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## **Development and evaluation of a venesection and cannulation training manikin**

Andy Levy

Andy Levy  
8 Bell Barn Road  
Stoke Bishop  
Bristol BS9 2DA

[andy.levy@bristolmedicalpro.com](mailto:andy.levy@bristolmedicalpro.com)

0117-968-7648  
0781-129-3016

Prof of Endocrinology, School of Clinical Sciences, University of Bristol, England, and Hon Consultant Physician, UHBristol NHS Foundation Trust

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## **ABSTRACT**

The design and construction method of a training manikin for venepuncture is described. Developed and refined over several years, the manikin consists of a shaped pad that the training partner secures during use by gripping the handles that extend behind the elbow or forearm. A thin layer of reinforced silicone rubber is stretched over a pad of polyurethane foam that loosely houses a length of thin-walled pure latex tubing fed with artificial blood from a bag worn around the trainer's neck. A needle-proof shield and synthetic fur backing protect the trainer's arm in case of over-enthusiastic or inept needle insertion. The whole assembly is inexpensive to make and allows the doctor/patient interaction to be closely simulated. A tourniquet can be positioned and released at the appropriate times: the feel and movement of a blood vessel beneath the skin to palpation and the changes in resistance as the needle is inserted first through the skin and then into the blood vessel is highly realistic. The method for producing the manikin, free of intellectual property limitations or restrictions, and a summary of its use in undergraduate assessments are provided.

## **INTRODUCTION**

In practice it may be difficult to avoid the 'see one, do one, teach one' paradigm for the acquisition of new clinical skills. It may not, however, be a strategy best placed to protect patients from harm. Even for the simplest and most mundane interventions, such as venepuncture, it is important to ensure that operatives are as highly trained as possible before allowing them into the clinical arena. As valuable as it is for students to practice on each other, health and safety monitors in teaching labs take an increasingly dim view of training sessions that risk vasovagal episodes and potential head injuries. It was such an event that led to changes in operating procedures at our own institution. Therefore until such time as virtual training rigs with haptic feedback are perfected and affordable enough to be widely available, relatively basic training manikins for many physical skills are the only recourse. In theory such manikins afford students the opportunity to rehearse every element of the techniques in question. In practice, such devices have many shortcomings, particularly when addressing skills that necessitate manikin injury during routine use by cutting, suturing or needle insertion. There is an intimate tradeoff between creating a realistic experience for the trainee, and the practical consideration that if a manikin is to be subjected to vigorous use by a class of inexperienced and eager students, it must be economical enough in construction materials and time to be considered essentially disposable.

Venepuncture manikins have been designed and built in house for training, and used successfully in summative exams at our institution for a decade. Over this period, over 2000 students have used the manikin to demonstrate their competence at venesection or cannulation during high stakes assessments. Construction of the manikins is straightforward, rapid in terms of man-hour input and inexpensive. The manikin design lasts for several hundred careful venepunctures before the skin surface is too lacerated to be realistic.

## **MANUFACTURING METHOD**

### **Mould making**

The skin texture for the surface of the manikin was originally created by taking an alginate impression of a suitably large area of skin such as the thigh (Dental Alginate Cavex CA37 (DAE150038), Minerva Dental Ltd., Courtney House, Cardiff CF24 3DT). Immediately after setting, an impression was taken by coating it with a thin layer of green, low melt casting wax (Alec Tiranti, 27 Warren Street, London W1T 5NB). The wax impression was carefully removed immediately after setting and gently pressed absolutely flat whilst still warm. The wax sheet bearing the negative skin texture surface was fixed to a sheet of thick cardboard using brown modeling wax (a formulation that is very soft at 37°C: Tiranti) and cut to the shape shown (Figure 1 panel a). Markers (arrows) and lines were added to the surface of the wax pattern to indicate to users the extent of the target area. The master pattern was then coated with a 2cm thick layer of Dentstone KD plaster (South Western Industrial Plasters, 63 Nether Street, Bromham, Chippenham, Wilts SN15 2DP) mixed to a soft slump consistency. After setting at room temperature the wax was removed from the plaster mould and after drying for several hours, the mould surface was left to absorb a coating of petroleum jelly softened with white spirit as a release agent. Any extra petroleum jelly was wiped off with a cloth before use (Figure 1 panel a). Apart from the occasional addition of a thin layer of petroleum jelly after use, the moulds require no further care and do not wear out.

### **Manikin making**

Twenty mL of Silastic 3483 (Dow Corning. South Western Industrial Plasters) with the addition of brown silicone pigment made by mixing red and green silicone pigments, was mixed with Silastic curing agent according to the manufacturer's directions (usually 5% of curing agent 83), and spread out onto the mould without prior degassing (Figure 1 panels b and c). Note that a small amount of silicone pigment produces a skin tone typical of Caucasians.

Highly realistic darker skin tones are achieved by adding the same silicone pigment at higher concentrations.

Once cured, a further 20mL of a 30mL aliquot of Silastic 3483 prepared as above was used to re-coat the surface, and after 2 - 5 mins to allow the viscous silicone to level out somewhat, covered with a layer of stretch polyester mod mesh reinforcement (sometimes sold as power mesh/net fabric (4 way stretch) Fabricland, Bond Street, Bristol BS1 3LZ) wide enough to allow it to wrap over two bars made of 2mm metal core diameter pvc-coated garden wire (such as Apollo 2mm from any hardware store) (Figure 1 panel d and f and Figure 2 panel a).

With the garden wire in place and the stretch mesh looped over it and coated with a small amount of Silastic 3483 left over from above (10mL of the 30mL aliquot) to keep it in place, four reinforcement panels of stretch denim (Figure 1 panel e) were coated with a little Silastic 3483, and looped back over 9mm diameter wooden dowels with cast general purpose polyester resin studs at either end (Figure 2 panels b and c). The assembled reinforced skin, metal wire stretchers, denim reinforcement strips and handles were compressed used a series of shaped Dentstone plaster weights (Figure 2 panel d) and the whole allowed to set.

A standard crystalloid fluid administration set was cut off 60cm from the sight chamber, the regulator wheel removed and the cut end polished using a flame. An insulated steel wire was then fed carefully through the tubing to puncture the microembolus and gas embolism filter as these are designed for non-blood product infusion and can block relatively easily when exposed to particulate food dyes and other debris (Figure 2 panel e).

Pure latex is the only material with sufficient memory to re-seal itself after being punctured. A 17cm length of pure latex tubing, (1/8" internal diameter (3.17mm), 1/32" walls (0.8mm) : Grafco Pure Amber Latex Tubing (Medco Supply Company, 500 Fillmore Avenue, Tonawanda, NY 14150 USA) was glued to the end of the administration tubing using a dab of liquid latex and the distal end of the tube tied off with a single knot (Figure 2 panel f).

The soft subcuticular tissue was made from a trapezium of approximately 10mm thick flexible polyurethane foam, 170mm long decreasing from 110mm in width to about 60mm. A soldering iron was used to create a channel in the foam and perforate it 10mm from the distal end and 20mm from the proximal end. The latex tube assembly was threaded through the polyurethane foam to lie loosely within the channel (Figure 3 panel a). The assembled 'vein' with its polyurethane foam bed was then coated at the edges with a small amount of Silastic 3483 and inverted onto the back of the skin assembly (Figure 3 panel b).

A strip of 25mm wide fiberglass weave tape (East Coast Fibreglass Supplies, South Shields, NE33 5BY) was impregnated with polyester resin and allowed to set in a slight arc by resting it over a length of 60mm diameter plastic tubing (Figure 3 panel c). Designed to protect against all but the most purposeful and

determined attack, the impermeable resin and fiberglass shield was stuck convex side down between the polyurethane foam and a panel of synthetic fur to further protect the user (Figure 3 panels d and e). The whole assembly was allowed to cure in a gentle arc as shown (Figure 3 panel e).

Synthetic (rather than cochineal) red liquid food dye - usually about 10mL per 500mL with 1ml black liquid ink (such as Quink, Parker Pen Company) to confer added depth of colour and opacity, is introduced into a bag of saline or dextrose. The manikin is primed by drawing air from a centimeter or two above the distal end of the tubing (avoiding the knot), then in use, held over the arm and forearm as shown (Figure 3 panel f). A length of ribbon allows the bag to be worn reasonably comfortably during use, so that the teacher/assessor can wear a tourniquet, react realistically to all stages of the procedure, observe it at close range and even alter the extent to which the vessel is visible and mobile by adjusting the tension on the wooden handles. Although the manikins take up to 3 days to complete using standard cure catalyst, the hands on elements amount to little more than an hour of time. With fast cure catalyst (81-VF), a venesection manikin can be made from scratch within a day.

A video of the procedure is available on You Tube (<https://youtu.be/fAcKqKiz96E>) and a further description of the rationale and manufacturing method is shown about 5 minutes into a TEDx talk given by the author (<https://www.youtube.com/watch?v=p6rXDO2ITJ0>).

## **EVALUATION**

Developed through 3 iterations, the manikin was used in objective, structured, clinical MB ChB finals exams from 2003 until 2013 when this type of practical assessment was deleted from the portfolio.

Candidates were asked to obtain blood samples in appropriate tubes for specific tests such as a full lipid profile, creatinine and HbA1c. The marking schedule award up to 5 marks for asepsis, preparation and communication, up to 5 marks for clearing up and disposal of sharps, through to minus 10 marks for leaving sharps out, marks for labeling and using the correct tubes, and 55 marks for obtaining sufficient blood at the first attempt, 25 marks at the second attempt, 10 marks for obtaining an insufficient sample and no marks for trying to obtain blood more than 3 times, irrespective of the outcome. The pass marks for the station varied from 50% to 58.8%, and attracted very little adverse feedback from candidates or examiners. Typical mark ranges over several years are shown in Figure 4. In total, 2028 candidates (not including re-sitting candidates) carried out venesection and/or cannulation using the manikin in summative, high stakes assessments.

The manikin was also used in a national postgraduate exam (the Bristol Foundation Assessment) to determine whether foreign graduates were suitably trained to take up junior hospital jobs in the UK. In the latter

assessment it was noted that many candidates inserted the needle all the way to the hub when carrying out venesection. When asked, candidates explained that 'that's the only way to get blood out of a manikin', demonstrating the negative consequential validity of some manikin designs. If manikins are too expensive to allow the skin to be frequently replaced, sites of multiple previous venepunctures rapidly become very obvious, again undermining their validity in training and summative assessments.

A drawback of the present design is that when vacuum blood collection tubes are used, a 'miss', will release the vacuum and not allow students to collect a blood sample even if they advance further towards the blood vessel and successfully enter it. The same applies if a student skewers the latex tube, puncturing both its anterior and posterior walls and then attempts to draw blood into a vacuum tube. In this circumstance there is a further small risk that by pulling the needle back through the vessel, some air will be introduced into the 'vein'. This tends to displace the blood, which can sometimes make it more difficult for the subsequent candidates. In practice, this has rarely been an issue not least because the manikin is automatically re-primed by the next (competent) user, who might find that the first vacuum tube does not fill completely although subsequent tubes do. Lastly, if part of the test protocol involves securing a cannula to the skin, this may prove more difficult than normal as Silastic is relatively nonstick compared to human skin.

## **DISCUSSION**

For economic reasons it was important at the outset to constrain the design to address only those elements that are required for the skills in question to be rehearsed. A forearm and antecubital fossa venesection and cannulation manikin should simulate the feel of the skin and the change in feel to palpation over a blood vessel, the initial and changing resistance as the needle is inserted, a target vessel for venepuncture of similar size, depth, orientation, mobility and wall resistance to the medial cubital vein or the median or cephalic veins of the forearm, realistic flashback and flow of blood into the container/s and cessation of 'bleeding' when the needle is withdrawn. The manikin should also allow the hygiene elements and psychosocial considerations of venesection to be addressed by having the assessor/patient intimately associated with the device, essentially wearing it, yet protect the operator from injury caused by more inept trainees, as well as allowing a tourniquet to be placed and released at the appropriate points in the procedure.

For venepuncture, the skill involves interaction with the 'patient' and a practiced, fluent and effective technique that is likely to cause minimal discomfort to the patient and fills the collection tubes to their intended capacity with blood first time with minimal fuss is the ideal.

By making manikins in house, the pressure to market manikins is lifted and there is, therefore, little need for the manikin to be designed to be physically realistic and include the shoulder and upper arm, distal forearm or palm of the hand, none of which are actually used for venesection or contribute to mastering the techniques in question.

With the exception of pure latex tubing, all of the materials required to make the manikin are widely available. Latex tubing 1/8" internal diameter (3.17mm) with 1/32" walls (0.8mm) can be more difficult to source and suppliers vary greatly in their stocks. It is not easy to make in house. As far as latex allergy, the tubing is buried inside the manikin and would not be expected to cause a problem for routine users. Once the various components have been sourced, with a little practice, the production of a venepuncture manikin is straightforward and in material terms, very economical. The mould can be re-used indefinitely, and although the complete manufacturing process takes several days, as each layer of silastic has to be left to cure, the actual hands on time is relatively brief.

## **CONCLUSIONS**

A cost effective venepuncture training manikin that exceeds the utility of commercial manikins can be easily constructed without any specialist facilities or equipment. The manikin described has the advantage of being 'worn', so that all of the social and procedural elements of the interaction between the patient and phlebotomist can be repeatedly rehearsed without causing anyone physical discomfort.

## **FIGURE LEGENDS**

Figure 1. Panel a. shows the shaped plaster skin texture mould ready for use. Panel b. shows a thin layer of coloured silastic rubber being spread over the base of the mould. Panel c. shows the layer of silicone rubber that is too thin to cover the surface by gravity alone. Panel d. shows the highly flexible trapezium of stretch reinforcement, and on the left, a length of wire to stiffen the edges of the manikin and one of the wooden doweling handles with beads of polyester resin at either end. Panel e. shows the shape and dimensions of the stretch denim reinforcement for the hands and panel f, the reinforcement panel lying on the second coat of liquid silastic with the wire reinforcements in place.

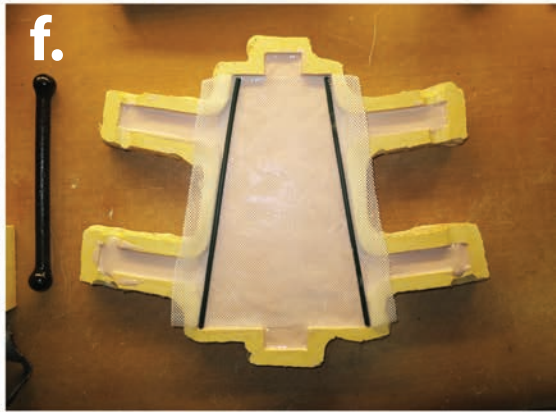
Figure 2. Panel a. shows the stretch reinforcement folded over the wires and in panel b, the four denim handle reinforcements. Panel c shows the denim reinforcements folded back around the handles and all of the elements

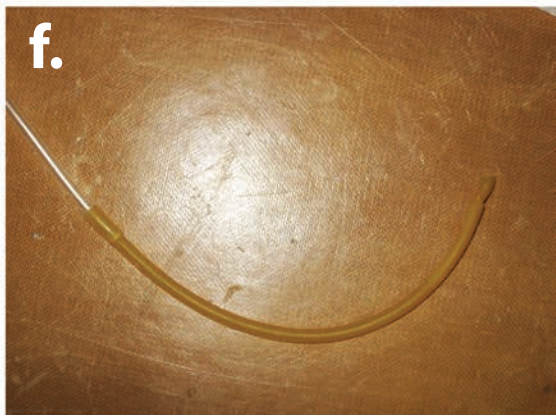
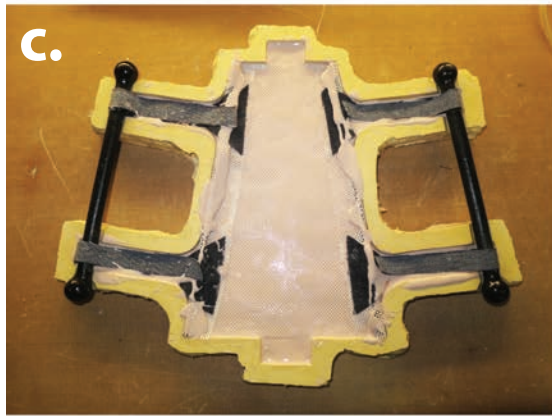
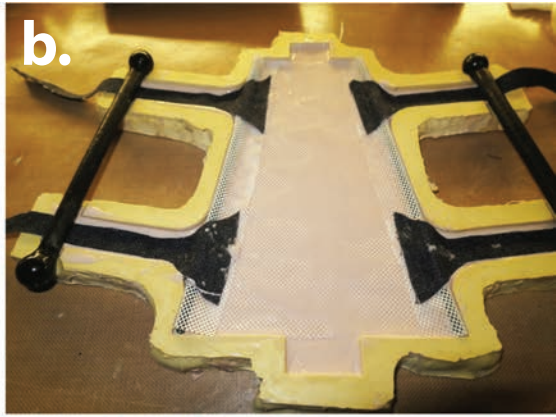
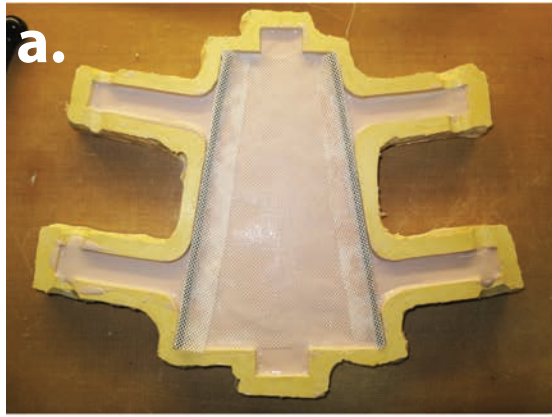


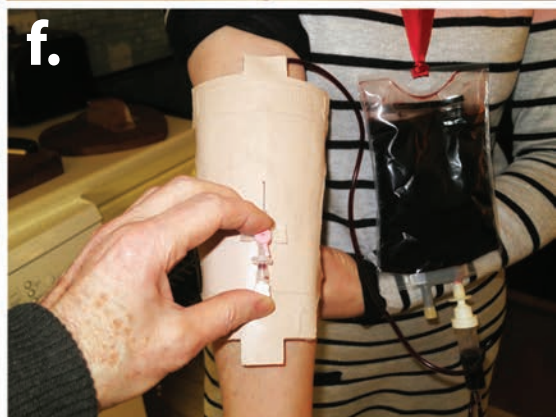
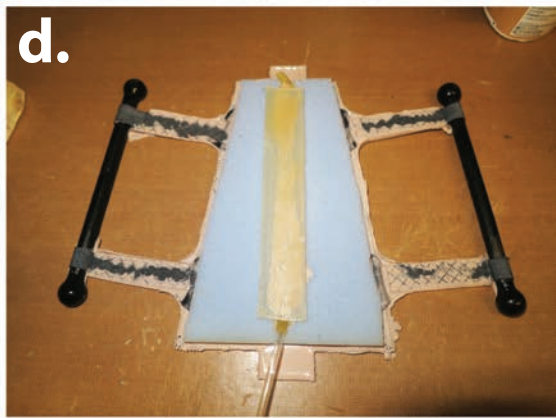
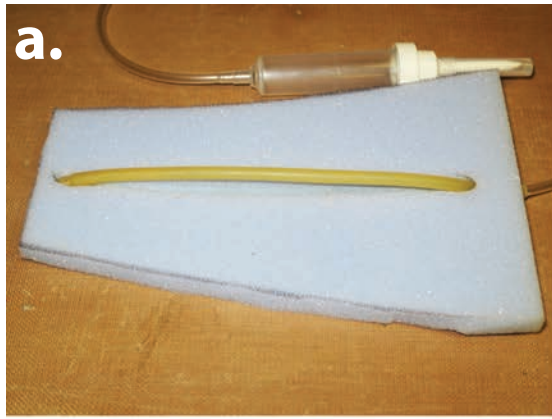
compressed and held in place overnight by various fitted weights (Panel d). Panel e shows the microembolus filter pierced by a wire threaded through the tube and panel f. the length of pure latex tubing that forms the blood vessel, attached to the polished end of the administration tubing.

Figure 3. Panel a. shows the latex tubing threaded through and lying unrestrained in a shallow gutter formed on the surface of a trapezoid panel of polyurethane foam. The deeper the gutter, the more buried the vessel feels in the final assembly. Panel b. shows the foam and vessel assembly inverted onto the skin assembly using a small amount of Silastic around its perimeter. Panel c. shows a 6cm diameter cylinder, coated with cling film onto which a length of 25mm wide woven fiberglass tape impregnated with polyester resin is being allowed to set to form a slightly cylindrical needle penetration guard. Panel d. The fiberglass shield glued with another few drops of Silastic, and in panel e the whole assembly with an additional panel of artificial fur material allowed to set into a slight curve. The position of the finished manikin in use is shown in panel f.

Figure 4. Representative examples of ranked scores of the objective, structured clinical exam (OSCE) phlebotomy station from 2003 (n = 146 candidates), 2005 (n = 167), 2006 (n = 173), 2008 (n = 219) and 2010 (n = 263 candidates). Marks were awarded for asepsis, preparation, communication, labeling appropriate collection tubes and disposal of consumables and sharps. Obtaining a blood sample first time was awarded 55%, with an automatic fail if a candidate attempted to obtain a blood sample on more than three occasions. A heavy penalty was imposed for failing to dispose of needles safely.







Rank ordered candidate scores over 5 successive years

