The Development Of Sensing Architecture For Inferior Alveolar Nerve Block Clinical Simulator Kit

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Abstract. This paper presents the development of sensing architecture for Inferior Alveolar Nerve Block (IANB) clinical simulator kit. The ultimate objective of this project is to emulate the environment of anaesthesia administration on an IANB which considers the integration of 3D printing technology and internet of things (IoT) concept. The 3D model of a lower jaw is obtained through Digital Imaging and Communications in Medicine (DICOM) data via dental Cone Beam Computed Tomography (CBCT) on a patient. The obtained model is further refined to facilitate the integration of the electronic circuit by utilization of a commercial computer-aided design (CAD) software package. The printed model is then integrated with a sensing mechanism to provide real-time data feedback during simulation of local anaesthesia administration training. From the validation results, it shows that the prototype able to give real-time data feedback and display the results on the user interface.

1. Introduction
Local anaesthesia is an essential part of dental treatment and is formally taught in the dental curriculum. It is compulsory for dental students to study and understand the relevant concepts of anatomy that is crucial for the administration of local anesthesia [1]. The inferior alveolar nerve block (IANB) is one of the most frequent local anaesthesia techniques (injection) used in dental procedures [2]. However, this technique is reported to have a high failure rate among dental students and interns [3]. Thus, it is imperative for dental students to have proper practical training in order to reduce mistakes and ensure that they master local anaesthesia administration skills prior to treating real patients in their clinical years. Currently, the common practice in pre-clinical training is through student-to-student administration of local anaesthesia in most dental schools worldwide [4]. This method is proven to be effective in mastering the anaesthesia administration technique. The above-mentioned conventional teaching method is also exposed to potential risks such as when it is injected at the wrong position, i.e, beneath the mandibular foramen or too close to the anterior border of the ramus which could result in physical complications [5]. For instance, if the needle is positioned too superiorly or posteriorly, the anaesthesia may pass the parotid gland and anaesthetize the Facial Nerve or Cranial Nerve VII that may cause transient facial paralysis. Symptoms of this temporary loss will affect the motor functions of the muscles of facial expression which includes the inability to close the eyelid and drooping of the labial commissure on the affected side for a few hours [6]. In another example, if the needle is placed too medially, the medial pterygoid muscle (a muscle of mastication) can be injected, resulting in trismus,
which is the inability to open the mouth fully [7]. Furthermore, this conventional teaching method is also prone to be dangerous if conducted in the event when the students are distracted or psychologically unfocused.

It is strongly believed that modern teaching and assessment methods could address the above problems. A simulator kit with a simulation-based training will provide students with skills and competencies in handling anaesthesia administration [8]. To effectively reduce and alleviate the physical complications and further ensure that dental students master the correct anaesthesia administration technique, we propose an IANB clinical simulator kit. The simulator kit facilitates the students with repetitive practice and data feedback as an educational platform to achieve precision in pre-clinical administering local anaesthesia training prior to treating real patients.

Historically, since the 1930s, simulation-based assessment has been deployed in the health care field, which much of it derived from military and aviation industries [9]. The simulation may exist in different forms such as virtual patients, interactive mannequin simulators and screen-based (computer) simulation that provide users with knowledge and experience that mimics real-life application [10]. Such simulator features can provide training and assessment to replace conventional teaching methods in the dental curriculum. Augmented reality (AR) and virtual reality (VR) are among recent technology that is used in developing the simulation for the IANB training [11-12]. Apart from that, the physical type of simulator has also been developed and used for IANB administration training. The development of these simulator has progressed positively since two decades ago to further improve the sensing mechanism and sensation during injection training [13]. As advancements in electronics and mechanical aspect in manufacturing namely additive manufacturing, numerous applications such as measurements and complex models of the human part become viable, therefore, an alternative sensing mechanism is proposed in the direction of developing a physical simulator kit for administering of local anaesthesia training skills.

2. 3D Modeling of Human Lower Jaw

This section discusses the first requirement in realizing the simulator prototype of the lower jaw (mandible) model that could mimic the human lower jaw. For this purpose,

![Figure 1](image_url). Illustration of (a) Front view of the 3D model, (b) Side view of the 3D model, (c) Top view of the 3D model, (d) Target location of IANB administration at the red circle.
A Digital Imaging and Communication in Medicine (DICOM) data was used to generate the 3D model of the lower jaw including nerve pathways and bone which was obtained via Cone-Beam Computed Tomography (CBCT) scan on a patient. The CBCT image files were converted and stored in DICOM, and then, extracted and imported to Simpleware® software package for rendering process of a 3D model of the lower jaw. The Simpleware® software is able to open DICOM files and subsequently, convert the files to stereolithography (STL) files which are the crucial step of producing the 3D model. However, further refinement of the 3D model is required to facilitate the integration of the electronics, commercial CAD software was utilized. The refinement process in this sense included structure manipulation to create passageways and slots for the wiring harness, micro-controller, and sensors.

The 3D model was built by using fusing deposition modeling (FDM) which is categorized in the additive manufacturing process. The built prototype is integrated with electronic circuits and sensors to give feedback for the training purpose. Figure 1 shows the completed 3D model in perspective views.

3. Integration of Electronics

This section discusses the integration of electronics and circuits on the printed prototype to provide a feedback system for the IANB simulator kit. Core electronics elements include Arduino Pro Mini and capacitive sensor. 18mm x 33mm Arduino Pro Mini in dimension is considered small and has the capacitive features onboard. This microcontroller is used to process data from sensors and communicates with the user through the serial monitor via a USB connection. Capacitive sensors are used as sensing mechanisms on the prototype. 10 capacitive sensors are embedded on target locations of the IANB administration (mandibular foramen) as representative of the target area that will be assessed during the injection. Figure 2 shows the illustration of the prototype with the integration of electronics and circuit.

![Figure 2. Illustration of the prototype with the integration of electronics and circuit](image)

The prototype is programmed to give feedback and display its result to the users. The operational flow of the prototype is shown in Figure 3.

![Figure 3. Logic of operation process flow for IANB simulator kit](image)
4. Prototype Testing and Validation

This section discusses prototype testing by replicating the real IANB administration technique. A syringe is partially modified by winding the copper wire around it to activate the capacitive sensor when an injection is performed. The copper winding will allow electric current flow from the user’s hand to the capacitive sensor on the simulator kit. Figure 4 depicts the syringe that was utilized in the trial session.

![Figure 4. Illustration of copper wire is wound up around syringe](image)

The functionality of the prototype was tested and evaluated by dental students. They injected the prototype at several locations to view the results of the trial session, as shown in Figure 5.

![Figure 5. Illustration of (a) Accurate position during trial session, (b) Acceptable position during trial session, (c) Incorrect position during trial session](image)

Colour code is used to differentiate the assessment results, i.e., LED light. The colour indication is working fine as it turns green signifying accurate position, blue for an acceptable position and red for
incorrect position. The physical indicator (LED) eases students to be aware of their injection accuracy status. Apart from that, the serial monitor displays the result as well to the users in the digital environment. Figure 6 shows the result of the injection at different locations displayed on the serial monitor.

The students gave positive feedback on the trial session as the prototype was capable to provide users with real-time feedback of the accuracy of the user’s injection. The assessment of the injection was clearly indicated by different LED colours. Apart from that, the result is shown in the serial monitor with a description of the injection which gives detailed information to the users. The sensing mechanism shows good results and the prototype performed reasonably well upon the prescribed task.

The user interface display the results with data analysis to the users as shown in Figure 7. The user interface can be accessed by the users during the training session to monitor the performance of the user with data analytic in term of successful attempt with graphical charts. Real-time data feedback from the simulator is displayed in the user interface with the availability of internet connection.
5. Further Direction for the Prototype

This section discusses improvements that can be made to the prototype in order to create a more comprehensive IANB simulator kit for IANB administration training. The sensing mechanism will be encapsulated with a composite material that mimics the properties of human gums. By encapsulating the prototype, the training becomes more challenging as the users do not see the landmarks of the embedded sensors.

The life-like sensation of the IANB administration is an important criterion to be considered for IANB training. Therefore, the prototype will be inserted into dental mannequin heads easily available at the dental faculty such as shown in Figure 8.

![Side view of the removable head mannequin](image1)

![Upper body mannequin with the removable head](image2)

![Top view of the removable head mannequin](image3)

**Figure 8.** Illustration of (a) Side view of a removable head mannequin, (b) Upper body mannequin with removable head, (c) Top view of the removable head mannequin

The advancement of technology and in particular IoT utilized as a smart assessment system for the simulator kit. A graphical user interface (GUI) will be used to display and show training results for each student by allocating their data in a database system. Each student can log in to the system before training.
commences. Therefore, lecturers can assess their students based on records and trends of the training. Systematic training method can be applied to replace the conventional training method with a complete online assessment system.

6. Conclusion

Current stage development of the prototype has met with the requirements of practitioners in the dental profession as well as within the dental education environment. The prototype will be able to act as the primary learning platform for the administration of local anaesthesia in dental schools before continuing with student-to-student injection method. The current stage of the prototype was able to provide profound physical and digital environment feedback which is considered significant information for the users. However, there are several concepts that are under consideration to further enhance the simulator kit. One of the ongoing efforts is to encapsulate the simulator kit prototype with suitable composite material to resemble the human gum. We aspire that the durability of the composite material will not leave definite marks on the model and provide a real tactile sensation of the oral environment for the user when performing the IANB injection. Thus, each student can train repeatedly on the model due to its durability. The lower jaw model might be attached to a human mannequin to provide a life-like training on a real patient instead of a stand-alone simulator as per the conventional teaching method. Apart from that, data stored from training sessions may be used for precise assessment and record-keeping purposes to achieve an effective teaching and training system. Overall the IANB simulator kit will provide a profound teaching and learning experience for both students and educators as well as being able to improve team resource management in the dental clinical education environment.

Acknowledgment

This work was supported in part by the UiTM Internal Grants MITRA PERDANA (600-IRMI/DANA 5/3/MITRA (P) (002/2018-1)).

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