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Validation and Usability of a Mobile Phone Application for Epidemiological Surveillance of Traumatic Dental Injuries

Running title: Mobile phone application for the epidemiologic surveillance of TDI

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Conflict of interest statement

The authors declare that they have no conflict of interest.

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ABSTRACT

Background/Aim: Traumatic dental injuries (TDI) are a public health problem, given their prevalence and consequences. However, their epidemiology is uncertain due to a general lack of quality data capture. The aim of this study was to evaluate the validity and usability of a mobile phone-based application for community-based surveillance of traumatic dental injuries.

Materials and Methods: A mobile phone-based application, Dental Trauma Tracker (DTT), was developed. This system involves a mobile application for general users to report TDIs and a Web application for researchers to generate epidemiological data. The DTT evaluation used mixed methods and was conducted in three phases: 1) validation of a trauma identification system using preselected TDI images; 2) design evaluation by experts; and 3) usability evaluation measured by the reporting of three fictitious TDI cases and using the System Usability Scale (SUS).

Results: In the first phase, 182 participants participated. Most images showed over 95% accuracy, indicating that they adequately represented the type of dentoalveolar trauma being evaluated (Kappa=0.75). The design evaluation identified nine usability problems - four of them with a 'High priority' to be fixed, four with 'Low priority', and one 'No fix necessary'. A total of 29 volunteers participated in the usability evaluation. The mean time for users to complete all of the reports was 7.8 ± 3.0 minutes. Mean SUS score was 67.4 ±

21.9 (Range: 0-100; worst to best). The global agreement between cases registered with the gold standard was also 'Substantial' (Kappa=0.71).

Conclusions: This preliminary evaluation confirmed the App's usability, using a sample of potential users, as well as reporting on the results of an expert panel review of the DTT. These are the minimum requirements necessary before further expansion and widespread implementation occurs to confirm these results.

INTRODUCTION

Traumatic dental injuries (TDIs) and their sequelae are a public health concern given their high prevalence (up to 60%) and the consequences for the quality of life of those affected[1]. It is estimated that over a 20-year period, more than one billion people have suffered TDIs worldwide[2]. However, the overall prevalence varies widely from one population to another[3]. This variability is due to a number of factors, including a current lack of a single system to collect information on dental trauma, the variety of case definitions and diagnostic methods, and because patients with less severe TDIs do not always seek oral health care[4,5]. Even when they do, patient data and information resides within particular hospitals or oral health care facilities, leading to an inability to trace data on TDIs. This lack of data access hinders the development of oral health promotion and prevention strategies for TDIs as there is limited information and knowledge to fully determine the real magnitude of this problem[3].

One of the challenges facing oral care health providers and the wider community is how to improve the accuracy of data collection and the accessibility of dental trauma data. Information and Communication Technologies (ICT) have made available a series of tools which could help improve the epidemiologic records of TDIs[6,7]. These tools include web-based surveillance systems, dissemination of disease-related information and the use of complex algorithms for surveillance activities[8].

Traditionally, disease surveillance data has been collected from healthcare facilities. Although this source of information is important, other valuable sources of clinical information are often overlooked. Furthermore, some communities may not have access to healthcare facilities with effective disease surveillance systems. Community-based disease

surveillance strategies have the potential to benefit from improved data quality and access, improving the coverage of other surveillance systems[9]. There are many potential community-based sources of data that are useful for oro-dental injury surveillance purposes such as from schools, gymnasiums, sport centres, community swimming pools, faculties/schools of dentistry, etc.

The use of mobile technology is widespread, facilitating not only easier communication, but also offering the opportunity to develop innovative participatory surveillance strategies that rely on the design and deployment of digital and mobile technology solutions[10]. For these reasons, the development of an oro-dental trauma surveillance system, the 'Dental Trauma Tracker' (DTT) was proposed[11].

The aim of this study was to evaluate the validity and usability of a mobile phone-based application for community-based surveillance of Traumatic Dental Injuries. More specifically, the objectives were: i) to validate a tool for epidemiologic surveillance for non-oral health professional users; ii) to confirm the correct function of the individual DTT system components and to confirm that they follow the requirements and specifications created during the design stage by experts; and iii) to evaluate the usability of the DTT on whether the DTT operation and the proposed users' model addresses the needs of the end-users (e.g, teachers, gym instructors, etc.) and provides meaningful results.

METHODS

The Dental Trauma Tracker is a mobile phone application for the epidemiologic surveillance of traumatic dental injuries. This system involves two components, the mobile application designed for general users who report the TDI, and the Web application used by researchers to manage the data and collect dental trauma reports to generate epidemiological data[11] (see Figure 1).

The DTT App is supported by multiple platforms such as iOS and Android and has three user profiles (health professionals, oral health professionals and laypeople) for data input. The DTT App allows collection of TDI data following recommendations from the Centers for Disease Control and Prevention's Minimum Essential Data Set for oro-dental trauma, which represents the standard format for dental trauma data to be recorded for each type of dental trauma[12].

Upon opening the DTT trauma App, before specific trauma data collection, there is a conventional login procedure where a username and password are entered, as well as a "consent" page where the trauma patient agrees to his/her data being collected. The trauma data to be collected include four sections: identification of the user (socio-demographic data of the person who suffered the TDA (six screens); incident data (when, where, how) (eight screens); injury data (dentition and teeth affected, type of TDI, soft tissues involved, etc.) (seven screens); and for those with an oral health background, a section to report the treatment received (two screens) (Figure 2). The user has the option to upload his/her own pictures of the injury using the phone camera and upload them to the server. In the final screen, after completing the questionnaire, providing the data and other resources such as photos, the user can then submit the report to the server where it is stored in a database. The user can also view a summary of the input.

The App was designed for general users such as health professionals, teachers, gym instructors, etc. The questions use non-technical language so that they can be answered by any user. For non-oral health professional users, a set of representative images (i.e., photos) was validated to facilitate the identification of the type of TDI. Users can select from a library of images of most common injury, the one that most closely matches their case (See example in Figure 2). To facilitate DTT international use, the App allows for the creation of questionnaires in multiple languages.

The design to validate the DTT used a mixed-methods approach, incorporating expert review of content, along with user involvement to evaluate the format of the prototypes and user interface. The validations consisted of three phases: 1) validation of a tool for epidemiologic surveillance for non-dentist users; 2) design evaluation by experts; and 3) usability evaluation by users. The Ethics Committee of the Universidad de La Frontera, Temuco, Chile approved the study protocol (resolution Nº 061/2015).

1) Validation of trauma identification system

A trauma identification system was developed for non-oral health professional users. The system was based on fictional cases with selected images that represented different types of traumatic dental injuries. For this purpose, a set of de-identified traumatic dental injury images sourced from the Faculty of Dentistry, Universidad of La Frontera and the

Universidad de Valparaíso were selected. Following Andreasen's classification system for TDIs[13] the selected images included: subluxation, extrusion, lateral luxation, intrusion, avulsion, enamel-dentine fracture, enamel-dentine-pulp fracture, crown-root fracture and alveolar fracture.

A preliminary test was organised using a group of 40 volunteers (7 males and 33 females, aged 25 to 50 years) to validate the selected images. Five percent of the volunteers were dentists, 29.0% were healthcare workers and 66.0% indicated other professional backgrounds. Volunteers compared the selected images with images used as reference standards for each type of TDI (www.dentaltraumaguide.org).

After this initial testing, some images were changed and a text was included with each image to help users with the trauma identification.

The main evaluation included 182 participants from health care centers, including oral health professionals, school's teachers, and laypeople who agreed to participate in the second phase of the validation. Data from this phase was reviewed with the purpose of identifying the images with identification error (i.e., accuracy) and to assess the reliability (i.e., equivalence) between participants using Cohen's Kappa coefficient.

2) Design evaluation

To evaluate whether the application's screen design conformed to established mobile application principles, the DTT was evaluated by experts using Heuristic evaluation (14). This is a "discount usability engineering" method for evaluating user interface and system functionality to determine whether they conform to 10 established principles of usability and good design, defined by Nielsen[14] (Table 1).

Following Thyvalikakath and collaborators' recommendations,[15] a convenience sample of four information technology experts with experience in the development of apps and computer systems, working at the University of Melbourne and the Federation University in Australia plus the University of La Frontera in Chile, who did not take part in the development of DTT, independently inspected the application's user interface to identify any heuristic violations (usability problems). They compiled the potential problems for each of the ten principles defined by Nielsen into a single list (Table 1). For each item, the

evaluators were asked to determine the priority to resolve each problem detected, in the following categories:

(Code 0) No problem: It is not a usability problem.

(Code 1) Very low priority: Cosmetic problem: Not necessary to fix unless there is time to spare (very low priority)

(Code 2) Minor problem: Fixing it is not very important (low priority)

(Code 3) Serious problem: It is important to fix it (high priority)

(Code 4) Catastrophic problem: It is imperative to fix it (very high priority)

3) Usability testing

To assess the usability, three approaches were used: effectiveness, efficiency, and satisfaction. Effectiveness was evaluated by measuring the completion rate. Efficiency was measured in terms of the time a participant took to successfully complete a task. Satisfaction was measured by the Single Ease Question (SEQ) 7-point Likert scale (1: 'Very difficult'; 7: 'Very easy')[15] and the System Usability Scale (SUS)[17]. The SUS contains 10 items on a 5-point Likert scale where the respondent indicated his/her degree of agreement or disagreement with each statement. An overall usability score was computed by adding the score of each element and multiplying the sum of the scores by 2.5[17]. The SUS score can range from 0 to 100, with higher scores indicating better usability.

In addition, to better assess the participants' understanding of the objectives and level of satisfaction with the DTT App, they were asked whether, in their opinion, the App fulfilled its objectives. Two open-ended questions were applied to seek participant feedback on its utility (i.e., "what do you think is the utility of the App?"), and whether they had any other ideas or recommendations for improvements (i.e., "what improvements would you make to the App?").

A convenience sample of 29 (10 dentists, 10 health personnel, and 9 laypeople) participants were asked to install the DTT App on their smartphones and to complete three fictitious, ad-hoc cases of TDI using the application in the presence of a researcher. Cases were presented in consecutive order, with the first being the least complex and the third the most complex case. The researcher provided no additional information to the participants

regarding the objectives or navigation of the App. They were asked to take their time to complete each case study. Once the participants had completed the three cases, in a separate session, they were invited to complete the usability battery which was distributed online by Google Forms to participants to avoid influencing their answers.

The usability analysis provided basic descriptive information (frequency, mean and standard deviation) on the time needed to complete the task and the distribution of responses according to SUS criteria. The analysis provided descriptive information on the participants' background. Bivariate associations were evaluated using Chi-squared analysis and the Kruskal-Wallis test. The agreement among cases registered by the users with a reference standard was assessed using Cohen's kappa statistic. Additionally, this analysis includes a description of participants' qualitative insight into the tasks completed.

RESULTS

One-hundred and eighty-two participants took part in the validation of the trauma identification system component of the study, with ages ranging from 19 to 65 years, with a mean age of 36.2 ± 9.3 years. The majority (70.9%) were female. By professional background, 32.4% (n=59) were dentist; 20.9% (n=38) were healthcare workers (i.e., GP, nurses, etc.), another 20.9% (n=38) were school teachers and 19.8% (n=36) indicated other professional backgrounds. Eleven (6.0%; n=11) dental assistants answered the survey.

The majority of images (n=6) showed over 95% accuracy, indicating that they adequately represented the type of dentoalveolar trauma being evaluated. Images with greater identification error corresponded to extrusion, lateral luxation and alveolar fracture with accuracies of 73.0%, 60.0% and 66.0%, respectively.

The global Kappa was 'Substantial', according to the Landis and Koch's criteria[18] at 0.75. The lowest Kappa obtained (0.62) was for dental assistants, which is still considered 'Substantial'. Laypeople showed an agreement of Kappa = 0.66. Health care personnel showed greater accuracy (Kappa = 0.75). On the other hand, dentists obtained an 'Almost perfect' level of agreement (Kappa = 0.87).

Four experts participated in the design evaluation component. From a total of 40 possible entries (10 items by four evaluators), the heuristic evaluation identified nine violations.

Four of them were classified as Code 3: 'High' priority, four as Code 2: 'Low' priority, and the remaining one as Code 1. More importantly, there was no Code 4. The domain most affected was "Error prevention". The domains "Recognition rather than recall" and "Aesthetic and minimalist design" did not present usability problems.

Some of the more important violations found in the heuristic evaluation were:

- Error Prevention: The system requested the same information more than once (e.g., age and birthdate) (Code 3).
  When the images are selected, the system did not confirm which image was selected (Code 3).
  In cases with more than one injury per tooth, the system only allowed selection of one injury identification per tooth (Code 3).
- Visibility of system status: The system did not deliver enough visibility about the remaining steps to finish the report (Code 2).
- Consistency and standards: The system used terminology that might confuse users not familiar with "jargon" used in dentistry (Code 2).
  When the system asked for the soft tissue involved, it was not possible to enter more than one response (Code 3).
- Flexibility and efficacy of use: The links for the use of the system were visible and easily accessible, however it was not always intuitive (Code 2).
- Help user recognize, diagnose, and recover from error: While it was easy to use, one needed to familiarize oneself with the different stages, before using it for the first time (Code 2).

Of a total of 29 participants in the usability testing phase of the study of which 69% were female. The average age was 36.5 ± 8.6 years (range 27 to 60). The majority of participants had between 5-10 years of experience using smartphone devices (55.2%) and 41.4% had more than 10-years of smartphone experience. Only one participant (3.4%) had fewer than five years of smartphone experience. By professional background, 34.5% were dentists, 34.5% were healthcare workers and 31.0% indicated other professional backgrounds.

All participants completed the reports representing a completion rate of 100% (i.e., effectiveness). On average, participants' mean time to upload data from the first case was

7.8 ± 3.0 minutes, 6.8 ± 2.4 minutes for the second case, and 6.6 ± 2.6 minutes for the third case. The overall mean time for users to complete each of the three the reports was 7.1 ± 2.6 minutes (range 3.7 to 15.0 minutes). Although no significant differences were present by professional background, laypeople tended to require less time to complete the reports 6.6 ± 2.4 minutes (Table 2).

The difficulty score to complete the task ranged from 1 (Very difficult) to 7 (Very easy) with the majority (51.7%) scoring either 6 or 7. Another 24.2% rated the difficulty as 5 and the remaining 24.1% scored 3 or less. Healthcare professionals had the least number of difficulties completing the task and 90% of them scored 5 or higher. Among dentists, 70% scored 5 or higher and 66.6% of laypeople scored 5 or higher in the difficulty scale. No significant differences were found by professional background.

Most participants agreed or strongly agreed with the SUS items. For example, 80% either strongly agreed or agreed that they would like to use the system (See Table 3) Also, more than 65% either strongly agreed or agreed that there was little inconsistency in this system. However, despite this generally good usability assessment, replies in some respects were moderate. For instance, 46.3% disagreed with the statement that most people would learn to use this system quickly. Additionally, 41.4% did not consider that various functions in this system were well integrated (Table 3).

The mean usability score was 67.4 ± 21.3 (range 22.5 to 97.5). By professional background, healthcare professionals had the higher scores with mean scores of 71.0 ± 20.6 followed by dentists (68.3 ± 17.4). Laypeople had a mean usability score of 62.5 ± 26.6. No significant differences were found by professional background and no differences were found by gender or smartphone experience ($p>0.05$). The usability was significantly correlated with the level of difficulty of completing the task ($p < 0.0001$).

The global level of agreement for all participants and cases included with the gold standard was a Kappa of 0.71 (range 0.61 to 0.83) which is considered 'Substantial' according to the Landis and Koch's criteria[18].

The majority of respondents (69.0%) believed that the DTT achieved its objectives while 27.6% were not certain whether it had achieved them. Only one layperson (3.4%) was of

the opinion that it had not achieved its objectives. When asked about improvements to the DTT App, 28 recommendations were collected. The recommendations were heterogeneous and included comments about the number of questions asked (n = 4), the need to include treatment options (n=3), and the need to improve the way data are collected, particularly for the questions related to soft tissues (n=5).

DISCUSSION

Smartphones have been used to improve disease surveillance in areas such as cardiovascular disease, oral cancer and tuberculosis[19, 20]. Mobile technology not only improves data collection, but also allows timely access to the information[10]. Furthermore, the World Health Organization (WHO) has recently released a statement about the use of appropriate digital technologies for public health, which explicitly highlights the potential to obtain information directly from the public to support disease surveillance[21].

Consistent with this call from the WHO, the DTT was designed with a view towards operators who do not normally participate in TDI surveillance. As far as the authors are aware, this is the first study of a mobile phone an evaluation of a mobile application for dental trauma surveillance. The usability testing demonstrated that the DTT was effective, efficient and that it was accepted by its users as a community-based disease surveillance tool. Furthermore, the App was shown to be highly accurate, even for users with no previous oral health backgrounds.

Previous studies have validated remote diagnosis through images and have shown that it was comparable to diagnosis conducted in person.[22, 23] This study expanded current knowledge by describing the development and piloting stages of a smartphone application for surveillance of TDI. More specifically, this study described the initial development of the DTT App features, and has tested its operation, efficiency and usability using a mixed-methods approach.

Evidence showed that heuristic evaluation and usability testing are complementary and produce more valid results[24, 25]. On the other hand, expert opinion also allowed the detection of a larger number of heuristic violations, ensuring the accuracy of the results. The maximum number of reviewers recommended in the literature was used[15]. Information technology experts reported four violations with a high priority to fix. These were:

redundancy of stages (i.e., use of date of birth and age), possibility of recording more than one injury per tooth or soft tissue, and the lack of confirmation of the selected images. Interestingly, these violations were consistent with those detected by the users in the usability test.

Regarding usability, it was initially considered that 30 examinations would be sufficient to determine the usability of the App under controlled conditions and to identify barriers to implementation as well as to provide recommendations towards wider adoption of this approach. However, as mentioned before, for practical limitations only 29 participates were included for this stage of the testing. This constituted a larger sample than that used in other studies on App validation[26]. Thus, it was considered that this sample size would allow for initial conclusions about the usability of the App.

A central problem would be the need for the user to become familiar with the App. In this trial, participants were expected to be ready to start using the App. This may have affected their responses and created potential bias against the DTT. However, it was considered that in a real-life situation, no specialist information or training would be available before using the DTT, thus this would provide a test for an App operating under those conditions. In any case, usability was confirmed throughout the efficiency test (brief time needed to complete cases) and the high average score of the SUS. Furthermore, although the mean difficulty score for completing the task was moderate (5.0 ± 1.8) and within acceptable limits (4.8 - 5.1)[16], all users completed their reports.

The findings also indicated that users took more time to complete the first case than the most complex case (the third case) which involved more traumatized teeth, without significant differences between the various users' backgrounds. That is, the time to complete a case decreased due to self-learning as the user gained more experience. This shows that the DTT App can be used by any person, regardless of their level of knowledge of dental trauma. This is very relevant since the objective of the DTT is to be need as a tool for trauma surveillance.

Additionally, DTT showed high levels of agreement between the reported cases and the reference standard, confirming that the data registered was of good quality.

The methodology used valuable information from experts and the target users group, which assisted in the refinement of this smartphone application. However, apart from ethics' requirements, no explanations were given to participants which might explain their results and criticisms of the App (e.g., some usability problems).

Most recommendations made by either the experts or the participants have been incorporated in the App now. For example, the correct selection of the images and sections was made more visible, information that was redundant was eliminated, and it is now possible to mark more than one alternative for soft tissue injuries, as suggested by evaluators. Additionally, to make the application more user-friendly and intuitive, following the participants' request for additional illustrative information, a video describing the App, its purpose, and operation was incorporated into the App (Available at: https://youtu.be/S3R-c1OWxVE). This presentation is now part of the DTT when it starts and can also be accessed at any time using the Help feature.

For a number of reasons (e.g., legal and regulatory), this evaluation was not based on real TDI data or data collected in real-time. Instead, it used fictitious case-studies. This was done with the purpose of standardising cases and to better assess the level of difficulty, and to record the time needed to complete the task, etc. On the other hand, this approach does not consider additional mediating circumstances that may influence usability. For example, the anxiety of the affected person or the person making the report at the time of the dental trauma event. Thus, after this preliminary testing, the next challenge will be to carry out a more rigorous testing of the DTT under real-life conditions with actual cases of trauma, and in the different settings where an TDI can present (e.g., schools, sports centers, healthcare facilities, etc.), to ensure that the App performs correctly from a technological point of view. In addition, the accuracy and quality of the information reported under emergency conditions should be evaluated.

Future development may also be directed toward the design and evaluation of DTT implementation strategies in conjunction with other epidemiological surveillance systems. In addition, although this prototype has been initially developed for Spanish and English-speaking users, future versions could allow for the addition of other languages. It is also expected that, in the future, a real-time communication feature would be added to this

system. This would enable live consultation with a dental trauma specialist to assess the trauma and receive management and treatment advice.

The results of this project were used to guide and inform improvements to the App. Future studies using real conditions will confirm the utility of the DTT. The combination of participatory community-based approaches with mobile technology provide the information needed for the identification of specific environmental, socio-demographic and anatomical predictors of oro-dental trauma. This would allow for the identification of environmental risk and "at-risk" groups. Additionally, new information will inform the development of healthcare promotion, guidelines, policies and legislation aimed to create safer environments to help prevent TDIs.

The DTT is a tool with the potential to obtain better epidemiological information on TDI which currently may be missed through conventional surveillance systems. Information collected for this purpose must be timely, accurate, reliable and include all the required information. The DTT provides a quick, engaging and easy-to-use tool that can be utilized in any setting by non-oral health professional users. As such, the DTT represents a useful addition to improving available TDI data. There is no doubt that the DTT could be improved further and refinement of features could be included in the future.

CONCLUSIONS

This preliminary evaluation has confirmed the App's usability as well as reporting on the results of an expert panel review of the DTT. These are the minimum requirements necessary before further expansion and widespread implementation occurs.

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Table 1: The 10 Usability Heuristics for User Interface Design

- Visibility of system status
- Match between system and the real world
- User control and freedom
- Consistency and standards
- Error prevention
- Recognition rather than recall
- Flexibility and efficiency of use.
- Aesthetic and minimalist design
- Help users recognize, diagnose, and recover from errors.
- Help and documentation

From: https://www.designprinciplesftw.com/collections/10-usability-heuristics-for-user-interface-design

Table 2. Mean time and (standard deviation) in minutes to upload trauma cases by user's background

Case	Dentist (n=10)	Health professionals (n=10)	Laypeople (n=9)	Total
1	8.8 (3.0)	8.6 (3.9)	8.0 (2.7)	8.5 (3.2)
2	7.1 (3.3)	5.2 (1.8)	6.0 (2.3)	6.1 (2.6)
3	7.6 (3.0)	6.5 (2.1)	6.1 (2.1)	6.7 (2.4)
Total	7.8 (3.0)	6.8 (2.4)	6.6 (2.6)	7.1 (2.6)

Table 3. Percent response by all participants to items in the System Usability Scale

	1 Strongly disagree %	2 %	3 %	4 %	5 Strongly agree %
I think that I would like to use this system frequently	3.3	16.7	--	70.0	10.0
I found the system unnecessarily complex	30.0	23.3	13.3	16.7	16.7
I thought the system was easy to use	6.7	16.7	13.3	30.0	33.3
I think that I would need the support of a technical person to be able to use this system	36.7	20.0	13.3	20.0	10.0
I found the various functions in this system were well integrated	6.9	13.8	20.7	34.5	24.1
I thought there was too much inconsistency in this system	36.7	30.0	13.3	10.0	10.0
I would imagine that most people would learn to use this system very quickly	23.3	13.3	16.7	13.3	33.3
I found the system very cumbersome to use	40.0	23.3	13.3	6.7	16.7
I felt very confident using the system	10.0	6.7	23.3	20.0	40.0
I needed to learn a lot of things before I could get going with this system	56.7	10.0	--	23.3	10.0

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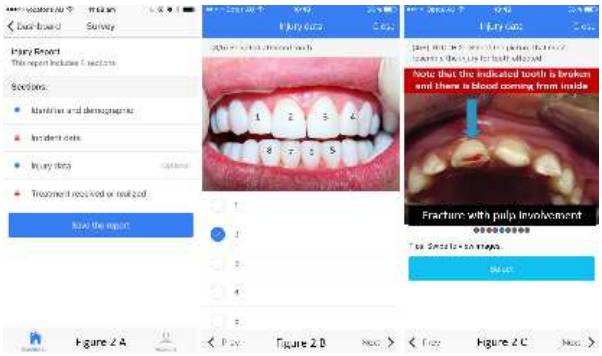

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