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Development of a Needle Injection Pad Trainer for Simulating Intradermal, Subcutaneous and Intramuscular Injections: Used in Student Nurse Training

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Abstract

The objective was to develop a low cost needle injection pad for training nursing students to perform intradermal, subcutaneous and intramuscular injections. Of special focus was to design a pad that had the feel of human tissue and would show a bleb under the skin after a correct intradermal injection. The pad had three layers: dermis, subcutaneous (fat) and muscle. A thin fourth layer was placed over the pad to simulate the epidermis. The materials to fabricate the pad were Smooth-On Dragon Skin FX-Pro skin silicone rubber (PartA and PartB) and Slacker tactile multilator (PartS). Fourteen pads were made with various mixture ratios of PartA, PartB and PartS. After a subjective evaluation the faculty in the College of Nursing stated that Pad7 had the best feel. The Pad7 dermis layer had a mixture ratio of 1PartA, 1PartB and 0.5PartS; the fat layer had a mixture ratio of 1PartA, 1PartB and 1.5PartS; and the muscle layer had a mixture ratio of 1PartA, 1PartB and 0PartS. Nursing feedback indicated that the 1mm epidermis layer resulted in the best bleb formation and that the pads could be used to check for skin turgor.

Keywords: Injection pad, trainer, simulation, bleb.

1. Introduction

The skin has the following four layers (Hoffman, 2014): 1) epidermis which is the outermost layer of skin that provides a waterproof barrier and creates skin tone, 2) dermis which contains tough connective tissues, hair follicles and sweat glands, 3) subcutaneous tissue which is made up of fat and connective tissue and 4) the intramuscular layer.

Injections are generally made into the intradermal layer, subcutaneous tissue and intramuscular layer (Figure 1). Intradermal injections are administered into the dermis just below the epidermis and used for TB (tuberculosis) tests, allergy and local anesthesia. A bleb (wheal or bubble) of 6-10mm in diameter should be produced when the injection is done correctly. The bleb is generally quickly absorbed. If the test was improperly administered another test can be immediately administered near the original injection (Stoppler, 2019).

The World Health Organization (2014) has published guidelines for administering, reading and interpreting a TB skin test.

Intravenous injections (IVs) involve inserting a needle into a vein to allow the medication to directly enter the bloodstream. This type of injection is frequently used in administrating medications in an inpatient setting.

Subcutaneous injections are used to administer medications that are absorbed more slowly than if injected into veins such as insulin and morphine.

Intramuscular injections are used to deliver medications deep into the muscles thus allowing the medications to be absorbed quickly into the bloodstream. Vaccines and flu shots are administered by intramuscular injections (Cafasso, 2019).

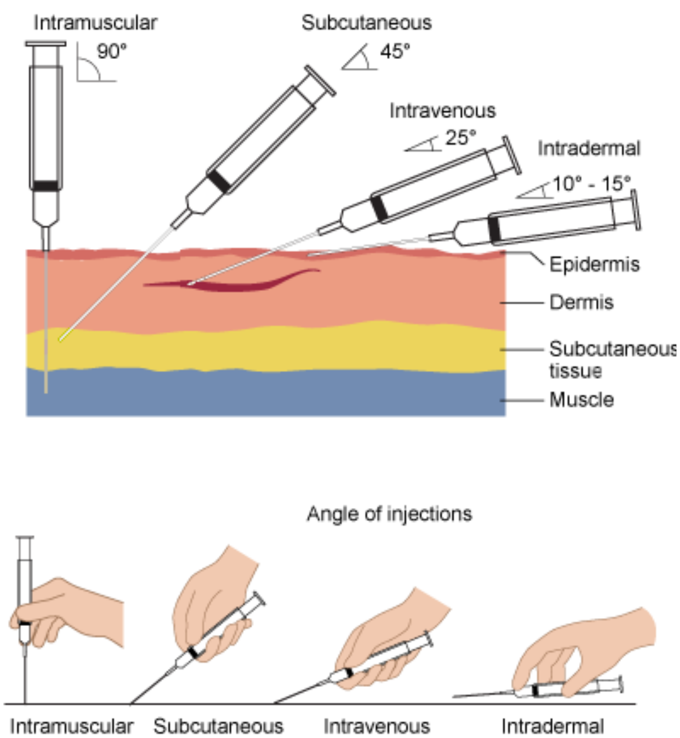

Figure 1. Needle insertions.

The objective of this research was to develop a needle injection pad for training nursing students to perform intradermal, subcutaneous and intramuscular injections. Of special focus was to design a pad with the feel of human tissue and for intradermal injections that would show a bleb, or blister, under the skin after a correct injection.

A secondary objective was to determine the feasibility of an expendable injection pad trainer that could possibly be given to each nursing student to practice needle injections.

There may be complications resulting from incorrect intramuscular injections. For children muscular contracture occurs most commonly after injections in the anterior and lateral thigh. Sciatic nerve injury is the most reported serious complication of the gluteal area (Bergeson etal., 1982). The site of needle insertion, needle size and angle are important

The feel of human tissue of an injection pad is a very subjective opinion. However, it was decided that the opinions of the experienced nursing faculty that had performed many injections was probably the best measure of pad feel.

An experimental design was structured containing a number of injection pads with varying mixture ratios. An injection pad consisted of three ingredients: 1) Smooth-on (Dragon Skin FX-Pro PartA, Dragon Skin FX-Pro PartB and 3) Smooth-On Slacker PartS. The addition of PartS will alter the feel of the silicone rubber to a softer and more flesh-like material.

Section 2 of this paper contains a literature review. However, the literature is limited on the fabrication of injection pads. Section 3 discusses the injection pad trainers that were fabricated in this study using various formulations. Section 4 presents the injection pads for creating the feel of skin tissue and for creating the bleb. Section 5 gives the feedback from the nursing faculty, cost estimates for making a disposable pad and conclusions.

2. State of the Art

Mitcallef etal. (2020) have developed an intramuscular injection simulator for nursing students. Jumbo cupcake trays with a diameter of 3.5 inches were used as molds. The simulator included three layers. A 2.5 inch diameter sponge was placed between the subcutaneous and intramuscular layers to absorb the liquid (water) from the needle. Also, a small straw segment was inserted from the sponge to the outside of the pad to drain the liquid from the pad. The straw was removed after pouring the pad layers.

For many injections intramuscular injections are preferred over subcutaneous injections because of the increased vascularity of muscle tissue providing ideal absorption of the drug being administered. Education and training in the simulation of intramuscular injections can increase success rate. As an example, the successful gluteal intramuscular injection rate increased from 52% to 75% after additional training (Soliman etal., 2018).

Hirsch and Strass (2019) stated that insulin injection technique may be as important as the insulin dose. Insulin injections are delivered into the subcutaneous (fat) layer because insulin absorption and action are more consistent than when delivered into the intramuscular layer.

Davidson and Rourke (2013) have studied the intramuscular injection of vaccines and medications into the deltoid muscle with emphasis on teaching nursing students best practices. The authors discussed the flattening technique and selection of needle length.

Mitcallef etal. (2020) are currently researching a 3D printed model of a shoulder that will simulate the deltoid site for intramuscular injections. This will result in a more realistic simulator; however, the difficulty is to give the shoulder a more realistic feel. The authors have proposed using the 3D printed model as a mold for making (pouring) a silicone rubber shoulder.

Boyd etal. (2013) identified the following factors associated with successful intramuscular injections: 1) nurses' frequency of injections ($p=0.008$), 2) landmarks used to select injection site ($p<0.001$), 3) quick needle insertion ($p<0.001$) and 4) use of nonsyringe hand to compress injection site. The results imply that nurse training is critical to successful injections; consequently the value of injection pad trainers.

3. Methods and Materials

The developed needle injection pad trainer has four layers representing the epidermis, dermis, fat and muscle layers. The materials used to fabricate the pads were Smooth-on Dragon Skin FX-Pro skin effects silicone rubber and Smooth-on Slacker tactile mutilator (Smooth-on 2020). Figure 2 is the fabrication of the dermis, subcutaneous and muscle layers for Pads1-3. Figure 3 shows the various layers for Pads1-3. Figure 4 shows the finished Pads1-5. Figure 5 shows a close-up of the layers for the finished Pad1.

Figure 2. Injection pad fabrication.

Table 1 gives the fabrication data for Pads1-9. The total amount of Smooth-on (Dragon Skin FX-Pro PartA and PartB and Slacker) that was mixed for each pad was 202ml. The weight of the finished pad varied between 180-195ml indicating that 3-11 percent of the mixture remained as waste in the mixing cups. The mean thickness of the layers for Pads1-9 was:

- Dermis 3.0mm.
- Subcutaneous (fat) 11.5mm.
- Muscle 9.5mm.

Figure 3. Injection pad layers for Pads1-3.

Figure 4. Pads1-5.

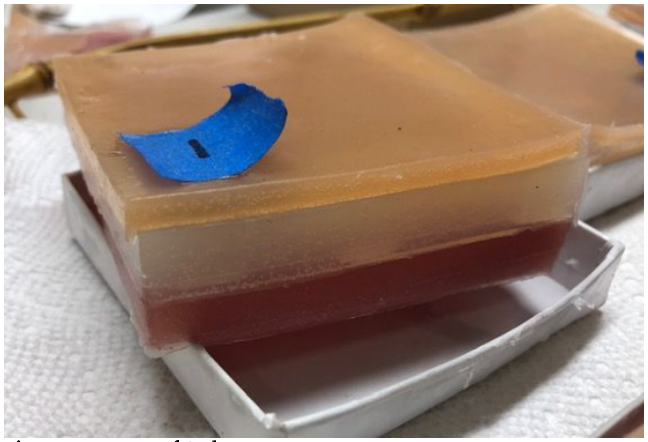

Figure 5. Layers of Pad1.

The silicone rubber ratio of the fat layer in Pad3 resulted in the fat layer remaining very tacky and not hardening. Consequently, Pad3 remained in the box mold to contain the tacky fat layer.

Table 1. Injection Pads1-9.

Pad #	Layer	Mixture ratio Dragon Skin FX-Pro PartA	PartB	PartS
Pad1	Dermis D	1	1	0
	Subcutaneous (fat) F	1	1	0
	Muscle M	1	1	0
Pad2	D	1	1	0
	F	1	1	1
	M	1	1	0
Pad3	D	1	1	0
	F	1	1	2
	(F layer tacky and not hardened. Left in mold)			
	M	1	1	0
Pad4	D	1	1	0
	Brushed on 1:1:2 and then inserted Tyvek pad			
	F	1	1	0
	M	1	1	0
Pad5	Discarded			
Pad6	D	1	1	0.5
	F	1	1	1
	M	1	1	0
Pad7	D	1	1	0.5
	F	1	1	1.5
	M	1	1	0
Part8	D	1	1	0.25
	F	1	1	1.5
	M	1	1	0
Pad9	D	1	1	1
	F	1	1	0
	M	1	1	0

Table 2 summarizes the partial Pads10-14 made to evaluate epidermal injections. The thickness of the epidermis layer for these pads was between 1.0-1.7mm. These pads only consisted of the dermis layer and a very thin epidermis layer since these pads were only used to evaluate intradermal injections.

Figure 6 is Pad10 with the fourth layer, the epidermis layer. This epidermis layer can be quickly peeled back to release any liquid after injection training. A new epidermal layer can then be readily installed.

The silicone rubber ratio of 1:1:1.5 for the epidermis layer in Pad14 remained very tacky and did not harden. Consequently, Pad14 was discarded.

Table 2. Intradermal injection Pads10-14.

10	Epidermis E 1mm	1	1	1
	Dermis D	1	1	0
11	E 1.3mm	1	1	1
	D	1	1	1
12	E 1.7mm	1	1	1
	D	1	1	0
13	E 1.7mm	1	1	1
	D	1	1	1
14	(Discarded)			
	E 1mm	1	1	1.5
	D	1	1	1

Figure 6. Pad10 with epidermal skin layer.

The final weight of the Round Pad1 was 260 ml. A mixture of 1:1:1 was brushed onto the interior walls of the mold. After partially drying the layers were then poured into the mold. When a layer had almost cured another layer was poured. Consequently, the layers were fused together. The end result is an encapsulate pad on the bottom and sides. The subcutaneous layer was still very tacky and had not hardened. However, it did not leak since the layer was encapsulated.

The Round Pad1 was a different design (Figure 7). The pad design was:

- Dermis 13mm Mixture ratio 1:1:0.
- Fat 13mm Mixture ratio 1:1:2.
- Muscle 12mm Mixture ratio 1:1:0.

Figure 7. Encapsulated Round Pad1.

The Round Pad2 weighed 191ml. The design was:

- Dermis 7mm Mixture ratio 1:1:1.
- Fat 14mm Mixture ratio 1:1:2.
- Muscle 7mm Mixture ratio 1:1:0.

4. Results and Discussion

One objective of the research was to develop a needle injection pad that had the feel of human tissue. Consequently, a number of pads were made with different silicone rubber ratios of PartA, PartB and PartS (Tables 1 and 2). The addition of PartS, the Smooth-on Slacker, altered the feel of the silicone rubber to a softer and more flesh-like material. It also altered the rebound properties of the silicone rubber, making it feel more like human tissue.

The second objective of the research was to develop a pad for simulating intradermal injections. An intradermal injection is a shallow or superficial injection into the dermis. A successful injection will result in a bleb at the point of injection. If the needle is inserted deeper into the dermis the bleb will not occur.

A number of options were evaluated and failed to obtain the bleb. Some of the failed options were:

- Injection directly into the top dermis layer of the pad (1:1:0 and 1:1:1 ratios).
- Reducing the thickness of the top dermis layer (1:1:0 ratio).
- Adding different sheets of material between the dermis and fat layers of the pad.
- Adding a silicone paste (1:1:1 ratio) between the dermis and fat layers.

The successful option was a thin layer of skin using Dragon Skin FX-Pro (1:1:1 ratio). This layer was allowed to flow freely onto a substrate (paper plate). As a result a very thin layer of approximately 1mm was made to simulate the epidermis (Figure 8). Figure 9 is the intradermal injection showing the bleb.

The dermis layers in the pads were thicker and harder. Consequently, the injected water could not readily penetrate the dermis layer and resulted in the bleb. After several seconds the water spread out and the bleb disappeared. Once the thin epidermis skin layer was peeled back the water could be drained.

Several more thin layers of silicone rubber were also made representing the epidermis skin layer (ratio 1:1:1). The thickness of these layers was 1.3, 1.7 and 1.7mm and placed on Pads9-12, respectively. Figure 10 shows the three thicknesses still in the molds (molds were plastic food container lids).

An intradermal injection in Pad8 with the 1mm epidermis layer showed the best bleb. It appears that the thin epidermis layers created a more effective bleb. The remaining water between the layers appears to impact the formation of the bleb after a second intradermal injection. The thin epidermis layer probably should be removed and dried after each injection to insure successful injection training. An option to solving the water problem may be to design the pad with a small arc to cause the water to run out between the layers.

Figure 8. 1mm epidermis layer.

Figure 9. Intradermal injection showing bleb.

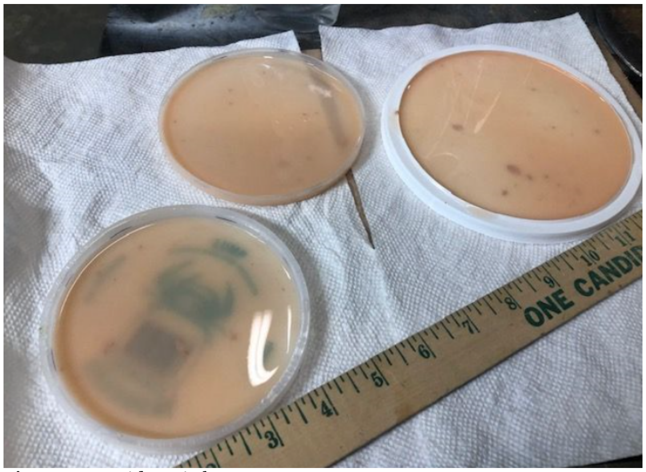

Figure 10. Epidermis layers.

The feedback from the nursing faculty in the College of Nursing (CoN) at the University of Alabama in Huntsville was:

- Pad7 had the best feel, followed by Pad8 and then Pad6.
- The epidermis layer of 1ml provided the best bleb (Pad8).
- The Slacker material gave the pad a skin feel, especially when pinched.
- Pad1 was too rigid (none of the layers had any Slacker).
- Pad2 also was too rigid (no Slacker in dermis layer; however, Slacker was in fat layer).
- Pad9 also was too rigid (Slacker in dermis layer; however, no Slacker in fat layer).

Based on the nursing faculty feedback it appears that the Slacker material must be in both the dermis and fat layers to obtain the feel of human tissue.

The CoN faculty liked the size of the pad. The smaller pads lowered material costs and consequently could also be considered as an expendable item.

During the evaluation the faculty stated that the pads could possibly be used to train students on checking for skin turgor. Skin turgor is a sign of fluid loss (dehydration). To check for skin turgor the health care provider grasps the skin between two fingers so it tents up. The skin is held for several seconds and then released. Skin with normal turgor will rapidly snap back to its normal position. Skin with poor turgor takes time to return to the normal position. A delay in flattening (tenting) is characteristic of dehydration. The faculty stated that Pad7 simulated skin with a normal turgor.

5. Conclusions

The cost of the Smooth-On PartA, PartB and Slacker is approximately $50(US)/gallon, or $0.40/ounce. Based on the feedback an injection pad between 3-4 ounces (89-118ml) and 2.75-3.25 inches in diameter and 1.5 inches in height is a good size that can be easily held. Furthermore, a good shape would be a conic frustum such as a muffin baking pan (a frustum is the portion of a cone that is between two parallel planes).

The material cost for such a 3-4 ounce pad would be $1.22-$1.56 depending on the volume of material. Therefore, such a pad could be disposable. Nursing students could be given a pad for training on their own outside the lab.

Simulation Based Learning Experiences (SBLEs) are structured activities that represent actual or potential situations in nursing practice. These activities allow participants to develop or enhance their knowledge, skills, and attitudes and to analyze and respond to realistic situations in a simulated environment. (Lioce etal., 2015). SBLEs occur in a simulation laboratory where nursing students come for a given amount of time to engage in activities specifically designed around a set of learning objectives. These activities are developed into simulation cases with realistic patient scenarios. The combination of visual and tactile feedback that is obtained from SBLEs is a valuable learning tool for nursing students.

The College of Nursing (CoN) at the University of Alabama in Huntsville has developed over one-hundred SBLEs (Moeller etal., 2015). The injection pad trainers are being integrated into the appropriate SBLEs. Once fully implemented a more thorough evaluation of the injection pads can be conducted.

In summary the feedback from the faculty in the College of Nursing indicated that Pad7 had the best feel, followed by Pad8 and Pad6. Pad7 dermis layer had a mixture ratio of 1PartA, 1PartB and 0.5PartS (Slacker); the fat layer had a mixture ratio of 1PartA, 1PartB and 1.5PartS; and the muscle layer had a mixture ratio of 1PartA, 1PartB and 0PartS. Nursing feedback indicated that the 1mm epidermis layer resulted in the best bleb formation and that the pads could be used to check for skin turgor.

The Smooth-on Slacker (PartS) altered the feel of the pad to a softer and more flesh-like material, making it feel more like human tissue. The top three pads all contained Slacker.

There appears to be a limit to the amount of Slacker before the layer becomes excessively tacky and does not harden. Such was the case for Pad3 where the mixture ratio for the fat layer was 1PartA, 1PartB and 2PartS. In fact, the fat layer could not be removed from the mold.

A successful bleb was obtained with a 1mm epidermis layer overlay (Pad8). A correct needle injection (angle and depth) is critical for a successful bleb formation.

Retained water between the epidermis and dermis layers after an injection will impact the quality of the bleb in subsequent intradermal injections. Ideally the water should be removed after each injection.

There are several areas for follow-on research. One area is the further evaluation of additional ratios of PartS Smooth-On Slacker on pad feel. A related area is to make the pad look more finished which could include the design and fabrication of a 3D printed box to hold the pad and to retain the water after multiple needle injections. A third area of follow-on is to vary the flesh tone dyes to add more realism to the epidermis and dermis layers.

It appears that the retention of water resulting from the needle injections is an issue. As previously stated one approach to the problem is the addition of a thin layer of sponge between the subcutaneous and muscle layers and a vent for the water to be squeeze from the pad. However, it the pad is disposable the addition of the water removal system may not be necessary. The question that needs to be answered is the number of times the pad can be used before the problem occurs.

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