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Review

Skin simulators for dermatological procedures

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Abstract

Background: A variety of skin simulators are available on which to practice procedures; however, choice of a suboptimal substitute compromises realism and productive practice.

Objective: Skin simulators for basic dermatological procedures are reviewed.

Methods: The authors' anecdotal experience with various skin simulators for different procedures is shared.

Results: The following simulators are suggested: an unripe banana for elliptical excision, pork belly for undermining, pork belly for simple interrupted and buried suture, capped needle on a human shoulder for intramuscular injection, ripe tomato or hotdog with skin for intradermal injection, eggplant for shave biopsy, pork belly for punch biopsy, plastic tape over a dark surface for cryosurgery, and beef liver for electrosurgery. Flaps are best practiced with foam sandwiched between foam tape or artificial anatomical models created specifically for this purpose.

Limitations: The utility of one simulator over another was not compared in a controlled study.

Conclusion: Efficient, realistic skin simulators are readily available for practice, which should enhance the safety of the practitioner and improve outcomes of novices.

Keywords: procedure, skin substitute, punch biopsy, shave biopsy, suture, KOH, venipuncture, flaps, grafts, elliptical excision, undermining, simple interrupted suture, simple suture, buried suture, intramuscular injection, local anaesthesia, cryosurgery, electrosurgery

Introduction

Trainee self-injury during dermatological procedures is common [1]. Dermatological procedures are technically demanding and often involve many steps. The "simple suture" for example has 20 individual steps [2]. Those who do not perform a procedure frequently remain on the dangerous proximal end of their learning curve and are prone to self-injury [3]. Competency is achieved when procedures are taught in fundamental component steps and practiced repeatedly [4]. The vast majority of dermatology residents are taught surgical skills in the procedure room on patients [5]. Developing proper technique on a safe substrate prior to practice on patients, an accepted practice across many surgical specialties [6, 8, 9], should reduce occupational exposures [10-18] as well as improve patient outcome. Procedural skills we regard important to acquire during dermatology residency are: excisions, suturing technique, intramuscular injection, injecting local anaesthesia, shave biopsy, punch biopsy, cryosurgery, electrosurgery, venipuncture, KOH preparations [5, 9], repair of surgical defects including undermining, flaps, and grafts. We review the published literature and our experience with different materials that can be used for dermatological procedural simulation.

Excision

Desired Substrate Properties: Substrates for excision should allow precise control of the angle, depth, and the fluidity and direction of scalpel movements [10, 19].

Substrates: An unripe banana is a simple, inexpensive model to practice blade control [10]. The banana demonstrates effects of blade control after resection, specifically smooth contours, intentional or unintentional bevelling of edges, and depth appropriateness. Firmness of the peel, however, does not mimic skin laxity.

Animal meat with the skin intact has higher tissue fidelity to human skin. Pork belly simulates human back skin, and the more delicate ox tongue or chicken thigh simulate facial skin [15, 20]. Drawbacks are odor, single usage, and need for refrigeration.

Synthetic skin models include SynTissue™ (Syndaver) and high-fidelity cutaneous surgical training models such as Il Duomo™ (DermSurg Scientific LLC). SynTissue has the anatomically correct layers of the skin and is available in large sizes. Il Duomo is the most realistic synthetic model, closely mimicking skin, vessel and nerve anatomy of the head. Disadvantages are cost and the number of excisions that can be done using a single model.

Undermining

Desired Substrate Properties: Substrates for undermining should allow for the creation of two layers from one thicker layer, rendering the simulated skin free for movement into a wound with reduced wound tension upon suturing. An ideal substrate should provide mild to moderate resistance to separation with scissors and should have a texture that enables tactile feedback for optimal control.

Substrates: Pork belly is the superior animal substrate because of skin softness. [Figure 1]. Ox tongue is useful to practice undermining in delicate skin.

Common foam products such as Reston™ Self-Adhering Foam (0.875x7.875x11.75 inch sheets) (3M, St. Paul, Minnesota) and Topifoam™ (Byron Medical, Tucson, Arizona) have limited utility alone but may be layered with elastic foam tape such as Microfoam™ Tape (4inx5.5 yrd roll) (3M) [18]. What occurs with this specific combination is that when the tape is undermined off the foam, it takes a thin layer of foam on its underside, such that it becomes freely mobile vaguely akin to human skin. This is especially useful for practicing flaps provided they are kept small (we recommend under 5 cm x 5 cm).

Figure 1. Undermining. Pork belly is ideal to practice undermining.

Suturing

Desired Substrate Properties: Substrates for suturing should allow for visualization of wound edge approximation, should be flexible enough to allow for wound edge eversion, and should be sturdy enough to hold the suture upon knot tightening without the suture's lacerating the intervening tissue between suture placement and wound edge.

Substrates: Fruit peels lack a division of epidermis, dermis and subcutaneous tissue, are stiff, and do not evert readily. The suture may also cut into the fruit skin when tying a knot too tightly.

Pork belly is the superior animal substrate due to skin thickness and flexibility, which allows for clear visualization of vectors of tension. We favor pork belly to pig's feet as the latter require extensive undermining before one can suture comfortably. Ox tongue and chicken thighs simulate more delicate skin [15, 20]. Camelo-Nunes et al. noted that the contrast in colors between the epithelium and subcutaneous tissue of ox tongue allows trainees to visualize and adjust suturing techniques. A single ox tongue also offers varying degrees of elasticity and resistance: the ventral surface is delicate while the dorsal surface is rough and tough [15].

SynTissue and Il Duomo are especially useful for subcuticular and intradermal sutures due to their thick dermal layers. Elastic recoiling of foam boards demands extensive undermining.

Injections

Desired Substrate Properties: Needle stick injuries remain the most common type of accidental injuries reported among dermatology residents [1]. Substrates for intradermal injections should allow for visualization of a bleb or wheal as feedback for correct needle placement. Deliberately injecting slightly deeper than intradermally allows practice for subcutaneous injections. Substrates for intramuscular injection should allow for mild but not extreme resistance to needle penetration, be thick enough to allow for penetration of a ¾ inch needle to its hub, and should be at least the length of the practitioner's hand.

Substrates: A ripe tomato allows for bleb formation when the needle is placed between the flexible skin and fruit pulp [Figure 2a]. A sausage, with its very thin membrane, or a hotdog with skin allows for wheal formation similar to human skin [Figure 2b]. Ox tongue also functions well [15]. Il Duomo is an excellent synthetic alternative.

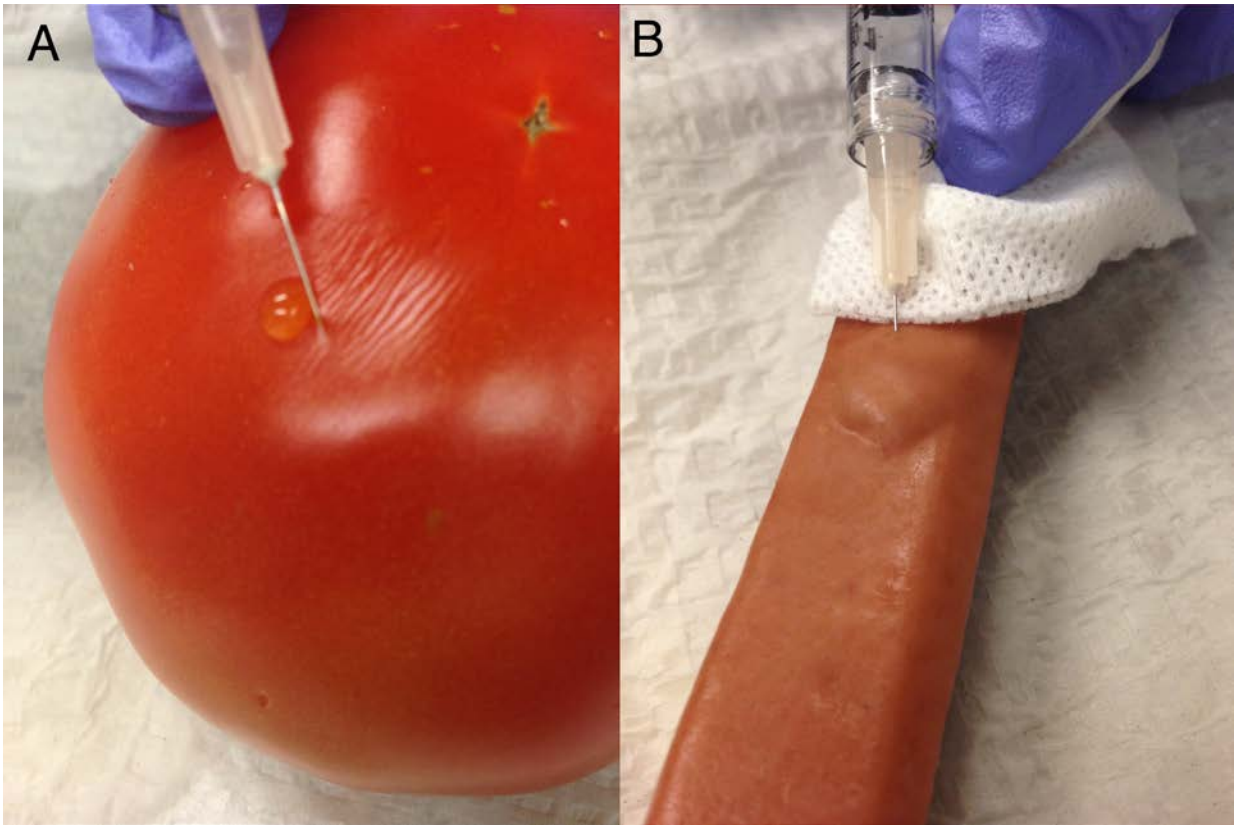

Figure 2. Intralesional injection. A) Note bleb formation inferior to the needle tip in the skin of a ripe tomato. B) Hotdog skin works well too.

Intramuscular injections can be practiced easily on the shoulder of a friendly colleague with the needle capped. Synthetic arms (i.e., Life/form™ model LF01028U by Nasco) are also available.

Shave removal

Desired Substrate Properties: Substrates for shave removal should have three layers simulating epidermis, dermis, and subcutaneous fat, in similar ratios as they appear in humans. The outer layer should allow for visual feedback of both depth and contour of the shaved material. The material should require that traction be placed behind the blade to facilitate initial blade entry into the simulated skin without slippage.

Substrates: A tomato, as previously proposed by Chen and Mellette [11], is a reasonable simulator. "Lesions" of different shapes can be drawn with a marker. The tomato skin simulates the initial cut required to break human skin. The defect made in the tomato skin reveals the jagged edges of improper technique or the smooth contours of a properly executed shave. The authors prefer eggplant as the contrast of color between black (epidermis) and white (dermis) flesh gives better visual feedback on borders and depth. Paper "lesions" can be glued to surface [Figure 3]. Unfortunately, none of the plant substrates requires traction, an important aspect to be practiced for successful shaving.

Figure 3. Shave biopsy. Shave biopsy can be practiced on eggplants. The "skin lesion" is cut out of a Post-It® note and stuck on the eggplant before surgery. The dark "epidermis" and the white "subcutaneous tissue" of the eggplant makes it very easy to judge the depth and borders of the shave. Alternatives include a tomato or a cucumber.

While Il Duomo works for shaves, multiple shaves ruin the mannequin for more complex simulations. The rubbery texture of the skin requires traction but is hard to penetrate with a blade at first.

Punch biopsy

Desired Substrate Properties: Substrates for punch biopsy should have three layers simulating epidermis, dermis, and subcutaneous fat, in similar ratios as they appear in humans. The epidermis should be loose enough to deform under pressure if traction is not placed opposite that pressure. This will allow for placing traction along one axis such that the circular punch defect will deform into an oval upon release of that traction. It will also make traction a prerequisite to prevent skin slippage under the punch when rotating it. There should be even resistance through epidermis and dermis with less resistance at the deeper subcutaneous layer. The simulator should be thick enough to allow for full penetration of the trephine to its hilt.

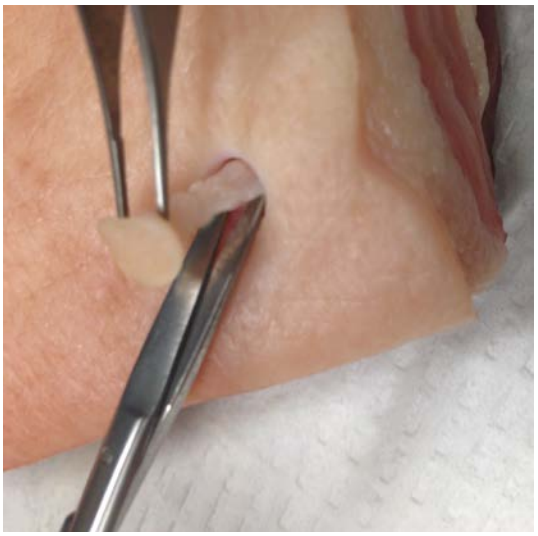

Figure 4. Punch biopsy.

Substrates: Fruit tends to be unsatisfactory for punch biopsy practice. Fruit skin is either thick and stiff (e.g., orange or banana) or thin and friable (e.g., plum or tomato). Fruit skin does not require traction and small size precludes practice of associated hand placement.

Pork belly or pig's feet are useful due to the presence of mammalian epidermis and dermis [Figure 4]. Foam boards can be used but are unrealistically stiff and shallow. Il Duomo is an excellent inorganic substrate but full depth penetration may be precluded by its plastic frame. Correct hand and finger placements can be practiced on a colleague's arm using a capped trephine or the reverse side of a disposable trephine.

Cryotherapy

Desired Substrate Properties: Substrates for cryotherapy practice should allow for a change of color upon cooling such that one can easily visualize the contrast between the water condensation of the frozen target area and its background. If one draws a target circle to freeze, one can assess the rate of fill of the circle, the tendency to freeze outside the borders, and the ability to maintain the freeze exactly up to the border for 10 to 30 seconds.

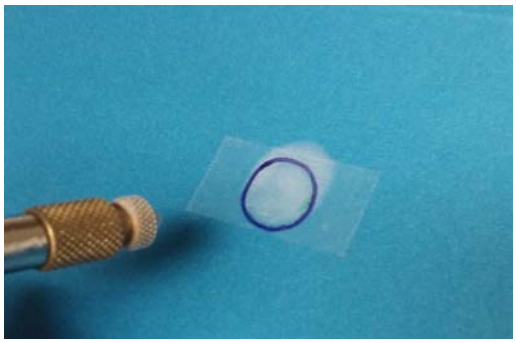

Figure 5. Cryotherapy. Cryotherapy practiced at targets drawn on clear tape over a dark surface allows for visualization of water condensation, indicating diameter of freeze.

Substrates: Any plastic surface is suitable for practicing cryotherapy. Darker shade plastics or clear plastic placed over a dark sheet of paper allows visualization of the freezing effect. Clear plastic tape is a versatile alternative and can turn any

surface into a practice substrate. Clear plastic tape has the additional benefit of accommodating drawings of lesions so one can practice applying different manual pressures to achieve a particular area of freezing [Figure 5].

Electrosurgery

Desired Substrate Properties: Substrates for electrosurgery should allow for burning of tissue due to electrical conductance. It should be transectable to show differences in depths of destruction created by various electrosurgical settings. The substrate should be homogeneous in texture and change color from its original state when burned to allow for obvious visual feedback of the damage created with a given setting.

Substrates: Beef and chicken livers are homogenous in texture and become dark and charred after "operation" [21]. Depth and type of tissue damage using different settings or tips can be visualised by a simple cross-section through the center of a treated area [Figure 6]. One way to practice is to manipulate the variables of an electrosurgical device: voltage/power, monopolar vs. bipolar, monoterminal vs. biterminal, sharp vs. blunt tip, fulguration vs. electrodessication/coagulation vs. cutting vs. cautery [22].

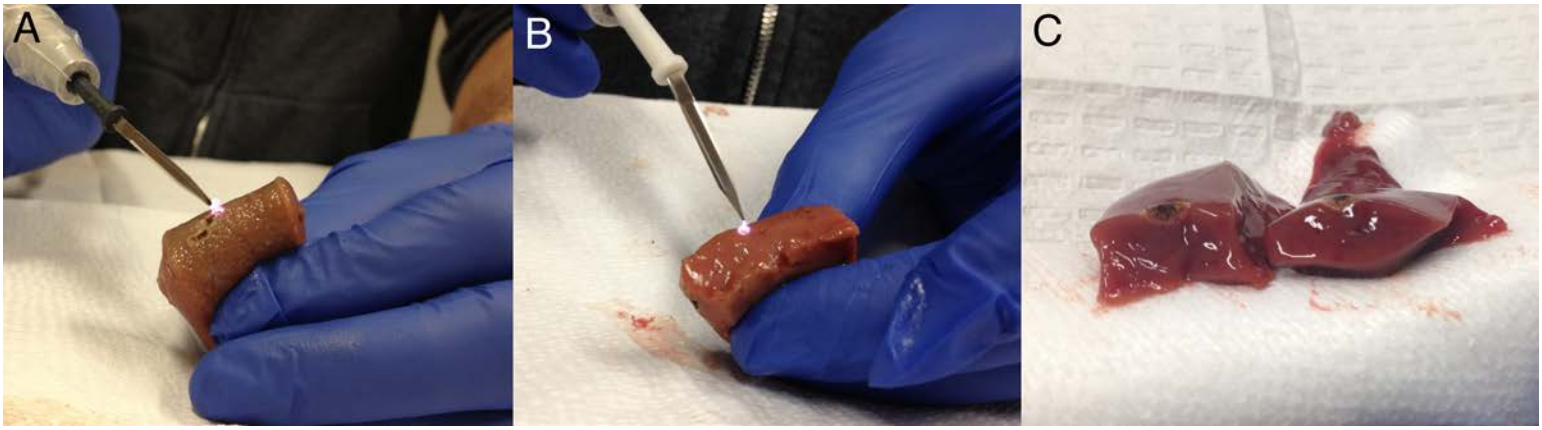

Figure 6. Electrosurgery. A) Electrofulguration, blunt tip (top left) and B) electrofulguration, sharp tip (top right). C) Visual feedback of tissue damage from blunt tip (bottom left) and sharp tip (bottom right) when practiced on a piece of liver.

Venipuncture

Desired Substrate Properties: Substrates for venipuncture practice should allow for relative ease of penetration of the needle in the artificial skin. Substrates should preferably be in the shape of an arm. A tube under skin simulating a hidden vein is ideal, but merely having a soft rubber tube can be acceptable. Drawing a vein on a piece of rubber is also acceptable as much of the skill in venepuncture lies less with properly piercing the vein as it does with correctly tying a tourniquet and not displacing the needle during tube transfer while the needle is in the arm or vein. The substrate ideally would allow for traction of skin overlying the vein and require that the vein be stabilized to prevent rolling during venipuncture.

Substrates: Special rubber arms with rubber tubing containing red food coloring simulating veins exist (i.e., Life/form model LF01121U by Nasco). Disappointingly, these models can be cumbersome, the skin can be stiff, and the veins too sturdy and too easily pierced, offering a false sense of security. We have found that an arm made of a foam core with rubber coating intended for suturing practice (i.e., Life/form model LF01028U by Nasco) works well (one must draw a target vein on the arm) but lacks visual feedback of a blood flash. Feeling for and placing traction on a vein can be done on a live human arm after tourniquet placement.

Potassium hydroxide (KOH) preparation

Desired Substrate Properties: Substrates for KOH preparations should allow for simulated scale to adhere loosely to human skin and be easily scraped off with a glass slide or 15 blade.

Substrates: Powder from a marshmallow, baking soda, or flour can be placed on the arm of a colleague, which can mimic scale. Techniques for gently scraping off the scale to a glass slide using either a 15-blade or another glass slide can be practiced. A correct amount of force and appropriate rapidity of iterative sweeps should result in powder on the slide without causing discomfort to the colleague [Figure 7].

Figure 7. KOH preparation. KOH preparation can be simulated by scraping (arrow) various flour-like materials off a colleague's arm.

Flaps and skin grafts

Desired Substrate Properties: Substrates for flaps and grafts should have the same properties as those indicated for excision, undermining, and suturing. Substrate tissue should be deformable to allow for rotation or sliding of flaps.

Substrates: Because Mohs surgery often involves delicate facial skin, chicken thighs and ox tongue are ideal [15, 20]. Pork belly can also be used. However, these materials do not mimic the different anatomic regions and structures of the face for optimal practice.

The synthetic model of adjoining the adhesive sides of 3M Reston Self-Adhering Foam to 3M Microfoam Tape provides a neat, reliable substrate for drawing and planning flaps, excision along drawn lines, undermining, and simple sutures [18] [Figure 8]. Flaps should be drawn on a relatively small scale (5cm x 5cm at most) and extensive undermining is required. Il Duomo is the current state of the art platform for practicing flaps given its high fidelity to facial anatomy, including anatomically correct location of facial arteries and nerves [Figure 9]. Its use is limited by price and the number of procedures that can be performed on the model before exhausting its use.

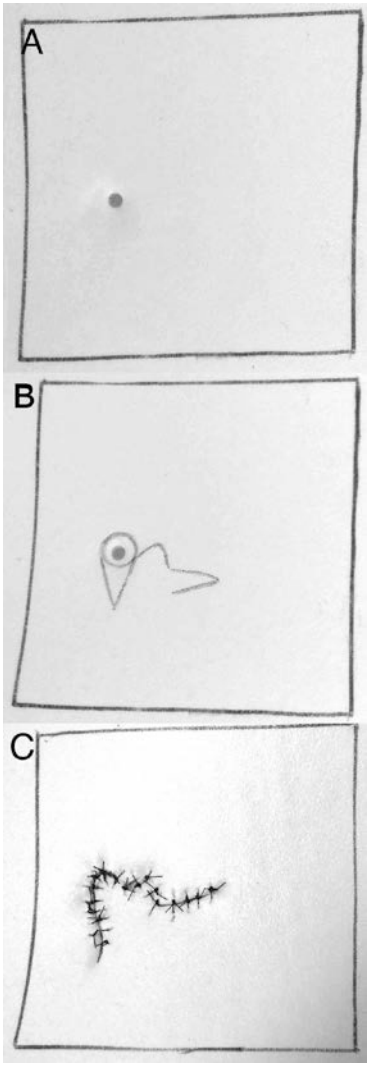

Figure 8. Flaps. Flaps can be practiced provided the area is limited to about three square inches. Here, a transposition flap is shown. A) initial defect, B) plan, C) final outcome. **Figure 9**. Il Duomo.

For split thickness skin grafting, mounting a section of Microfoam tape to a 3-liter bag of saline works well. The closed-cell foam stretches in all directions, does not absorb water, and is easily malleable to surfaces [23].

Discussion

Surgical education is seeing a shift from the traditional apprenticeship model to simulation based teaching. Interestingly, for a number of procedures across different specialties, studies have shown low-fidelity models appear to be as effective as high-fidelity ones [24-26]. In particular, simple suture skill acquisition was equal among novices trained on EVA-based foam boards compared to pig's feet in one study [24].

Despite the abundance of literature available on materials that can be used as training models, most dermatology training programs lag behind in their use of simulators [5,9]]. The potential of a simulation-based curriculum as a new model for surgical education has been extensively studied and is receiving more acceptance [9, 27-29]. The manner in which the training program is implemented is as important as the simulator or bench model itself [30]. This means a curriculum that has well-rounded instruction and timely feedback would best benefit the novice trainees. While not proven, we believe the majority of injuries experienced while learning or newly on the job can be prevented by the acquisition of refined skills on simulators in conjunction with video instruction followed by guided in-person feedback [1].

Table 1

Material	Procedure	Advantages (+) and Disadvantages (-)
Animal		
Pork belly	Punch biopsy Elliptical excision Suturing Undermining Flaps	(+) Cheap, high tissue fidelity to human skin (-) Higher storage requirements and offensive smell, limited reusability
Pig's feet	Punch biopsy Elliptical excision Suturing	(+) Cheap, moderate tissue fidelity to human skin (-) Requires extensive undermining for suturing (-) Higher storage requirements and offensive smell, limited reusability
Ox tongue	Punch biopsy Elliptical excision Suturing Undermining Flaps	(-) Cheap, moderate tissue fidelity, versatile for different types of skin, especially facial skin (-) Higher storage requirements and offensive smell, limited reusability (-) May be difficult to obtain in American supermarkets
Chicken thigh	Elliptical excision Suturing Flaps	(+) Cheap, moderate tissue fidelity for facial skin. (-) Higher storage requirements
Liver (chicken or cow)	Electrosurgery	(+) Direct visual feedback
Hotdogs	Injection	(+) Good tissue fidelity and direct motor feedback (-) Simulation for skin traction not possible
Plant		
Orange	Punch biopsy Suturing	(+) Cheap, minimal storage requirement (-) Less tissue fidelity compared to other materials for the same indication
Banana	Elliptical excision Suturing	(+) Cheap, minimal storage requirements (+) Good tissue feedback on blade control (-) Not suited for subcuticular suturing
Tomato	Shave biopsy Injection	(+) Cheap, minimal storage requirements, (+) Good tissue fidelity (+) Direct visual feedback on the effects of the procedure
Eggplant	Shave biopsy	(+) Cheap, minimal storage requirements, (+) Good tissue fidelity (+) Direct visual feedback on the effects of the procedure
Synthetic		
Foam boards	Elliptical excision Suturing	(+) Minimal storage requirements (-) Low tissue fidelity
SynTissue	Elliptical excision	(+) Minimal storage requirements

	Suturing Flap	(+) Good tissue fidelity (-) Low fidelity to facial structure
Il Duomo (DermSurg Scientific)	Elliptical excision Suturing Undermining Punch biopsy Flaps	(+) High fidelity to skin tissue and facial structures (-) Costly
Others		
Flour, Soda powders	KOH preparation	(+) allows for motor memory (-) no cells to see under microscope

Table 2

Procedure	Substitute	Advantages (+) and disadvantages (-)
Excision	Banana	(+) Allows practice of blade control (smooth contours, beveling of edges, depth) (-) Firmness of the peel does not mimic skin laxity (-) Cannot practice placing traction while cutting
	Pork belly	(+) Simulates human back skin (+) Can practice placing traction (+) Can practice use of forceps and skin hooks
	Ox tongue	(+) Simulates delicate facial skin
	Chicken thigh	(+) Simulates delicate facial skin
	Synthetic models	(+) SynTissue: anatomically correct layers of the skin (+) Il Duomo: mimics skin, vessel and nerve cranial anatomy
Undermining	Pork belly	(+) Less stiff since it is not attached to itself circumferentially.
	Pig's feet	(-) Spatially cumbersome due to rounded contour
	Ox tongue	(+) Mimics delicate and durable skin
	Foam boards	(-) Unrealistic but useful in the context of doing a flap
	Synthetic models	(+) Does not spoil (+) Very realistic feel
Suturing	Banana	(-) Very stiff (-) Suture cuts tissue when tying tightly
	Orange	(-) Same as banana
	Pork belly	(+) Thickness allows practice of intradermal, subcuticular, and simple sutures. (+) Clear visualization of vectors of tension placed by different suture configurations
	Ox tongue	(+) Simulates delicate facial skin (+) Contrast in colors between the epithelium and subcutaneous tissue (+) Varying degrees of elasticity and resistance
	Chicken thigh	(+) Simulates delicate facial skin
	Foam boards	(-) Elastic recoiling may create unrealistic skin behavior
	Synthetic models	(+) Especially useful for subcuticular and intradermal sutures due to thick dermal layers
Injections	Tomato	(+) Ripe tomato allows for bleb formation
	Sausage	(+) Allows for bleb formation
	Synthetic models	(+) Larger simulation arms allow both hands to be engaged (-) Difficult to form intradermal bleb
Shave removal	Tomato	(+) Can draw imitation lesions with marker (-) Cannot practice applying traction
	Eggplant	(+) Contrast of color between black (epidermis) and white (dermis) gives better visual feedback on borders and depth (+) Simulates aged skin when dried to rubbery texture (-) Dark skin makes marking difficult (-) Cannot practice applying traction
	Synthetic models	(+) Can practice applying traction (-) Multiple shaves can ruin the model
	Pork belly	(-) Epidermis and dermis are colored similarly, reducing visual feedback
Punch biopsy	Pork belly	(+) Separation of epidermal and dermal layers. (+) Can practice applying traction (+) Tissue resistance approximates human skin
	Pig's feet	(+) Same as pork belly
	Ox tongue	(+) Same as pork belly
	Synthetic models	(-) Model can be too shallow for full thickness punch
Cryotherapy	Plastics	(+) Darker plastics allow visualization of freezing area

	Clear plastic tape	(+) Can be applied to any surface to use for cryotherapy practice (+) Can draw lesions with marker without damaging original surface
Electrosurgery	Liver (beef, chicken)	(+) Become dark and charred after procedure (+) Depth and tissue damage can be visualized by cross-section
Venipuncture	Synthetic models	(+) Rubber simulation arms with foam core provide more realistic resistance than specialized models with tubing
KOH preparation	Baking soda	(+) Easy to use and visualize
	Flour	(+) Easy to use and visualize
	Marshmallow powder	(-) Comparatively less available
Flaps, skin grafts	Chicken thigh	(+) Simulates delicate facial skin
	Ox tongue	(+) Excellent simulation of skin feel
	Foam board	(+) Can draw and plan flaps (+) Can excise along drawn lines (-) Unrealistic simulation of skin feel
	Synthetic models	(+) Il Duomo: high fidelity to facial anatomy (including anatomically correct location of facial arteries and nerves)
	Microfoam tape + saline bag	(+) Helpful for split thickness skin grafting

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