatma Gandhi Vidyamandir Karmaveer Bhausaheb Hiray Dental College & Hospital (MGVKBHDC) in Nashik, India, during the 2015 Sinhast Kumbh Mela (14 July-25 September). The MGVKBHDC institutional ethics committee reviewed and approved protocol MGVKBHDC/15-16/571 for clinical data collection in Nashik, India. Deidentified data was transferred and analyzed at Massachusetts Institute of Technology (MIT) in Cambridge, MA, according to MIT Committee on the Use of Humans as Experimental Subjects approval for protocol 1512338971. **Table 1** shows the number of subjects who completed each test. Subjects could exit the study at their convenience, and the study design allowed for different numbers of subjects for each test (**Table 1**). Inclusion criteria, ethical consideration, and consent procedure are described in the supplementary appendix.

Medical questionnaire and routine health screenings: A designated physician administered a medical questionnaire, where subjects provided verbal answers and the physician was responsible for entering their answers into a computerized interface. The detailed questionnaire included geographic and demographic questions as well as questions about past medical history and current illnesses but did not capture data from past healthcare records. Height, weight, systolic and diastolic blood pressure, resting heart rate, and temperature were also each measured, separately by a different physician.

Technology-enabled screening: FDA-approved devices were used to image patients, CellScope Oto (CellScope Inc. USA) for the tympanic membrane, D-EYE Direct Ophthalmoscopy Adapter (D-EYE Srl, USA) for the optic nerve head, and SOPROCARE (SOPRO Acteon Imaging, France) for dental health. Microsoft Kinect (Microsoft Corporation, USA) was used to record subjects performing gait and coordination tests (**Supplementary Fig 1**). AliveCor Mobile ECG (AliveCor Inc, USA) was used to capture and analyze a 30-second rhythm strip. A CMS 50-DL Pulse Oximeter (Contec Medical Systems, USA) was used to measure blood oxygen saturation levels of hemoglobin. All devices and clinical evaluations have been previously described elsewhere [17-20, 23, 25-29]. The supplementary appendix details specific procedures for each device and the principles by which each operates.

Data analyses: Expert physicians conducted diagnostic feature annotation of de-identified images and videos collected by TES via a web-based examination portal in order to maximize time in the field for screening additional subjects **(Supplementary Methods)**. This password-protected secure interface displayed an image or video for one patient at a time for a given examination. Physicians were able to mark specific features in the videos by drawing boxes around them that paused that specific frame, assign an overall score of 1 (best) to 5 (worst) for the entire video, and to write clinical features that were present for specific frames or the entire video (**Supplementary Fig 2**). A panel of at least three physicians for each type of examination was assembled who remotely and independently annotated the data facilitated by the web interface. The majority ratings for each subject were then calculated for all TES tests. For subjects with no majority rating, the lesser of the tied ratings was chosen to not overstate the prevalence of diagnosed illnesses. On average, each physician spent tens of seconds to approximately a minute annotating each per video. Results from each test were analyzed for cross-correlations with medical questionnaire responses, age and sex. Analyses of results from specific tests include data from all subjects who completed that test.

RESULTS

Medical history and routine health screenings: Results of routine health screenings are shown in **Table 1**, with gender and age range breakdowns in **Supplementary Table 1.** Medical questionnaire responses are shown in **Supplementary Tables 2, 3, and 4**. Accepted clinical ranges for each condition identified by routine health screenings through consultation with physicians and were applied automatically to the routine health screening data without requiring physicians to annotate the data on a per-patient basis (**Supplementary Methods**) [25, 30, 31]. Obesity (39.7%) and elevated blood pressure (19.3%) were identified as most prevalent among the screened population. In comparing our data to the latest release of the National Family and Health Survey, we detected higher prevalence of high BMI and elevated blood pressure for both females and males but a similar prevalence of low BMI (**Supplementary Tables 5, 6**) [32].

Population demographic analysis: It took an average of approximately 35 minutes for each patient to complete the medical questionnaire, routine health screenings and TES screening. Overall, there were more male than female participants which is likely at least in part the consequence of the fact that there are generally more male pilgrims at outdoor Indian religious festivals, including the Kumbh Mela. The gender breakdown for nearly all tests was approximately 60% males and 40% females, though gait analysis had an equal percent of both because the subjects who stayed long enough to complete that screening happened by chance to be split equally among males and females (**Supplementary Fig 3**). Adolescents (18 and 19 years of age) and old adults (65-90 years of age) were approximately 30% of the total population (**Supplementary Fig 4**). The remaining 70% of the population comprised approximately 31% of young adults (20-39 years) and approximately 39% middle age (40-64 years) subjects (**Supplementary Fig 4**). Three-fold more female than male adolescents and four-fold more old-aged males than old-aged females participated in the study, whereas other age groups had roughly equal numbers of males and females (**Supplementary Table 1**)

Medical questionnaire responses: Medical histories of dental issues, swollen joints, hearing difficulties, and leg cramps were each reported by 26.1%, 25.3%, 21.9%, 18.6% of the population, respectively (**Supplementary Table 2**). Several respondents reported a history of diabetes, blood pressure and cardiovascular diseases in their families. 8.9% of total respondents reported that they had been diagnosed with high blood pressure, and 6.3% were being treated for the disease (**Supplementary Table 2**). Subjects diagnosed with a certain clinical condition and/or undergoing treatment for it may not be the same individuals. 50.0% out of 494 respondents reported they wear glasses, indicating that they have refractive error vision problems. (**Supplementary Table 2**). Roughly equal numbers of both sexes responded yes to the majority of questions, with the exception of tobacco addiction, which was reported almost exclusively by males (**Supplementary Table 2**). **Supplementary Table 3** shows the age-cohort distribution of percentage of the people who said yes to a particular question (e.g. approximately 17% of the 98 subjects who said they had family history of diabetes were 18-19 year olds). Barring family history of diabetes, high blood pressure, and thyroid and cardiovascular diseases; higher percentages of middle- and older-aged adults said yes to the majority of all other questions (**Supplementary Table 3**). Additionally, higher percentages of individuals in the middle and old age groups vs. adolescents and young adults answered yes to medical history questions (e.g. approximately 35% of the 65 subjects in the 18-19 age group said they had a vision problem vs. approximately 67% and approximately 75% of 40-64 and 65-90-year-olds) (**Supplementary Table 4**). **Supplementary Tables 2, 3, and 4** each show the full list of questions asked in the medical questionnaire.

Prevalence of obesity and hypertension in males and low BMI in young females: Routine health screenings showed that approximately 19.3% of 455 subjects in the study had elevated blood pressure, and 0.9% had lower than normal blood pressure (**Table 1**). 22.5% of the 276 tested males of all age groups had elevated blood pressure measurements compared to 14.5% of the 179 tested females (**Table 2**). High BMI was measured in 39.7% of the tested population (**Table 1**). Middle age adults (40-64 years) had statistically significantly higher BMI than young adults (20-39 years) and old age subjects (65-90 years) (**Supplementary Table 7**). Middle and old age subjects also had statistically significantly higher BP than adolescents and adult participants in the study (**Supplementary Table 7**). Approximately 18.0% of the tested population was underweight (**Table 2**). More females in the 18-19 and 20-39 age groups and more males in the 40-64 and 65-90 age groups had lower BMI than subjects in other age groups (**Supplementary Table 5**). Overall, more males aged 20-39 were found to be obese compared to females of that age group (p=0.0375) who in fact were scored as underweight by statistical significance. Forty-two subjects, the majority in the 40-64 age group, suffered from hypertension and had high BMI. Underweight males and females between the ages of 40-64 also found to be at higher risk for elevated blood pressure (n=9).

Comparisons between medical questionnaire and results from routine health screenings: Adults aged 40 years and older of both sexes who were classified as abnormal in any routine health screening were the largest group of subjects correspondingly reporting family history, being diagnosed with, or receiving treatment for several diseases on the questionnaire. **Supplementary Table 8** lists p-values and percentages for cross-correlations between medical histories and results from routine health screenings. Statistically significant correlations between obesity and subjects who wore glasses (58.7%), reported high blood pressure (13.3%) or had a family history of diabetes (24.5%) or hypertension (20.9%) were identified (*p* = 0.0024, *p* = 0.0091, *p* = 0.0384, *p* = 0.0173, respectively) (**Supplementary Table 8**). Interestingly, overweight subjects were more statistically significantly likely to be non-smokers; conversely, underweight subjects were more likely to be either addicted to tobacco and/or smokers (*p* = 0.0406, *p* = 0.0122, respectively). Occurrences of high blood pressure cross-correlated with several groups of individuals' with a medical history of swollen joints, difficulty walking and diabetes (*p* = 0.0425, *p* = 0.0483, *p* = 0.0004, respectively). Subjects reporting either history of hypertension (n=7) or undergoing hypertension treatment (n=14) were statistically significantly more likely (*p* = 0.0006, *p* = 0.0002) to be measured with high blood pressure during our screening (**Supplementary Table 8**). High BMI and high blood pressure were additionally found to be correlated with many conditions on the medical questionnaire (**Supplementary Table 9**).

Identification of clinical conditions using TES: **Fig 2** shows representative diagnostic images and associated diagnoses captured using TES. Intraoral fluorescent (63.3%), tympanic membrane (13.0%) and oxygen saturation (4.2%) imaging examinations identified the largest percentage of unhealthy subjects (**Table 1**). **Supplementary Table 10** shows the breakdown of abnormal results by gender and age range. Approximately 38.0% of subjects had dental caries and 28.0% had one or more teeth missing. Periodontal diseases were found in 14.8% of the population (**Supplementary Table 11**). Previously undiagnosed subjects with abnormalities in their ECG rhythm strip (n=1), optic nerve imaging (n=9), gait analysis (n=5) and finger-nose coordination (n=3) test results were identified (**Table 1**). The expert physicians annotated all nine subjects identified with abnormal optic nerve heads with a cup-to-disc ratio more than 0.3. All subjects who completed the hand tremor and finger-count tests were found to be normal.

A slightly larger percentage of tested female participants compared to males were determined to be unhealthy across the majority of TES tests, although the differences were not statistically significant with the exception of middle-aged females who were statistically more likely to have poor dental health than middle-aged males (*p*=0.0266). Middle-aged (n=120) and older (n=66) adults of both sexes encompassed 70.7% of all subjects with abnormal oral TES results (**Supplementary table 10**). Statistically higher prevalence of dental diseases was measured in 65-90-year-olds and 40-64-year-olds compared to 18-19-year-olds and 20-39-year-olds (*p*<0.0001 in all four cases). Low blood oxygen saturation and abnormal tympanic membranes were found in 13 and 26 subjects, respectively, who also had dental issues (**Supplementary table 12**). One subject each had low blood oxygen, tympanic membrane problems and unsatisfactory performance in the gait test. Adults aged 40 and above of both sexes were the majority of the subjects who failed two TES tests.

Identification of subjects with abnormal routine health screenings and TES results: Numbers of subjects who were scored not normal in one test each from TES and routine health screening are shown in **Supplementary Table 13**. High and low BMI followed by elevated blood pressure measurements were most prevalent in subjects with abnormal TES results. Underweight individuals made up 18.0% of the population (**Table 1**), and 42.1% of these individuals also had low blood oxygen saturation (p=0.0110) (**Supplementary Table 13**). Similarly, approximately one third of the individuals with tympanic membrane abnormalities also had low BMI. Abnormal optic disc diameters were measured in four overweight participants (**Supplementary Table 13**). Dental screening identified the largest numbers of unhealthy subjects from the population who were measured with either high BMI, low BMI or elevated blood pressure, but these cross-correlations were not statistically significant due to extensive prevalence poor oral health in the community. Overall, high BMI (39.7%) and elevated blood pressure (19.3%) and poor dental health (63.3%) were widespread in middle-aged and older adults of the population (**Table 1, Supplementary tables 5 and 10**).

Comparisons between medical questionnaire and results from TES: Table 2 shows percentages of subjects who were scored as not normal in a particular TES test and responded yes to a medical history question. Individuals with swollen joints, hearing, and walking issues were found to be more likely to be scored as abnormal in TES tests compared to other groups. Four subjects (21.1%) measured with low oxygen saturation had a medical history of being smokers and this correlation was statistically significant (**Supplementary table 14**). 40.5% of the subjects for whom we identified tympanic membrane abnormalities reported hearing issues (p=0.0053). (**Supplementary table 14**). Presence of dental caries, gingivitis and or periodontal diseases was correlated with more statistically significant incidences of various clinical conditions reported in the medical questionnaire. High percentages of subjects scored as not normal in the finger-nose (n=3) and or gait tests (n=5) had reported hearing issues (**Table 2**). Similar to results in routine health screenings, individuals aged 40 years and older of both sexes were the largest group of subjects who gave affirmative responses to the questionnaire and abnormal TES results, although this was not statistically significant.

TES synergistically identifies unique subset of abnormal individuals in conjunction with routine health screenings: Data from subjects who completed the medical questionnaire, all routine health screenings and all TES tests (n=111) allowed comprehensive analyses. Subjects who exited the study before completing all routine health screenings and TES tests were not considered in these analyses. Routine health screenings identified 32 as normal and 79 as abnormal from these 111 subjects, compared to 41 normal and 70 abnormal subjects classified by TES (**Supplementary Table 15**). **Supplementary Tables 16 and 17** show the data for each of the

111 subjects. Our data indicates that a similar percentage of these 111 subjects benefitted from diagnosis offered by TES as those screened by routine health screenings. **Table 3** shows the age and gender profiles for 111 subjects and the differential diagnoses between the two screening methods.

Overall, we found abnormal BMI measurements and poor dentition led to the majority of the abnormalities in these 111. Tympanic membrane and BP abnormalities were the second-most widespread in this cohort. Medical questionnaire responses and TES screening results from these 111 subjects illustrate another use case with value for augmented screening. Several individuals with healthy medical histories were found to have either abnormal routine health screenings (n=12) or TES results (n=7) or both (n=6). Dental and ear issues were the most common TES abnormalities associated with these subjects with healthy medical histories. Importantly, all seven subjects with a healthy medical questionnaire identified as abnormal by TES (dental, n=5; optic nerve, n=1; tympanic membrane, n=1) had no previous diagnoses of these conditions and were different from the 12 individuals with abnormal routine health screenings. These results indicate the unique and synergistic value of TES in providing comprehensive care in conjunction with routine health screenings.

DISCUSSION

Many of the subjects identified by TES did not have any abnormal routine health screenings, indicating that TES can play a role in identifying subjects who need care but would not be identified by routine health screenings alone. Each TES test identified distinctive abnormities in different patients and played a distinct role in identifying at-risk or sick individuals. Because the TES tests screen for much different conditions than the routine health screenings, our results indicate mutually independent but not entirely mutually exclusive performances of both in identifying at-risk or sick subjects. We examined several potential moderators and old age was a statistically significant premonition for abnormal TES results, underscoring the crucial role for augmented screenings in middle-aged and geriatric individuals. Large proportions of subjects identified with abnormalities in oral (69.1%), tympanic membrane (59.5%), and retinal (33.3%) tests, as well as the only subject in the single-lead ECG test, did not report their respective conditions on their medical questionnaires. TES thus facilitates more thorough and non-invasive primary care screenings and may expedite early interventions for conditions not identified by routine health screenings.

Routine health screenings provided valuable insights into the rising epidemics of hypertension and obesity in the screened population in our study. Approximately 19.3% of the screened population in our study was suffering from hypertension. 18.0% of the screened population in our study was underweight (BMI <18.5) and several of these subjects were hypoxic, with low oxygen saturation, which can be considered a proxy measure for anemia. Pulseoximetry screenings identified 19 subjects with <90% SpO2. Vold et.al, in studies carried out in Norway, have reported high BMI, middle age and smoking as predictors of oxygen saturation[33]. Subjects with low blood oxygen had medical histories of smoking addiction and asthma. Most of them were middle-aged males, and the majorities were underweight. We also detected optic nerve abnormalities, dental diseases, gait and hearing difficulties in subjects with low blood oxygen, suggesting that a poor overall health status may co-exist with low blood oxygen measurements. Our data suggests the usefulness of deploying pulse oximetry for general health screenings, especially for underweight patients in LMIC.

Inadequate dental hygiene and resulting sequelae can have significant impact on quality of life and increase the risk of cardiovascular diseases[34, 35]. “Remote monitoring” and “Store-forward” approaches for dental examinations, reviewed elsewhere[36], have been used for teledentistry. In patients aged 65-74 years, the prevalence of caries was approximately 70% and multi-centric oral health survey reported the prevalence of carries to be 51-95% [37]. We found approximately 48% of 65-90-year-olds diagnosed with caries or periodontal disease. A high percentage of 45-60-year-old subjects in our study, who usually may not have been detected by traditional methods, were identified with poor dental health and may have been detected due to the more comprehensive evaluation offered by TES. Significant cross-correlations between patients reporting cardiovascular treatment with poor oral health (p=0.0267) was identified, underscoring the importance of routine dental care and calling for urgent attention to the oral disease epidemic in India.

There are approximately 11.2 million persons aged 40 years and older with glaucoma in India[38]. The most common optic nerve abnormalities that were detected in our study were optic nerve cupping as a risk factor for glaucoma, and optic nerve head neovascularization that is a sign of diabetic retinopathy. All nine patients who were scored as abnormal by optic nerve photography in our study had a DDLS scores of three, indicating early onset of glaucoma. The majority of these patients were females aged between 20-64 years whereas two old age males were marked abnormal. Four patients were also obese and high blood pressure was measured in two individuals, highlighting vulnerable status of young and middle aged obese Indian population.

Smartphone-enabled tele-otology has been deemed suitable for both on-site and remote diagnoses of tympanic membrane and Otitis media (OM) previously[39]. Perforated tympanic membranes (59.2%) and/or effusions (47.6%) were most prevalent in patients labeled as abnormal by ENT surgeons. These patients may have been suffering from OM infection and or a generalized inflammation. A large segment of these subjects were middle age or older adults and were also the predominant group that failed the gait and coordination test. Physician consensus, imaging data and a history of hearing issues emphasize the substantial challenges in diagnosing and treating these patients. We did not perform audiology or speeches tests with these subjects and thus are unable to cross correlate the imaging data with functional tests.

Due to acute shortages of trained neurologists, diagnoses of neurological disorders is extremely challenging in LMIC[40]. Three subjects in the finger-nose test were identified with incoordination and dysmetria. Seven out of the eight total subjects failing neurological tests were males older than 40 years, and three were underweight. The majority of subjects failing either the gait and/or finger-nose tests a medical history of swollen joints and a few said that they had difficulty in walking (all subjects were able to walk unassisted). It is conceivable that these issues may be unlinked or causal to their performance in the gait test. However, none of these conditions had previously been diagnosed in these individuals reaffirming a need for more aggressive and large-scale screening using TES methods. We are working on generative algorithms for classification of various neurological disorders and hope to incorporate these in future studies.

324 Physicians using TES devices in our study commented that a brief period of acclimatization was necessary in both use and interpretation of results from the devices before use in the study. Incorporating training for use of mobile technologies for diagnoses during medical school can reduce this learning curve. To our surprise, most of our tele-examination physicians could accurately diagnose presented conditions often with overwhelming consensus between them. Patients enrolled in our study were also pleased to see immediate results from TES and get rapid feedback from physicians. We acknowledge that TES devices may provide only an indication of the clinical pathologies they evaluate instead of a thorough diagnosis. Despite the claims made by device manufacturers, we also recognize that in their current form-factor TES will not replace or completely remove the physician from the loop. We used representative, clinically validated devices in this study, and our diagnoses may be generalizable to findings from similar datasets. Due to some subjects leaving the study early, the numbers of patients examined by each TES test and routine health screening were not identical, restricting more comprehensive analyses to the 111 subjects who completed all tests. Although this work is one of the largest, if not the largest, studies carried out using a wide array of different TES methods, a larger sample size in follow-up studies may result in more comprehensive identification of patient demographics and the full gamut of clinical conditions. We do, however, emphasize that one goal of this study was to conduct a cross-sectional analysis of both the population and the tests instead of focusing on only one TES method with a large sample size.

341 While routine health screenings continue to be important, this study demonstrates that the emerging techniques of TES can play an important synergistic role in stratifying populations and providing personalized screening and care, especially in LMIC. Multiple TES screening methods and data analyses outlined in this study can help in training and standardization for deployment of augmented, low-cost, non-invasive and portable screening approaches in conjunction with traditional primary healthcare exams, leading to increased clinical interventions, diagnoses and awareness of health conditions for individuals.

Footnotes

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Data sharing*: Anonymized patient level data and or full dataset will be made available following standard MIT Committee on the Use of Humans as Experimental Subjects data sharing protocols.*

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Author contributions: *Otkrist Gupta, Mrinal Mohit, and Gregory Yauney organized the data received from collaborating institution by pooling various test data for each patient, Otkrist Gupta created a web analysis platform for remote examinations; Pratik Shah, Otkrist Gupta, SV Subramanian, Vincent Patalano and Gregory Yauney analyzed and interpreted data labeled by expert physicians; Pratik Shah, Gregory Yauney, and Otkrist Gupta performed literature search; Gregory Yauney made figures; Pratik Shah and Gregory Yauney wrote the manuscript; Rikin Merchant led clinical data collection and coordinated transfer to MIT; Pratik Shah supervised the research and directed the study at MIT.*

FIGURE LEGENDS

Fig 1. Study design. Flowchart for overall screening procedure.

Fig 2. Representative images of labeled conditions detected in technology-enabled screenings.
(A) Normal images for technology-enabled screenings. Left-to-right, top-to-bottom: dental, periodontal, tympanic membrane, optic nerve.
(B) Labeled conditions for technology-enabled screenings. Left-to-right, top-to-bottom: caries, missing teeth, periodontal disease, perforated eardrum, effusion, width of optic rim 0.01-0.1.

Table 1. Results of routine health screenings and technology-enabled screenings.

	Female		Male		Total	
	Abnormal	Tested	Abnormal	Tested	Abnormal	Tested
Routine health screenings						
High BMI	75 (38.9)	193	121 (40.2)	301	196 (39.7)	494
Low BMI	42 (21.8)	193	47 (15.6)	301	89 (18.0)	494
High BP	26 (14.5)	179	62 (22.5)	276	88 (19.3)	455
Low BP	3 (1.7)	179	1 (0.4)	276	4 (0.9)	455
Technology-enabled screenings						
Low blood oxygen	5 (2.8)	179	14 (5.1)	276	19 (4.2)	455
Single-lead ECG	0 (0.0)	168	1 (0.4)	262	1 (0.2)	430
Oral	109 (68.1)	160	151 (60.2)	251	260 (63.3)	411
Retinal	5 (3.0)	169	4 (1.7)	235	9 (2.2)	404
Tympanic membrane	17 (13.5)	126	25 (12.6)	198	42 (13.0)	324
Hand tremor	0 (0.0)	127	0 (0.0)	186	0 (0.0)	313
Finger-nose	0 (0.0)	123	3 (1.6)	182	3 (1.0)	305
Finger-count	0 (0.0)	122	0 (0.0)	177	0 (0.0)	299
Gait	1 (1.0)	104	4 (3.6)	110	5 (2.3)	214

Numbers and percentages (in parentheses) of males and females with conditions identified by routine health screenings and technology-enabled screenings.

Table 2. Number of subjects identified with a clinical condition by a technology-enabled screening test and responded yes to a medical history question.

Abnormality	No. with abnormality	Glasses	Dental	Swollen joints	Hearing	FH diabetes	FH high BP	Tobacco	Difficulty walking	High BP	Diabetes	High BP Rx	Asthma	Smoking	FH cardiac	Cardiac Rx	Cardiovascular	Low BP	FH stroke	FH eye disease	Heart attack	Coronary bypass	Drinking	Eye treatment	Memory loss	Ear treatment	FH ear disease
Hypoxemia	19	7	9	3	5	2	0	3	3	0	0	0	3	4*	0	1	0	0	0	0	0	0	0	0	0	0	0
TM	42	22	14	14	17	7	6	3	5	5	4	4	3	1	2	1	1	0	1	0	0	0	0	0	0	1	0
Retinal	9	6	5	4	4	2	2	0	3*	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Oral	260	145*	82*	85*	72*	41	31**	27	36*	30	23	24*	15	13	7	8*	4	3	2	3	3	3	1	2	2	1	1
Finger-nose	3	1	1	3*	2	0	0	1	3*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gait	5	1	4*	4*	3	1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0

Total populations reflect the number of subjects with the particular condition in that row. Multiple subjects were associated with more than one condition or questionnaire response.
TM: tympanic membrane.
* $p < 0.05$, subjects are more likely to have responded yes to the column's question and have the condition.
** $p < 0.05$, subjects are less likely to have responded yes to the column's question and have the condition.

Table 3. Synergistic role of technology-enabled screening in identifying at-risk or sick individuals.

Routine health screenings	TES	Adolescent (18-19) Female	Adolescent (18-19) Male	Young adult (20-39) Female	Young adult (20-39) Male	Middle age (40-64) Female	Middle age (40-64) Male	Old age (65-90) Female	Old age (65-90) Male	Total (n=111)
✓	✓	5	0	3	0	0	2	0	0	10
x	✓	5	0	5	12	2	6	0	1	31
✓	x	4	0	5	4	5	3	0	1	22
x	x	5	0	3	7	9	15	2	7	48
Total in age cohort		19	0	16	23	16	26	2	9	111

Check marks indicate normal status while x indicates abnormalities in a particular screening method.

REFERENCES

1. Rivo, M. 2008 World Health Report emphasizes importance of primary health care. Am Fam Physician. 2009;79(12):1051.
2. Alwan, A, Maclean, DR, Riley, LM, et al. Monitoring and surveillance of chronic non-communicable diseases: progress and capacity in high-burden countries. Lancet. 2010;376(9755):1861-8.
3. Samb, B, Desai, N, Nishtar, S, et al. Prevention and management of chronic disease: a litmus test for health-systems strengthening in low-income and middle-income countries. Lancet. 2010;376(9754):1785-97.
4. Thakur, J. Key recommendations of high-level expert group report on universal health coverage for India. Indian J Community Med. 2011;36(Suppl 1):S84-5.
5. Shi, L. The impact of primary care: a focused review. Scientifica (Cairo). 2012;2012:432892.
6. Dhawan, AP, Heetderks, WJ, Pavel, M, et al. Current and Future Challenges in Point-of-Care Technologies: A Paradigm-Shift in Affordable Global Healthcare With Personalized and Preventive Medicine. IEEE J Transl Eng Health Med. 2015;3:2800110.
7. Topol, EJ. Transforming medicine via digital innovation. Sci Transl Med. 2010;2(16):16cm4.
8. Puri, RS, Athanassiadis, AG, Gill, N, et al. Design and preliminary evaluation of a wearable device for mass-screening of sleep apnea. Annual International Conference of the IEEE Engineering in Medicine and Biology Society 2016;38th
9. Pamplona, VF, Mohan, A, Oliveira, MM, Raskar, R. NETRA: Interactive Display for Estimating Refractive Errors and Focal Range. Acm T Graphic. 2010;29(4).
10. Swedish, T, Roesch, K, Lee, IH, et al. eyeSelfie: Self Directed Eye Alignment using Reciprocal Eye Box Imaging. Acm T Graphic. 2015;34(4).
11. Das, A, Swedish, T, Wahi, A, et al. Mobile phone based mini-spectrometer for rapid screening of skin cancer. Proc Spie. 2015;9482.
12. Giller, G. Using a Smartphone to Detect Cancer. Sci Am. 2014;310(5):28-.
13. Creuzot-Garcher, C, Martin-Phipps, T, Beynat, J, et al. Effectiveness of a Mobile Diabetic Retinopathy Screening Campaign to Encourage Diabetics to Undergo Regular Ophthalmic Follow-Up. Ophthalmic Res. 2014;52(4):206-11.
14. Pirnstill, CW, Cote, GL. Malaria Diagnosis Using a Mobile Phone Polarized Microscope. Sci Rep-Uk. 2015;5.
15. Granot, Y, Ivorra, A, Rubinsky, B. A new concept for medical imaging centered on cellular phone technology. PLoS One. 2008;3(4):e2075.
16. Jani, IV, Quevedo, JI, Tobaiwa, O, et al. Use of mobile phone technology to improve the quality of point-of-care testing in a low-resource setting. AIDS. 2016;30(1):159-61.
17. Muhlestein, JB, Le, V, Albert, D, et al. Smartphone ECG for evaluation of STEMI: results of the ST LEUIS Pilot Study. J Electrocardiol. 2015;48(2):249-59.
18. Rechmann, P, Liou, SW, Rechmann, BM, Featherstone, JD. Performance of a light fluorescence device for the detection of microbial plaque and gingival inflammation. Clin Oral Investig. 2016;20(1):151-9.
19. Gabel, M, Gilad-Bachrach, R, Renshaw, E, Schuster, A. Full Body Gait Analysis with Kinect. Ieee Eng Med Bio. 2012:1960-7.
20. Richards, JR, Gaylor, KA, Pilgrim, AJ. Comparison of traditional otoscope to iPhone otoscope in the pediatric ED. Am J Emerg Med. 2015;33(8):1089-92.
21. Eikelboom, RH, Mbao, MN, Coates, HL, Atlas, MD, Gallop, MA. Validation of tele-otology to diagnose ear disease in children. Int J Pediatr Otorhi. 2005;69(6):739-44.
22. Kopycka-Kedzierawski, DT, Bell, CH, Billings, RJ. Prevalence of dental caries in Early Head Start children as diagnosed using teledentistry. Pediatr Dent. 2008;30(4):329-33.
23. Russo, A, Morescalchi, F, Costagliola, C, Delcassi, L, Semeraro, F. A Novel Device to Exploit the Smartphone Camera for Fundus Photography. J Ophthalmol. 2015;2015:823139.
24. Baranwal, A, Anand, A, Singh, R, et al. Managing the Earth's Biggest Mass Gathering Event and WASH Conditions: Maha Kumbh Mela (India). PLoS Curr. 2015;7.

25. Nitzan, M, Romem, A, Koppel, R. Pulse oximetry: fundamentals and technology update. Med Devices (Auckl). 2014;7:231-9.
26. Gagnon, C, Mathieu, J, Desrosiers, J. Standardized finger-nose test validity for coordination assessment in an ataxic disorder. Can J Neurol Sci. 2004;31(4):484-9.
27. Norman, KE, Heroux, ME. Measures of fine motor skills in people with tremor disorders: appraisal and interpretation. Front Neurol. 2013;4:50.
28. Salzman, B. Gait and balance disorders in older adults. Am Fam Physician. 2010;82(1):61-8.
29. Spaeth, GL, Henderer, J, Liu, C, et al. The disc damage likelihood scale: reproducibility of a new method of estimating the amount of optic nerve damage caused by glaucoma. Trans Am Ophthalmol Soc. 2002;100:181-5; discussion 5-6.
30. Clinical Guidelines on the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults--The Evidence Report. National Institutes of Health. Obes Res. 1998;6 Suppl 2:51S-209S.
31. Pickering, TG, Hall, JE, Appel, LJ, et al. Recommendations for blood pressure measurement in humans and experimental animals: part 1: blood pressure measurement in humans: a statement for professionals from the Subcommittee of Professional and Public Education of the American Heart Association Council on High Blood Pressure Research. Circulation. 2005;111(5):697-716.
32. Kumar, A, Kalra, S, Unnikrishnan, AG. Metabolic state of the nation: Results of the national family health survey-4. Indian J Endocrinol Metab. 2016;20(4):429-31.
33. Vold, ML, Aasebo, U, Melbye, H. Low FEV1, smoking history, and obesity are factors associated with oxygen saturation decrease in an adult population cohort. Int J Chron Obstruct Pulmon Dis. 2014;9:1225-33.
34. DeStefano, F, Anda, RF, Kahn, HS, Williamson, DF, Russell, CM. Dental disease and risk of coronary heart disease and mortality. BMJ. 1993;306(6879):688-91.
35. Mendez, MV, Scott, T, LaMorte, W, et al. An association between periodontal disease and peripheral vascular disease. Am J Surg. 1998;176(2):153-7.
36. Jampani, ND, Nutalapati, R, Dontula, BS, Boyapati, R. Applications of teledentistry: A literature review and update. J Int Soc Prev Community Dent. 2011;1(2):37-44.
37. Veerasamy, A, Kirk, R, Gage, J. Epidemiology of dental caries among adolescents in Tamil Nadu, India. Int Dent J. 2016;66(3):169-77.
38. George, R, Ve, RS, Vijaya, L. Glaucoma in India: estimated burden of disease. J Glaucoma. 2010;19(6):391-7.
39. Mbao, MN, Eikelboom, RH, Atlas, MD, Gallop, MA. Evaluation of video-otoscopes suitable for tele-otology. Telemed J E-Health. 2003;9(4):325-30.
40. Gourie-Devi, M. Epidemiology of neurological disorders in India: review of background, prevalence and incidence of epilepsy, stroke, Parkinson's disease and tremors. Neurol India. 2014;62(6):588-98.

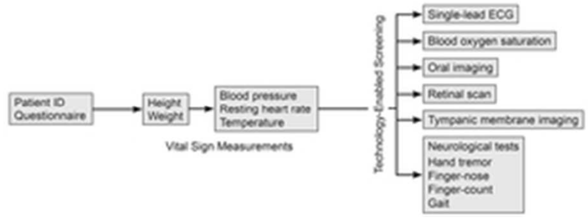

Fig 1. Study design. Flowchart for overall screening procedure.

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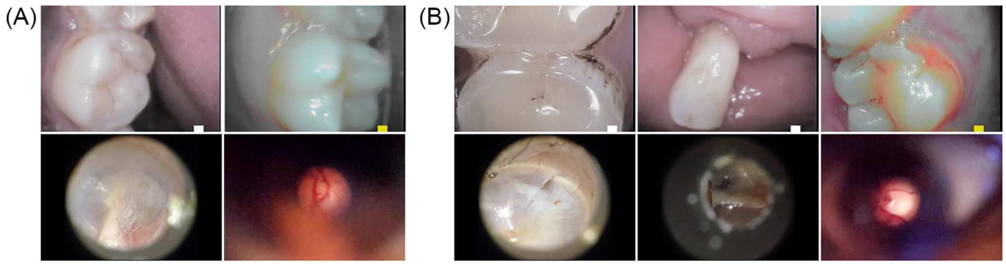


Fig 2. Representative images of labeled conditions detected in technology-enabled screenings.
(A) Normal images for technology-enabled screenings. Left-to-right, top-to-bottom: dental, periodontal, tympanic membrane, optic nerve.
(B) Labeled conditions for technology-enabled screenings. Left-to-right, top-to-bottom: caries, missing teeth, periodontal disease, perforated eardrum, effusion, width of optic rim 0.01-0.1.

149x38mm (300 x 300 DPI)

Supplementary Appendix

Contents

Supplementary Methods

Criteria, ethical considerations and consent procedure: Mahatma Gandhi Vidyamandir Karmaveer Bhausaheb Hiray Dental College & Hospital (MGVKBHDC) in Nashik was designated as one of the primary health provision and disaster management centers for the 2015 Sinhast Kumbh Mela (14 July-25 September). The hospital has an outpatient facility where pilgrims and local people were provided care, information and a resting area throughout the event. Indians between the ages of 18 years and 90 years of all ethnicities, races and genders were included in the study. Subjects younger than 18 years or older than 90 years were excluded from participation. 494 consenting adults were seen in the week that MGVKBHDC was soliciting volunteers. We anticipated pilgrims and out-of-state consenting adults would be the largest group to volunteer to be enrolled in this study, allowing us to examine inhabitants from all over the county, but local Indians were also allowed to participate. MGVKBHDC institutional human subjects review committee approved our consent procedure, clinical data collection and the plan for communication of testing results with the subjects (Protocol number: MGVKBHDC/15-16/571). Bilingual physicians from MGVKBHDC explained the scope of the study and consent forms (in English or Hindi) to subjects who were interested in participating. Subjects were asked to sign the consent forms and then remain in a waiting area before active participation in the study. Participants were free to leave at any point during their screenings. MGVKBHDC primary care physicians, dentists, ophthalmologists, otolaryngologists and neurologists performed the health screenings in the order outlined in **Fig 1**, communicated the results to subjects and provided appropriate referrals to patients needing additional medical care. De-identified data was transferred to the Massachusetts Institute of Technology (MIT) investigators for analysis after approval of the protocol by the MIT Committee on the Use of Humans as Experimental Subjects (MIT COUHES protocol number: 1512338971).

Data collection: A unique registration number (1-494) linked to each subject was used to store and annotate data from screening kiosks.

Medical history and routine health screenings: Self-reported responses of subjects to a detailed computerized questionnaire that included geographic and demographic questions, questions about past medical history and current illnesses. A bilingual physician recorded the medications and symptoms reported by the subjects as well as their reports of family medical history. An Omron 10 series wireless upper arm monitor with cuff (Model: BP786N) was used to collect systolic and diastolic blood pressure following the manufacturer's instructions (Omron Electronics, USA). Temperatures were measured using a digital thermometer. Height and body weight were measured using a digital scale and were recorded for all subjects.

Technology-enabled screening devices:

Blood oxygen saturation: A CMS 50-DL Pulse Oximeter (Contec Medical Systems, USA) was used to measure blood oxygen saturation levels of hemoglobin based on photoplethysmographic pulses and pulse rate from subjects' right index fingertips [25].

ECG: The AliveCor Mobile ECG (AliveCor Inc, USA) is a single-channel cardiac event recorder consisting of a device and smartphone app that can record and review ECGs [17]. a 30-second rhythm strip (lead I) recording was uploaded wirelessly for interpretation via the AliveCor algorithm, and an ECG analysis that indicated heart rate and presence of possible atrial fibrillation was displayed on the mobile phone. Before each use, a physician cleaned the two electrodes with alcohol-based sanitizer and launched the app on the smartphone (Nexus5, LG, South Korea).

Tympanic membrane imaging: Inspection of the external ear canal and eardrum was performed using the iPhone5 LEDs and camera with the CellScope Oto phone adapter (CellScope Inc. USA) [20]. A disposable ear tip attached to the device canula was used for imaging each subject.

Oral imaging: A commercially available FDA-approved intraoral camera with software, SOPROCARE (SOPRO Acteon Imaging, France), that automatically segments and displays images of plaque, caries and periodontal diseases was used [18]. Panning 30-second videos of the buccal surfaces of the upper first molars (16, 26), the buccal surface of the upper laterals (12, 22), the buccal surface of first lower molars (36, 46), as well as incisal, buccal and lingual surfaces of all accessible teeth were collected. The housing of the camera stick was covered in a clear disposable plastic sheath (U-line, USA) and sterile disposable camera bag. Subjects and clinicians wore UV protective eyewear during oral imaging. Images and video were collected by each of the following modes: (A) only 405nm LEDs powered, (B) only 450nm LEDs powered, (C) only white

LEDs powered. A HP 620 Notebook (Hewlett Packard, USA), Windows 7, (Microsoft Corporation, USA) with preloaded SOPROCARE software was used to store images and videos. A specialized scale for assigning patient scores vs. conventional DMFT (number of decayed, missing and filled teeth in an individual and in a population) or the Russell's periodontal indices was used by dentist examining the data. The camera system uses standard white light and three blue LEDS that emit non-ionizing light at 450 nm wavelengths. Inflamed gingiva can be scored due to fluorescence from porphyrins in blood. Illumination of microbial plaque with blue light induces fluorescence due to the bacteria and porphyrin content of the plaque.

Optic nerve head photography: Non-mydriatic digital retinal imaging using the D-EYE (D-EYE Srl, USA) direct ophthalmoscopy adapter attached to iPhone5s camera was performed to capture video and still images of optic nerves of subjects [23].

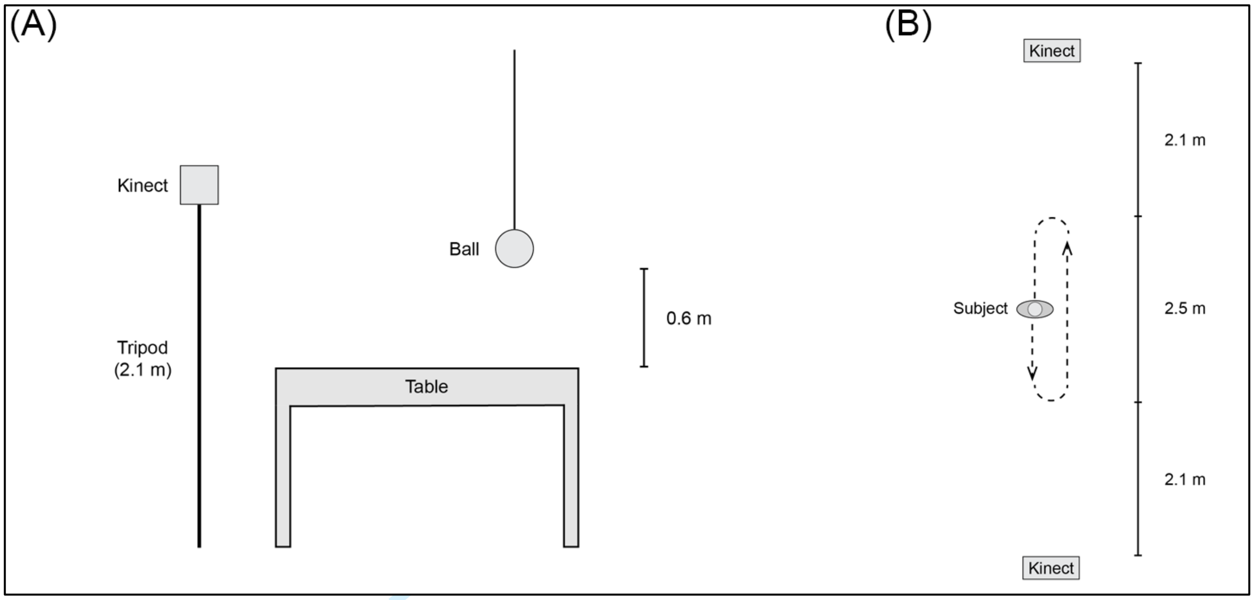
Gait and coordination analyses: The Microsoft Kinect (Microsoft Corporation, USA) sensor has an RGB camera, depth sensor and multi-array microphone, which provide full-body 3D motion capture, facial and voice recognition capabilities [19]. A 2D, depth and skeleton motion dataset of motor skills, hand-eye coordination, depth perception, neuromuscular stability of individual subjects was captured by the following protocol: a) finger-nose test with index finger touching a ball suspended from the ceiling two feet in front and then the nose: to identify tremors, incoordination, and dysmetria [26]; b) finger-count dexterity test to count to five using thumb touching fingertips: to detect slowness, tremors, and incoordination [27]; c) holding out hands steadily with palms facing down: to detect tremors and arm drift (upward, downward and lateral) [27], d) walking a distance of 2.5 meters in a straight line, turning around and walking back: to identify subjects who have posture abnormalities, tremors, imbalance (left/right), a penguin gait, or an asymmetric gait while walking [28]. Kinect sensors placed in front of and behind subjects were used to capture the walking in straight-line actions (**Supplementary Fig 1B**). For all other tests, one Kinect sensor was placed unobtrusively to the left or right of the subjects (**Supplementary Fig 1A**).

Data analyses: De-identified data assigned to unique subject IDs was split into five separate pools consisting of optic nerve, tympanic membrane, ear, oral and neurological videos for all study participants. BMI, blood pressure, resting heart rate and body temperature are routinely measured without sophisticated TES by most primary care providers and have been collectively annotated as "routine health screenings" throughout this study. Other imaging and smartphone-based tests have been designated as TES methods. Routine health screenings and responses to medical questionnaires were grouped together for computational analyses. Resting heart rate and temperature have clinically well-defined normal, high and low ranges. For BMI, numbers less than 19 were labeled low, between 19 and 25 were characterized as normal, and 25 and above were considered high [30]. For blood pressure, systolic pressure below 90 mmHg or diastolic pressure below 60 mmHg was considered low, systolic pressure between 90 and 140 mmHg and diastolic pressure between 60 and 90 mmHg was labeled normal, and systolic pressure above 140 mmHg or diastolic pressure above 90 mmHg was labeled high [31]. Blood oxygen levels of 90% or less were annotated low. The outputs from the AliveCor mobile app were readily used as annotations for ECG tests because they were labeled 'Normal' or 'Possible atrial fibrillation' [25].

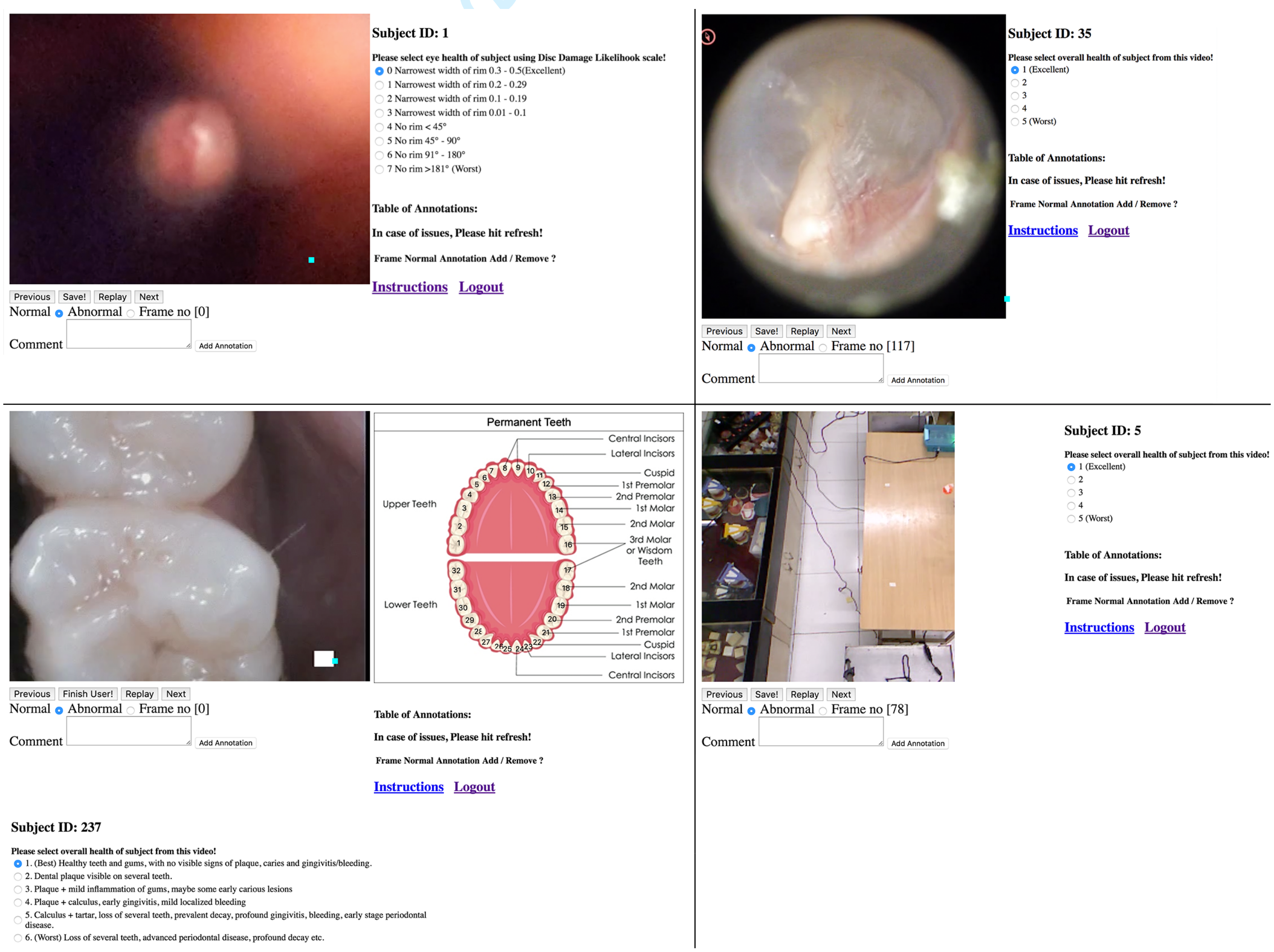
Videos captured by TES devices were categorized by patient ID and TES examination and displayed directly to expert physicians via a web-based examination portal conducted diagnostic feature annotation of de-identified images and videos. This password-protected secure interface was developed using web technologies (HTML, JavaScript, node.js) for this purpose and displayed an image or video for one patient at a time for a given examination. Annotators were able to mark specific features in the videos by drawing boxes around them that paused that specific frame, assign an overall score of 1 (best) to 5 (worst) for the entire video, and to write clinical features that were present for specific frames or the entire video (**Supplementary Fig 2**). A panel of at least three physicians for each type of examination was assembled and independently of each other remotely annotated the data facilitated by the web interface. Due to the greater quantity of Microsoft Kinect videos, three physician-trained raters annotated all the videos, and then an expert physician ratified their labels. The interface for optic nerve videos used a previously described Disc Damage Likelihood Scale (DDLS) scale for glaucoma screening [29]. The majority ratings for each subject were computed for all TES tests. For subjects with no majority rating, the lesser of the tied ratings was chosen to not overstate the prevalence of diagnosed illnesses. Results from each test were analyzed for cross-correlations with self-reported medical history responses, age and sex. Clinical findings for individuals who were tested at all six screening kiosks were also analyzed to generate population health profiles. Efficacy of routine health screenings vs. TES to identify at-risk or sick individuals examined during the study is discussed in the manuscript. Conditions outside the normal range identified by physicians for each TES test are as follows. Oral imaging: caries, missing teeth, periodontal disease;

tympanic membrane imaging: perforated eardrum, effusion; optic nerve head photography: width of optic rim 0.01-0.1; coordination analyses: abnormal finger-nose test.

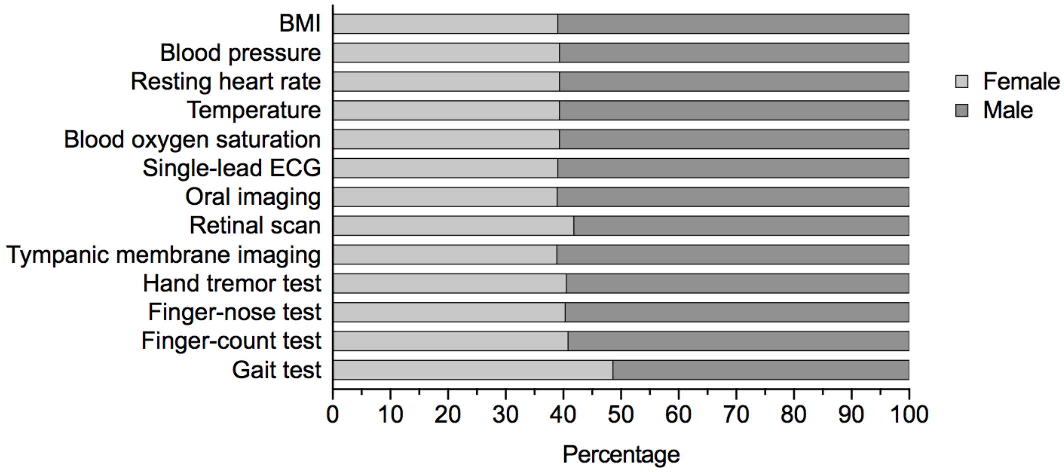
Statistical methods: Fisher's exact test was used to determine statistically significant correlations between diagnoses using TES or routine health screenings and number, age, sex and questionnaire responses of participating subjects. The significance threshold was set at $p < 0.05$. To determine in **Supplementary Table 7** whether high BMI was statistically more prevalent in one particular age cohort (out of a total of four age groups), we calculated four proportions representing the number of subjects in a specific age cohort who had high BMI compared to the total number of subjects in that age cohort. Each proportion was compared pairwise using Fisher's exact test, which reported *p*-values of 0.0014 and 0.0052 when comparing the proportion from the middle age cohort to the proportions from the young adult and old age cohorts, respectively. In **Supplementary Table 8** to determine that there is a statistically significant correlation between a subject being measured for high BMI and responding that they wear glasses, we calculated two proportions: 1) the number of subjects who had high BMI and said they wear glasses (115) compared to the total number of subjects with high BMI (196), and 2) the number of subjects who did not have high BMI and said they wear glasses (132) compared to the number of subjects who did not have high BMI regardless of whether they wear glasses (298). Fisher's exact test reported a p-value of 0.0024 when comparing these proportions, so we conclude that the correlation between high BMI and wearing glasses is significant. Analyses were performed on groups of subjects who completed each individual test to avoid considering subjects who did not have that test performed.



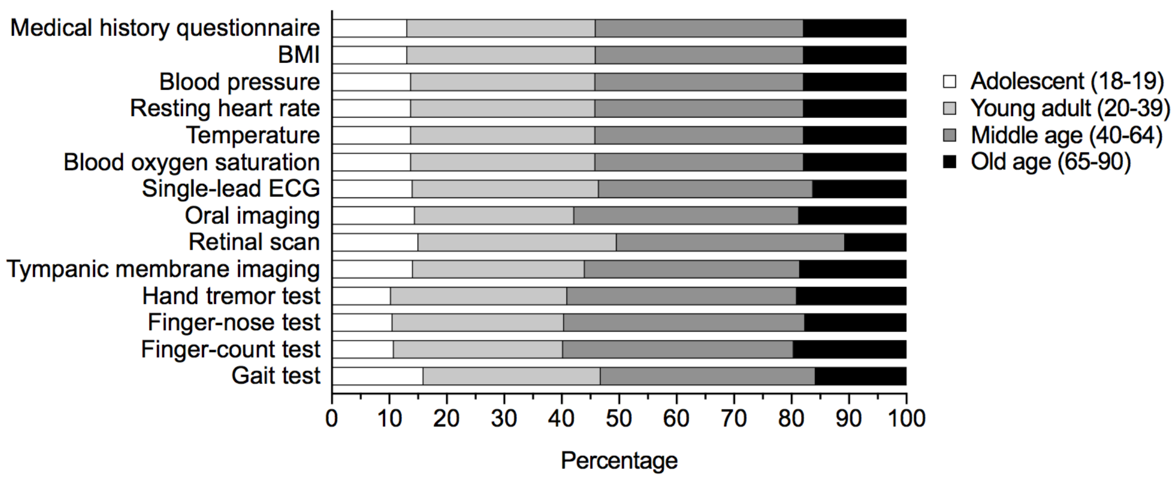
Supplementary Fig 1. Diagram of Microsoft Kinect placement for gait and coordination screening tests.
(A) Finger-nose test, from the side. Both the Kinect and ball are centered over the table with the patient facing the ball and the Kinect.
(B) Gait test, top-down. Both Kinects are 1 m off the ground and the subject walks in a straight line between them.



Supplementary Fig 2. Web interfaces for remote annotation used by physician experts for clinical evaluations.
Clockwise from top left: retinal scan, tympanic membrane imaging, gait and coordination tests, oral imaging



Supplementary Fig 3. Percentage of test populations of each gender.



Supplementary Fig 4. Percentage of test populations in each age cohort.
Age ranges for each cohort are in parentheses.

Supplementary Table 1. Test populations divided by gender and age cohorts.

	Adolescent (18-19)			Young adult (20-39)			Middle age (40-64)			Old age (65-90)		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
Medical history	39	26	65	64	88	152	73	115	188	17	72	89
Body mass index	39	26	65	64	88	152	73	115	188	17	72	89
Blood pressure	38	25	63	56	81	137	69	104	173	16	66	82
Resting heart rate	38	25	63	56	81	137	69	104	173	16	66	82
Temperature	38	25	63	56	81	137	69	104	173	16	66	82
Blood oxygen saturation	38	25	63	56	81	137	69	104	173	16	66	82
Single-lead electrocardiogram	36	25	61	58	81	139	60	100	160	14	56	70
Oral imaging	37	22	59	43	71	114	65	96	161	15	62	77
Retinal scan	37	23	60	61	79	140	63	97	160	8	36	44
Tympanic membrane imaging	30	9	39	35	52	87	49	80	129	12	57	69
Hand tremor test	24	8	32	41	55	96	50	75	125	12	48	60
Finger-nose test	24	8	32	37	54	91	50	78	128	12	42	54
Finger-count test	24	8	32	36	52	88	49	71	120	13	46	59
Gait test	30	4	34	33	33	66	34	46	80	7	27	34

Age ranges in years for each age cohort are in parentheses.

151
152 **Supplementary Table 2. Gender breakdown of self-reported medical history.**

	Female (n=193)	Male (n=301)	Total (n=494)
Glasses	54.9	46.8	50.0
Dental	21.2	29.2	26.1
Swollen joints	25.4	25.2	25.3
Hearing	17.1	24.9	21.9
Family history of diabetes	22.3	18.3	19.8
Leg cramps	19.7	17.9	18.6
Family history of high blood pressure	21.2	12.6	16.0
Fatigue	15.5	15.6	15.6
Acidity	20.2	11.3	14.8
Tiredness	13.0	15.0	14.2
Tobacco addiction	1.6	17.6	11.3
Surgery	9.8	10.0	9.9
Difficulty walking	10.4	9.6	9.9
High blood pressure	10.4	8.0	8.9
Diabetes	6.7	8.6	7.9
Snore Loudly	4.7	9.3	7.5
High blood pressure treatment	7.3	5.6	6.3
Environmental allergies	8.3	4.3	5.9
Sleepiness	5.2	5.6	5.5
Medication allergies	6.2	4.7	5.3
Asthma	4.7	5.0	4.9
Smoking addiction	0.0	7.6	4.7
Family history of cardiac diseases	3.1	3.3	3.2
Family history of asthma	3.1	3.0	3.0
Thyroid	5.7	1.0	2.8
Self-medication	1.0	4.0	2.8
Jewelry allergies	6.2	0.0	2.4
Past skin infection	3.1	2.0	2.4
Family history of thyroid disease	2.1	2.3	2.2
Cardiac treatment	1.0	2.7	2.0
Stop breathing during sleep	1.0	2.3	1.8
Oral infection	1.6	2.0	1.8
Kidney disorder	2.1	1.3	1.6
Skin problem	1.0	2.0	1.6
Skin infection	0.5	2.0	1.4
Food allergies	1.6	1.3	1.4
Hyperactivity	2.1	1.0	1.4
Cardiovascular	0.5	1.7	1.2
Migraine	2.1	0.7	1.2
Low blood pressure	2.6	0.3	1.2
Family history of stroke	2.1	0.3	1.0
Past ear infection	0.5	1.0	0.8
Family history of eye disease	0.5	1.0	0.8
Heart attack	0.0	1.3	0.8
Material allergies	1.0	0.7	0.8
Anxiety	0.5	1.0	0.8
Injury in past 6 months	0.5	1.0	0.8
Family history of depression	1.0	0.3	0.6
Coronary bypass surgery	0.0	1.0	0.6
Attention deficit disorder	1.0	0.3	0.6
Drinking addiction	0.0	1.0	0.6
Eye treatment	0.5	0.3	0.4
Family history of skin disease	0.5	0.3	0.4
Memory loss	1.0	0.0	0.4
Ear treatment	0.5	0.3	0.4
Lung diseases	0.5	0.3	0.4
Family history of ear disease	0.0	0.7	0.4
Cancer	0.5	0.0	0.2
Sexually transmitted disease	0.0	0.3	0.2
Liver disease	0.5	0.0	0.2
Skin treatment	0.5	0.0	0.2
Past gastric infection	0.0	0.3	0.2
Depression	0.0	0.0	0.0
Sleep disorder treatment	0.0	0.0	0.0
Heart murmur	0.0	0.0	0.0
Past lung infection	0.0	0.0	0.0

153
154 Percentage of total population by gender who answered yes to each medical history question.
155

Supplementary Table 3. Age cohort breakdown of self-reported medical history.

	Adolescent (18-19)	Young adult (20-39)	Middle age (40-64)	Old age (65-90)
Glasses	11	21	47	21
Dental	3	22	53	22
Swollen joints	0	10	51	38
Hearing	1	7	50	42
Family history of diabetes	17	44	34	5
Leg cramps	0	15	47	38
Family history of high blood pressure	18	46	33	4
Fatigue	1	21	55	23
Acidity	5	30	47	18
Tiredness	3	21	53	23
Tobacco addiction	0	18	46	36
Surgery	8	18	37	37
Difficulty walking	0	2	49	49
High blood pressure	0	9	57	34
Diabetes	0	15	64	21
Snore Loudly	0	27	65	8
High blood pressure treatment	0	6	55	39
Environmental allergies	17	41	34	7
Sleepiness	4	7	63	26
Medication allergies	15	15	54	15
Asthma	0	4	67	29
Smoking addiction	0	9	52	39
Family history of cardiac diseases	6	38	38	19
Family history of asthma	13	13	67	7
Thyroid	0	14	64	21
Self-medication	0	29	50	21
Jewelry allergies	0	33	67	0
Past skin infection	8	25	50	17
Family history of thyroid disease	18	55	9	18
Cardiac treatment	0	20	40	40
Stop breathing during sleep	0	33	33	33
Oral infection	0	11	67	22
Kidney disorder	13	13	50	25
Skin problem	0	0	50	50
Skin infection	0	29	57	14
Food allergies	0	29	57	14
Hyperactivity	14	29	57	0
Cardiovascular	0	33	67	0
Migraine	17	83	0	0
Low blood pressure	17	17	67	0
Family history of stroke	20	60	20	0
Past ear infection	0	75	0	25
Family history of eye disease	0	75	25	0
Heart attack	0	25	25	50
Material allergies	0	75	25	0
Anxiety	0	50	50	0
Injury in past 6 months	25	0	75	0
Family history of depression	33	67	0	0
Coronary bypass surgery	0	0	33	67
Attention deficit disorder	0	0	100	0
Drinking addiction	0	0	67	33
Eye treatment	0	0	0	100
Family history of skin disease	0	50	50	0
Memory loss	0	0	50	50
Ear treatment	0	0	100	0
Lung diseases	0	0	50	50
Family history of ear disease	0	50	0	50
Cancer	0	0	100	0
Sexually transmitted disease	0	100	0	0
Liver disease	0	0	100	0
Skin treatment	0	100	0	0
Past gastric infection	0	0	100	0
Depression	0	0	0	0
Sleep disorder treatment	0	0	0	0
Heart murmur	0	0	0	0
Past lung infection	0	0	0	0

Distribution of subjects, in percentages, who responded yes to a medical history question across age cohorts. Age ranges in years for each age cohort are in parentheses.

Supplementary Table 4. **Percentage of subjects in each age cohort who responded yes to a medical history question.**

	Adolescent (18-19)	Young adult (20-39)	Middle age (40-64)	Old age (65-90)
Glasses	43	34	62	57
Dental	6	18	36	33
Swollen joints	0	9	34	54
Hearing	2	5	29	51
Family history of diabetes	26	28	18	6
Leg cramps	0	9	23	39
Family history of high blood pressure	22	24	14	3
Fatigue	2	11	22	20
Acidity	6	14	18	15
Tiredness	3	10	20	18
Tobacco addiction	0	7	14	22
Surgery	6	6	10	20
Difficulty walking	0	1	13	27
High blood pressure	0	3	13	17
Diabetes	0	4	13	9
Snore Loudly	0	7	13	3
High blood pressure treatment	0	1	9	13
Environmental allergies	8	8	5	2
Sleepiness	2	1	9	8
Medication allergies	6	3	7	4
Asthma	0	1	9	8
Smoking addiction	0	1	6	10
Family history of cardiac diseases	2	4	3	3
Family history of asthma	3	1	5	1
Thyroid	0	1	5	3
Self-medication	0	3	4	3
Jewelry allergies	0	3	4	0
Past skin infection	2	2	3	2
Family history of thyroid disease	3	4	1	2
Cardiac treatment	0	1	2	4
Stop breathing during sleep	0	2	2	3
Oral infection	0	1	3	2
Kidney disorder	2	1	2	2
Skin problem	0	0	2	4
Skin infection	0	1	2	1
Food allergies	0	1	2	1
Hyperactivity	2	1	2	0
Cardiovascular	0	1	2	0
Migraine	2	3	0	0
Low blood pressure	2	0.7	2	0
Family history of stroke	2	2	1	0
Past ear infection	0	2	0	1
Family history of eye disease	0	2	0.5	0
Heart attack	0	0.7	0.5	2
Material allergies	0	2	0.5	0
Anxiety	0	1	1	0
Injury in past 6 months	2	0	2	0
Family history of depression	2	1	0	0
Coronary bypass surgery	0	0	0.5	2
Attention deficit disorder	0	0	2	0
Drinking addiction	0	0	1	1
Eye treatment	0	0	0	2
Family history of skin disease	0	0.7	0.5	0
Memory loss	0	0	0.5	1
Ear treatment	0	0	1	0
Lung diseases	0	0	0.5	1
Family history of ear disease	0	0.7	0	1
Cancer	0	0	0.5	0
Sexually transmitted disease	0	0.7	0	0
Liver disease	0	0	0.5	0
Skin treatment	0	0.7	0	0
Past gastric infection	0	0	0.5	0
Depression	0	0	0	0
Sleep disorder treatment	0	0	0	0
Heart murmur	0	0	0	0
Past lung infection	0	0	0	0

Age ranges in years for each age cohort are in parentheses.

Supplementary Table 5. Numbers of subjects in each age cohort identified by routine health screenings.

	Adolescent (18-19)			Young adult (20-39)			Middle age (40-64)			Old age (65-90)		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
High BMI	10	11	21	15	35	50	43	57	100	7	18	25
Low BMI	11	6	17	19	9	28	7	13	20	5	19	24
High BP	0	1	1	4	12	16	15	30	45	7	19	26
Low BP	1	0	1	2	0	2	0	1	1	0	0	0

Age ranges in years for each age cohort are in parentheses.

Supplementary Table 6. Percentages of subjects with each condition in our study and in each encompassing region from the National Family and Health Survey 4 (NFHS4).

	High BMI		Low BMI		High BP	
	Female	Male	Female	Male	Female	Male
Our study	38.9%	40.2%	21.8%	15.6%	14.5%	22.5%
NFHS4 India	20.7%	18.6%	22.9%	20.2%	8.8%	13.6%
NFHS4 Maharashtra	23.4%	23.8%	23.5%	19.1%	9.1%	15.9%
NFHS4 Nashik	22.9%	23.7%	25.8%	16.8%	5.7%	11%

Supplementary Table 7. Statistically significant prevalence of clinical conditions identified by routine health screenings across age cohorts.

				More prevalent cohort		Less prevalent cohort	
Condition	More prevalent in	Than in	*p*-value	No. with condition (percentage)	No. in cohort	No. with condition (percentage)	No. in cohort
High BMI	Middle age	Young adult	0.0014	100 (59.5)	168	50 (32.9)	152
High BMI	Middle age	Old age	0.0052	100 (59.5)	168	25 (28.1)	89
High BP	Young adult	Adolescent	0.0147	16 (11.9)	135	1 (1.5)	65
High BP	Middle age	Adolescent	<0.0001	45 (26.2)	172	1 (1.5)	65
High BP	Middle age	Young adult	0.0023	45 (26)	172	16 (10.5)	152
High BP	Old age	Adolescent	<0.0001	26 (31.7)	82	1 (1.5)	65
High BP	Old age	Young adult	0.0006	52 (66.7)	82	16 (10.5)	152

Age ranges in years for each cohort: 18-19 for adolescents, 20-39 for young adults, 40-64 for middle age, and 65-90 for old age.

Supplementary Table 8. Number of subjects with a routine health screening condition and responded yes to a medical history question.

Condition	No. with condition	Glasses	Dental	Swollen joints	Hearing	FH diabetes	FH high BP	Tobacco	Difficulty walking	High BP	Diabetes	High BP Rx	Asthma	Smoking	FH cardiac	Cardiac Rx	Cardiovascular	Low BP	FH stroke	FH eye disease	Heart attack	Coronary bypass	Drinking	Eye treatment	Memory loss	Ear treatment	FH ear disease	Cancer
High BMI	196	115*	48	52	38	48*	41*	23	19	26*	18	17	9	3**	5	5	1	1	1	3	2	1	1	0	2	2	1	0
Low BMI	89	39	21	23	25	11	10	16*	12	4	6	4	4	9*	1	1	0	2	1	0	0	0	1	0	0	0	0	0
High BP	88	54	24	30*	25	19	11	11	14*	17*	15*	14*	2	4	4	4	3	0	0	1	2	1	0	1	1	1	1	0
Low BP	4	3	1	1	1	2	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Total populations reflect the number of subjects with the particular condition in that row. Multiple subjects were associated with more than one condition or questionnaire response.
* $p < 0.05$, subjects are more likely to have responded yes to the column's question and have the routine health screening abnormality.
** $p < 0.05$, subjects are less likely to have responded yes to the column's question and have the routine health screening abnormality.

Supplementary Table 9. Statistically significant correlations between routine health screening conditions and self-reported medical history.

			Subjects with routine screening condition		Subjects without routine screening condition	
Condition	Medical History	*p*-value	No. responded yes (percentage)	No. with condition	No. responded yes (percentage)	No. without condition
High BMI	Glasses	0.0024	115 (58.7)	196	132 (44.3)	298
High BMI	FH diabetes	0.0384	48 (24.5)	196	50 (16.8)	298
High BMI	FH High BP	0.0173	41 (20.9)	196	38 (12.8)	298
Low BMI	Tobacco addiction	0.0406	16 (18.0)	89	40 (9.9)	405
High BMI	High BP	0.0091	26 (13.3)	196	18 (6.0)	298
Low BMI	Smoking	0.0122	9 (10.1)	89	14 (3.5)	405
High BMI	Smoking	0.0077	3 (1.5)	196	20 (6.7)	298
High BP	Glasses	0.0251	60 (68.2)	88	179 (48.8)	367
High BP	Swollen joints	0.0425	30 (34.1)	88	89 (24.3)	367
High BP	Difficulty walking	0.0483	14 (15.9)	88	33 (9.0)	367
High BP	High BP	0.0006	17 (19.3)	88	24 (6.5)	367
High BP	Diabetes	0.0004	15 (17.0)	88	22 (6.0)	367
High BP	High BP Rx	0.0002	14 (15.9)	88	17 (4.6)	367

Supplementary Table 10. Numbers of subjects in each age cohort identified by technology-enabled screenings.

	Adolescent (18-19)			Young adult (20-39)			Middle age (40-64)			Old age (65-90)		
	Female	Male	Total	Female	Male	Total	Female	Male	Total	Female	Male	Total
Blood oxygen saturation	0	2	2	2	2	4	3	5	8	0	5	5
Single-lead ECG	0	1	1	0	0	0	0	0	0	0	0	0
Oral	17	5	22	22	30	52	55	65	120	15	51	66
Retinal	2	1	3	2	7	9	9	8	17	4	9	13
Tympanic membrane	0	0	0	1	2	3	4	0	4	0	2	2
Hand tremor test	0	0	0	0	0	0	0	0	0	0	0	0
Finger-nose test	0	0	0	0	0	0	0	2	2	0	1	1
Finger-count test	0	0	0	0	0	0	0	0	0	0	0	0
Gait test	0	0	0	0	1	1	0	1	1	1	2	3

Age ranges in years for each age cohort are in parentheses.

Supplementary Table 11. Distribution of unhealthy subjects by clinical condition identified in each technology-enabled screening test.

Test	Condition	No. with condition (percent)	No. screened by test
Oral	Carious	156 (38.0)	411
Oral	Missing tooth	115 (28.0)	411
Oral	Edentulous	35 (8.5)	411
Oral	Periodontal disease	61 (14.8)	411
Retinal	Width of rim 0.01-0.1	9 (2.2)	404
Tympanic membrane	Perforated eardrum	25 (7.7)	324
Tympanic membrane	Effusion	20 (6.2)	324
Finger-nose	Abnormal	3 (1.0)	305
Gait	Abnormal	5 (2.3)	214

Supplementary Table 12. Number of subjects identified with clinical conditions in two technology-enabled screening tests.

	Tympanic membrane	Retinal	Oral	Finger-nose	Gait
Low blood oxygen	1	1	13	0	1
Tympanic membrane		0	26	2	2
Retinal			8	0	0
Oral				2	4
Finger-nose					0

Supplementary Table 13. Percentages of subjects identified with a clinical condition by a technology-enabled screening test and a routine health screening abnormality.

Abnormality	High BMI	Low BMI	High BP	Low BP
Low blood oxygen	21.1	42.1*	10.5	5.3
Tympanic Membrane	31.0	31.0	31.7	0.0
Retinal	44.4	11.1	11.1	0.0
Oral	40.4	17.3	20.6	0.8
Finger-nose	0.0	33.3	0.0	0.0
Gait	20.0	40.0	20.0	0.0

* $p < 0.05$, subjects are more likely to have the routine health screening abnormality if they have the technology-enabled screening condition.

Supplementary Table 14. Statistically significant correlations between conditions identified by a technology-enabled screening test and self-reported medical history.

			Subjects with condition		Subjects without condition	
Abnormality	Medical History	*p*-value	No. responded yes (percentage)	No. with condition	No. responded yes (percentage)	No. without condition
Low blood oxygen	Smoking	0.0087	4 (21.1)	19	15 (3.4)	436
Tympanic Membrane	Hearing difficulty	0.0053	17 (40.5)	42	65 (23.0)	282
Retinal	Hearing difficulty	0.0500	4 (44.4)	9	65 (16.5)	395
Retinal	Difficulty walking	0.0298	3 (33.3)	9	30 (7.6)	395
Oral	Glasses	0.0195	145 (56.9)	255	70 (44.9)	156
Oral	Dental problems	0.0043	82 (32.2)	255	30 (19.2)	156
Oral	Swollen joints	0.0002	85 (33.3)	255	26 (16.7)	156
Oral	Hearing difficulty	0.0017	72 (28.2)	255	23 (14.7)	156
Oral	FH high BP	0.0172*	31 (12.2)	255	33 (21.2)	156
Oral	Difficulty walking	0.0089	36 (14.1)	255	9 (5.8)	156
Oral	High BP	0.0339	30 (11.8)	255	8 (5.1)	156
Oral	High BP Rx	0.0490	24 (9.4)	255	6 (3.8)	156
Oral	Cardiac Rx	0.0267	8 (3.1)	255	0 (0)	156
Finger-nose	Difficulty walking	0.0009	3 (100)	3	27 (8.99)	302
Finger-nose	Swollen joints	0.0159	3 (100)	3	80 (26.0)	302
Gait	Teeth problems	0.0179	4 (80.0)	5	53 (25.4)	209
Gait	Swollen joints	0.0159	4 (80.0)	5	45 (21.5)	209

Supplementary Table 15. Age cohort and gender of subjects identified with any routine health screening or any technology-enabled screening abnormality.

	Adolescent (18-19)		Young adult (20-39)		Middle age (40-64)		Old age (65-90)		
	Female	Male	Female	Male	Female	Male	Female	Male	Total (n=111)
Routine health screening condition	10	0	8	19	11	21	2	8	79
Technology-enabled screening abnormality	9	0	8	11	14	18	2	8	70
Total in age cohort	19	0	16	23	16	26	2	9	

Supplementary Table 16. Detailed results of technology-enabled screenings and routine health screenings of the 111 subjects who completed all tests.

	Questionnaire	High BMI	Low BMI	High BP	Low BP	ECG	Hypoxemia	TM	Retinal	Oral	Finger-nose	Gait
Normal routine, Normal TES												
	x											
	x											
	x											
	x											
Routine health screening condition, normal TES		x										
		x										
			x									
		x										
		x										
		x										
				x								
			x									
		x										
	x	x										
	x	x										
	x	x										
	x	x										
	x		x									
	x		x									
		x		x								
		x			x							
	x	x										
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	x		x									
	x	x										
	x	x										
		x		x								
	x		x									
	x	x		x								
	x	x		x								
	x	x		x								
	x	x		x								
	x	x		x								
	x	x		x								
Normal routine health screening, Abnormal TES										x		
										x		
								x				
										x		
										x		
										x		
	x									x		
	x								x			
	x									x		
									x	x		
	x									x		
	x									x		
	x									x		
	x									x		
	x									x		
	x									x		
	x									x		
	x									x		
	x									x		
	x							x				
	x									x		x
	x						x		x	x		

Each row corresponds to a different individual whose age and gender have been anonymized
An x indicates that the subject was marked as abnormal in that row's test.
TM: Tympanic membrane.

Supplementary Table 17. Detailed results of technology-enabled screenings and routine health screening of the 111 subjects who completed all tests.

	Questionnaire	High BMI	Low BMI	High BP	Low BP	ECG	Hypoxemia	TM	Retinal	Oral	Finger-nose	Gait
Routine health screening condition, Abnormal TES			x							x		
			x							x		
		x		x				x				
	x			x						x		
	x	x						x				
	x	x					x					
			x					x		x		
	x	x								x		
	x	x								x		
			x					x		x		
	x	x								x		
			x					x		x		
	x			x						x		
	x	x								x		
	x			x						x		
	x			x						x		
	x	x								x		
	x	x								x		
	x		x							x		
	x			x						x		
	x	x								x		
	x	x								x		
	x	x								x		
	x			x						x		
	x		x					x				
	x	x						x				
	x	x								x		
	x		x							x		
	x	x								x		
	x		x							x		
	x		x							x		
	x	x		x						x		
	x	x						x		x		
	x			x				x		x		
	x	x						x		x		
	x	x							x	x		
	x	x							x	x		
	x	x		x						x		
	x	x						x		x		
	x	x							x	x		
	x	x		x						x		
	x	x		x						x		
	x		x	x						x		
	x	x		x						x		
	x		x							x		x
	x		x				x			x		x
	x		x	x				x		x		
	x	x		x				x		x		x

Each row corresponds to a different individual whose age and gender have been anonymized
An x indicates that the subject was marked as abnormal in that row's test.
TM: Tympanic membrane

STROBE Statement—Checklist of items that should be included in reports of ***cohort studies***

Page(s)		Item No	Recommendation
1	**Title and abstract**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
2			(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
	Introduction		
4	Background/rationale	2	Explain the scientific background and rationale for the investigation being reported
4, 5	Objectives	3	State specific objectives, including any prespecified hypotheses
	Methods		
6	Study design	4	Present key elements of study design early in the paper
6	Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
6, S2	Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up
n/a			(*b*) For matched studies, give matching criteria and number of exposed and unexposed
6, 7, S2, S3	Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
6, 7, S2, S3	Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
6, S2, S4	Bias	9	Describe any efforts to address potential sources of bias
6, S2	Study size	10	Explain how the study size was arrived at
6, S3, S4	Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
S3, S4	Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding
S3, S4			(*b*) Describe any methods used to examine subgroups and interactions
6, 8, 11, 12			(*c*) Explain how missing data were addressed
n/a			(*d*) If applicable, explain how loss to follow-up was addressed
n/a			(*e*) Describe any sensitivity analyses
	Results		
18, S7	Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
6, S2			(b) Give reasons for non-participation at each stage

Fig 1			(c) Consider use of a flow diagram
S6, S8	Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
18			(b) Indicate number of participants with missing data for each variable of interest
n/a			(c) Summarise follow-up time (eg, average and total amount)
n/a	Outcome data	15*	Report numbers of outcome events or summary measures over time
8-12, 19	Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
S3			(*b*) Report category boundaries when continuous variables were categorized
n/a			(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
8-12	Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
	Discussion		
13	Key results	18	Summarise key results with reference to study objectives
15	Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
13, 15	Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
15	Generalisability	21	Discuss the generalisability (external validity) of the study results
	Other information		
16	Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.