Injection Administration Practices, Guidelines, Training, and Kinematics: A Review of the Literature

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Motivation

The healthcare industry is consistently improving the quality of care it can deliver to patients. Advances in medication and technologies are the main drivers of constant progress in the efficiency and effectiveness of treatments. Technological advances usually come in the form of new tools that can be used in a hospital setting, such as ultrasound transducers and other imaging devices, electronic health records (EHRs), surgical devices, and more. As great as these advancements are, they are useless without nurses and doctors with the knowledge and skills to use them. Improvements in nursing are made through education by maintaining core values such as critical thinking, but also by adopting new tools to improve the quality of education. Most notable technological advances are in high fidelity simulation labs, but there are always limits to simulating the experience of caring for a real patient. Nevertheless, there seems to be an opportunity to leverage more modern technological capabilities to improve the quality of education. One form of technology that is now fairly accessible to the general public is motion capture systems. This enables individuals to record or visualize in real time the exact kinematics of a desired subject, in most cases the human body. There are a plethora of procedures, which are subject to change, that a nurse must be able to carry out with the proper steps and techniques. This paper provides a review on the current literature pertaining to a specific medical procedure carried out by nurses daily: injections. More specifically, literature on the kinematic parameters and training of the procedure.

In reviewing the errors made by novice nurses, Ebright et al. found “a significant portion of the reported errors occurred when the novice nurse was doing a procedure with which they had little or no experience” [21]. Novice nurses are not expected to be familiar with every procedure in health care, but it would be desirable to increase the amount of procedures nurses coming out of school are familiar with. Ebright et al. also notes “It is estimated that 75% of novice nurses commit medication errors (which includes errors in the administration of intravenous infusions, … Another study that tracked types of errors in novice nurses showed that as many as 88% of the errors involve medication and intravenous infusions,” [21]. If errors in administering medication are the most common, it would be logical to elevate the teaching of those procedures. Injections and infusions are procedures which require precise and unique technique dependent from case to case. Motion capture is a tool that can record precise information about the position and movement of the people and tools involved in these procedures. This data could prove to be extremely helpful in giving a nurse feedback on their performance, data analysis of technique parameters, and setting guidelines for procedures.

Background: Injection Types

There are a wide variety of injection types which deliver specific medications to different locations in the tissue. Of these various injection types, one of the most common, especially due the prevalence of the COVID-19 virus, is the intramuscular injection (IMI). While studying a nursing staff, Fekonja et al. state, “99.5% of participants reported they administer up to nine IMI per day” [2]. As the name may imply, an intramuscular injection is any medication that is injected into the muscle. This allows “larger volumes of drug [to] be injected due to the rapid uptake into the bloodstream through muscle fibres” [1]. Antibiotics, biologicals such as immunizations and vaccines, and hormonal agents are some of the most common medications that are delivered intramuscularly [24]. Due to the large demand for vaccines in recent years, injection education in nursing schools has been primarily focused around IMI. Anecdotal reports from nursing professors at the University of Massachusetts, Amherst highlight this focus and express the nursing students’ unfamiliarity with other injection types such as subcutaneous. Medications for subcutaneous injections are delivered into the fatty (subcutaneous) layer of tissue sitting just below the skin. It is “chosen when slow, continuous absorption of the drug is required, for example insulin and low molecular weight heparin” [11]. This is a shallower injection which requires a different technique from IMI, but intradermal injections go even shallower into the human flesh and require even more precision. Intradermal injections are less common and usually used for tuberculin and allergy testing where low volumes are deposited just below the epidermis [25]. Arguably the injection which requires the most precision is the intravenous (IV) injection, or injections into the vein. This procedure requires multiple steps if a catheter needs to be inserted into a vein. A catheter surrounds the needle which enters the vein first, then the catheter is pushed down the shaft of the needle and fed into the vein, after which the needle is removed. This requires precision, steady hands, and specific handling of the injection tools and patient. Jacobson et al. claim that IVs are the most common invasive procedures performed by nurses, yet in their study, a fourth of 339 observed IV insertions were unsuccessful [26]. This is a high rate of failure for such a common procedure which can cause “vein and nerve damage, hematoma, and neuropathic pain” according to Fujii [18]. Both Fujii and Jacobson et al. highlight the lack of research and data analysis of failure in this procedure, providing motivation for capturing motion data of this practice.

Nurse Training / Education

As stated before, the Elaine Marieb College of Nursing at UMass Amherst has reported that the vast majority of injection training pertains to IMI due to the high demand for vaccines in recent years. This is subject to change and Professor Cobb expects subcutaneous injections to become a higher priority in coming years. This requires a different technique and a more delicate touch according to Rodger and King since "under the muscle fascia has fewer pain sensitive nerves than subcutaneous tissue" [1]. The emphasis on proper technique is expected to elevate, thus a tool to improve the performance of nurses in training could prove to be very useful.

Currently, nurses learn how to administer certain injections based on the literature recommended by their curriculum and professor instructions. It has been found that the literature describing the parameters of injection techniques are not always consistent, resulting in variation throughout the practice. Petousis-Harris states:

> Prior to 2002 there were almost no published studies investigating the optimal technique for delivering intramuscular injections. This has led to inconsistencies in recommendations and practice as well as disagreements as to how vaccines should best be administered [15].

This sheds light on the need for data collection of injections. Additionally, anecdotal reports claim little time is spent in the nursing curriculum on the practice of administering injections, while students show a lack of dexterity and confidence in performing the procedure. A system which provides nurses in training with feedback could be conducive to accelerating their learning curve.

Kinematic Parameters: Injection Angle

One injection parameter that greatly influences the success of the injection is the angle at which the needle is inserted into the tissue. This is specified to ensure the needle reaches a certain depth depending on the type of injection. For intramuscular injections "Authors such as Craven & Hirnle (1996), Berger & Williams (1992) and others advocate introducing the needle into the site at 90 degrees" [1] while Pope suggests a 80-90 degree angle of insertion [13]. Petousis-Harris recognizes 90 degrees as the most popular specification for IMI angle and presented the following guidelines recommended by various sources [15]:

Source	**Angle (°)**	**Site**	**Aspiration/speed**	**Length**	**Gauge**
CDC [37]	90°	Deltoid >12 months	No/NS	1 in.	20–25
WHO [33]	90°	Thigh, deltoid for older infants	No/withdraw needle quickly	25 mm	23
IAC [38]	90°	Deltoid >12 months	No/rapid	1 in.	22–25
AAP [34]	90°	Deltoid >12 months	No/rapid	16 mm <12 months then 25 mm	NS
Canada [39]	90°	Deltoid >12 months	No/NS	1 in.	22–25
UK [31]	90°	Deltoid >12 months	Yes	25 mm	NS
Australia [40]	60°	Deltoid >12 months	Yes/slow	25 mm	23
New Zealand [41]	60–70°	Thigh <15 months	NA/controlled	16–25 mm	NS
	Or 90°	Deltoid >3 years	Not addressed		
New Zealand (MeNZB) [42]	60–70°	Deltoid (8–12 years)	Yes/slow	25 mm	20

NS: not specified; CDC: Centres for Disease Control (American); AAP: American Academy of Paediatrics; WHO: World Health Organization; IAC: Immunization Action Coalition.

Figure 1: Intramuscular Injection Angle Guidelines [15]

The table shows there is not a unanimous consensus on the angle parameter. Marshall et al. performed a study comparing 60 to 90 degree intramuscular injections, to evaluate for their success in injecting the medication into the muscle. This was confirmed or refuted using an ultrasound machine which found that 13/15 or 87% of administrations at 60 degrees were successful while 16/17 or 94.1% of administrations at 90 degrees were successful [19]. Although there is a slight difference in success rate, the sample size is small. More data would be useful in confirming the discrepancy, but this confirms the ambiguity behind injection angle. Katsma explains, “the rationale for the 90°-angle intramuscular injection is that as the angle of the injection deviates from 90°, the depth of the injection decreases’’ [16]. But simple trigonometry shows that small deviations from 90 degrees will have a very small impact in the actual depth. Figure 2 demonstrates this.

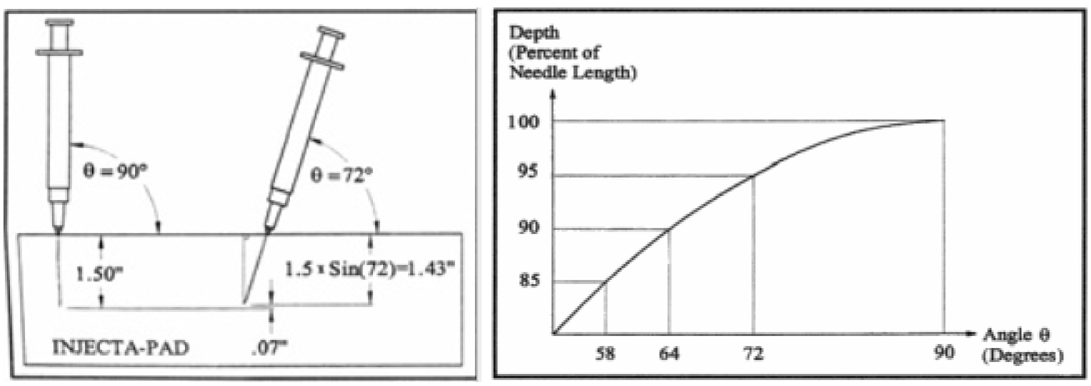

Figure 2: Needle Depth vs Angle [16]

Even at a 72 degree angle the depth only decreases by 5% from the maximum. Katsuma concludes that the angle for IMI does not have to be precise but the nurse should rather focus on using a comfortable hand position that will allow them to smoothly insert and remove the needle.

The angle of the needle and the actual length of the needle go hand and hand. For IMI, Beyea and Nicoll recommend “for adults, select a 1.5-in needle. For children, select a 1-in needle. Use a needle of 21-23 gauge” [9]. Marshall concurs with Beyea and Nicole, recognizing a 1.5 inch needle as the standard for adult IMI. Contrarily, Pope recommends a needle length of 0.5-1 inch for deltoid IMI and 0.5 for other locations (glute) in adults [13]. Rodger and King do not sit on either side of this disagreement of guidelines, they remark, “Needle size and dose is determined by palpating/pinching the fat and adding on a set length depending on area” [1]. They recommend this method since needle size guidelines are hard to establish while accommodating for different thicknesses of the subcutaneous layer of fat. Miscalculating the depth needed to reach muscle tissue for an IMI proved to be a problem in a study conducted by Cockshott et al. They utilized computer axial tomography (CAT) scans to determine where the medication injected into the dorsogluteal region by nurses was actually deposited. Results showed that "under 5% of the women and under 15% of the men would have actually received an intramuscular injection into the glutei" [4].

There are also inconsistencies in the guidelines for subcutaneous injection angles. Some sources set a loose range between 45 and 90 degrees depending on the length of the needle, with the 45 degree angle being recommended for needles longer than 8 mm (0.31 in) [10] [13]. Hunter sets the standard at 90 degrees which adjusts to that angle depending on the available subcutaneous tissue. She claims that accidental insertion into the muscle rather than the subcutaneous tissue will affect the rate of absorption and can cause the patient harm. She goes on to say this error is due to "a poor understanding of the technique" [11]. This alludes to the intuition and subjective judgment of the nurse which is required, to an extent, in most medical procedures. Although, that is not to say that feedback and more detailed guidelines on injection administration could improve a nurse's execution of the procedure.

The inconsistencies in angle specification could also be attributed to developments advocating for one technique over another. Martires et al. conducted a study, collecting patient feedback on how painful an injection of Lidocaine was at 45 degrees compared to 90. They reported the average and median pain experienced by 90 degree injections was lower than the 45 degree injection [17]. They hypothesized that the 90 degree injection was less painful because it was found to require less energy (in turn less force) than a 45 degree injection in a study conducted by Egekvist et al. [3]. Cocoman and Barron also acknowledged that with the introduction of shorter needles, "practice has changed from administration at a 45-degree angle to a 90-degree angle" [20]. With medical procedures constantly changing, a tool to enhance the learning of new techniques could expedite the education process and produce nurses with more uniform skills.

Intradermal and Intravenous (IV) injections require the shallowest angle of administration. Intradermal injections are shallower than the average IV with a recommended 10 degree angle between the skin and needle [25]. As one could imagine, this also affects how the nurse would hold the needle with their hand compared to a 90 degree injection since there is less of a concern of the patient's body obstructing the nurse's hand. Different hand placement is also used for IVs, since two hands are needed to manipulate the needle and catheter. The angle of IV injections vary depending on the patient, but there is a severe lack of data on the average angle in which IVs are administered. In one study, Fuji reported angles of IV administration on 64 subjects ranging from 10.7 to 21.8 degrees with a mean of 15.2 degrees [18]. Fuji remarks that there are no other experimental studies, to their knowledge, to compare these results to. For such a common practice in nursing with such a high rate of failure, ~25% [26], there is a need for data collection of the kinematics involved in this procedure.

Kinematic Parameters: Velocity

The velocity of needle insertion is a kinematic parameter which has not been outlined and studied thoroughly. Most sources describe this parameter by stating, "insert the needle smoothly" [11], "quick dart-like motion" [1] or "insert the needle with a steady pressure." [16]. A study conducted in 1997 is one of the few to record kinematic parameters of IMI. They compared novice nurses to experienced nurses and found their average peak velocities (+/- SD) to be 817.1 (+/- 250.7) mm/s and 606.9 (+/-) 285.6 mm/s [5] . Novices showed to have quicker injection velocities which somewhat disagrees with Egekvist et al. 's findings, assuming more experienced nurses deliver less painful injections. Egekvist et al. reported greater pain qualities to be correlated with slower injection speeds when comparing 2 mm/s and 19 mm/s injection velocities [3]. Another explanation is that nurses' attention to detail in their technique wanes in time. The 1997 study reported the average angle of IMI for novices was 82.5 degrees whereas experienced nurses averaged 75.6 degrees [5], further off from the common 90 degree recommendation. Although this difference in angle should not be significant for reasons stated previously. Jacobson et al. analyzed the success of IV administrations executed by nurses ranging in experience. They concluded that successful insertions were generally executed by more experienced nurses who completed them more quickly.

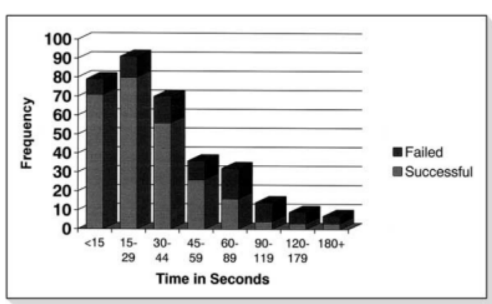

Figure 3: Frequency of Success and Failure of IV administrations vs Time to Complete [26]

Granted, this does not necessarily mean higher injection velocity because only the time to complete the entire procedure was measured. This information would be very useful to establish guidelines for instructing IV administration. Velocity is a useful parameter for nurses to know since it influences depth of injection and pain experienced. Kinematic data can also help identify poor technique not only in novice nurses, but experienced nurses as well.

Injection Rate/Volume

The rate and volume of a given injection can and does often result in various intravenous-related errors. A study in 1996 outlines a " high incidence (up to 90%) of bruising from any subcutaneous heparin injection techniques" [12]. This clearly demonstrates an area of training that could benefit from a revised education or training program. In literature concerning the current precedent for injection rate and volume, consistent evidence was shown for 1 mL every 10 seconds being an effective rate [1] & [9]. These studies also suggest a 10 second waiting period after injection before withdrawing the needle. However, another study reveals decreased site-pain intensity when injecting over a 30 second period [12]. Inconsistent and ambiguous statements in injection rate guidelines call for further data collection. Motion capture would be able to measure the velocity of the syring's plunger, thus the injection rate, providing a means of data acquisition. As seen in the table below, 73.3% of intravenous-related errors are at least partially due to an incorrect rate and 33.3% due to wrong volume [23].

Table 3 Type and severity of intravenous administration errors

Type of intravenous-related error	Number of errors (%)	Number of errors rated as serious (% of intravenous error type)
Wrong rate	266 (73.3)	95 (35.7)
Wrong volume	121 (33.3)	21 (17.4)
Wrong mix	21 (5.8)	5 (23.8)
Drug incompatibility	3 (0.8)	1 (33.3)
Total intravenous administrations with at least one clinical error	363*	99* (27.3)

*Sums exceed totals because of multiple errors within the same intravenous administration.

Figure 4: Type and Severity of Intravenous Administration Errors [23]

Fixes in training regarding these two areas would result in significant decreases in intravenous administration errors.

Hand and/or Body Position/Form

Another influential factor of administering injections, which is often overlooked, is how the non-dominant hand and rest of the body is positioned relative to the patient. Injections, for the most part, are two handed procedures. One hand holds/manipulates the syringe while the over holds and manipulates the patient's body around the injection site. Some literature in IMIs guides nurses to stretch the skin at the injection site with the thumb and forefinger of their free hand [6]. Other literature outlines a “Z-track technique” which involves pulling the fatty tissue “1+/-1.5 inches” to the side of the injection location [1]. This is meant to better seal the medication in one location and prevent it from leaking to unwanted parts of the tissue. Another technique of pinching the skin to “lift the adipose tissue from the underlying muscle” is suggested for subcutaneous injections, in order to prevent IMI [11]. Other sources lay out detailed guidelines on how to position the patient’s entire body, for example, “In a prone position, the patient can be instructed to "toe in," which internally rotates the femur. In a side-lying position, the upper leg can be flexed 20° to ensure internal rotation” [9]. This technique can help relax the muscle and allow the nurse proper access to the injection region. This also extends to how the nurse positions theirself, for certain procedures. Figure 5 outlines various responses from nurses on technique tips for administering IVs:

Table VII
Techniques or "tricks" used by nurses to facilitate IV insertion

Category	Actual nurse responses	Frequency
Position self	Stand, usually stand, always stand, sit down, sit down at bedside on chair or window sill, always sit down, get self in position so don't have to bend over (sometimes stand, sit, or kneel), squat or sit if need to use hand, kneel	18
Use mechanical stimulation	Flicked vein, tapped vein, rubbed vein, slapped site, rubbed with ETOH, rubbed vein, massaged vein, mashed vein to make it stand out, used increased friction/duration while cleaning site, rubbed arm downward	16
Stabilize vein	Stabilized vein, anchored vein, positioned to hold vein in place, pulled skin taut	15
Individualize tourniquet use	Did not use tourniquet, no BP cuff, released/reapplied tourniquet to bring up vein, had tourniquet on and off several times, used BP cuff instead of tourniquet, lowered arm and then placed tourniquet	9
Individualize threading technique	Threaded slowly, threaded gently, floated with IV going, threaded with fluid going, kept stylet in until completely threaded because of tough skin, when initial flashback stopped pushed needle above initial insertion site and threaded with difficulty, played with JELCO (advanced and pulled back)	9
Position arm dependent	Put arm off side of bed in dependent position, had patient let arm hang straight down, lowered limb	8
Position bed	Raise bed, bed elevated, bed in air, keep bed low, raise head of bed	7
Enhance vein visibility	Left skin wet with ETOH so could see vein better, vein only partially visible so palpated entire vein, shaved hair on arm, used exam light, closed eyes to feel for vein, did not use Betadine because obscures vein	7
Use lidocaine	Used lidocaine before insertion, 0.1 mL intradermal lidocaine, local anesthetic to decrease anxiety	6
Use heat	Applied moist heat, used warm towel	6

Figure 5: Techniques used by Nurses to Facilitate IV Insertion [26]

Many of these use relative positioning to improve the success of the procedure, motivating the new technical usefulness of collecting kinematic data to support certain techniques or improve upon them.

Injection Kinematics and Forces Current Research

There has only been one published study on the kinematics of a needle during injections to the author's knowledge. Katsma et al. compared the needle motion between novice and experienced nurses for IMI. They used "video motion analysis techniques" with a VHS camera to record subjects administering 5 IMIs into InjectaPads [5]. They were able to produce the data featured below.

Variable	Novice	Nurse	Probability
Vertical displacement	129.6 ± 31.4 mm	92.6 ± 32.8 mm	$p < .0001$
Horizontal displacement	23.4 ± 13.3 mm	23.3 ± 14.1 mm	$p = .983$
Depth	33.4 ± 4.1 mm	33.7 ± 4.1 mm	$p = .884$
Peak velocity	817.1 ± 250.7 mm/s	606.9 ± 285.6 mm/s	$p = .003$
Contact velocity	743.1 ± 240.7 mm/s	544.0 ± 296.3 mm/s	$p = .005$
Horizontal component of contact velocity	55.4 ± 35.2 mm/s	−34.8 ± 148.4 mm/s	$p = .835$
Path width	2.29 ± .9 mm	2.9 ± 0.1 mm	$p = .023$
Angle at contact	82.1 ± 7.1°	75.6 ± 9.7°	$p = .005$
Angle at completion	85.5 ± 5.3°	78.2 ± 9.5°	$p = .0005$
Delta angle	4.5 ± 4.5°	2.3 ± 4.2°	$p = .433$

Figure 6: Kinematic Parameters of IMIs [5]

Peak velocity, angle at contact, and vertical displacement show the highest discrepancies and are parameters of interest. This study was conducted 25 years ago, an updated study using more advanced motion capture equipment could shed new light on injection technique and provide a cross examination of data. An automated motion capture system could even be created to give a nurse feedback on their kinematic performance.

Other research has been conducted to attempt to aid in the administration of injections. One paper by Lorenzo et al. reported on their development of a "novel robotic coaxial needle insertion assistant" [14] which amplifies force experienced on the needle tip during an injection so the operator can feel when the needle enters a different type of tissue. They reported that this has increased the frequency of tissue change detection by "up to 50%", presumably giving the operator a better "feel'' for where the needle is located in the tissue. The success of haptic feedback to increase a nurse's knowledge and/or confidence motivates exploration into other modes of feedback such as visual or audio. The evaluation of this insertion assistant also yielded useful force data.

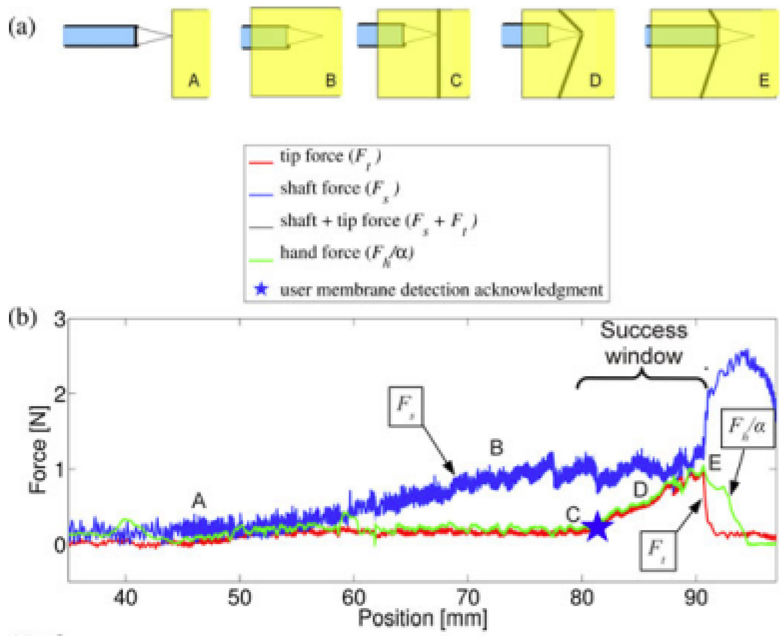

Figure 7: Force Experienced by Needle Tip Data [5]

Force data can be related to parameters discussed throughout this review including needle size, insertion technique, and tissue properties. The downside of this tool is that it is large and not realistic for use in actual practice. For this reason, motion capture tools that do not obstruct the procedure at all are being explored to validate if they can deliver accurate information about position, angle, velocity, and possibly even force.

Jiang et al. studied the forces a needle experiences during injections as well, some of their results are shown below [22].

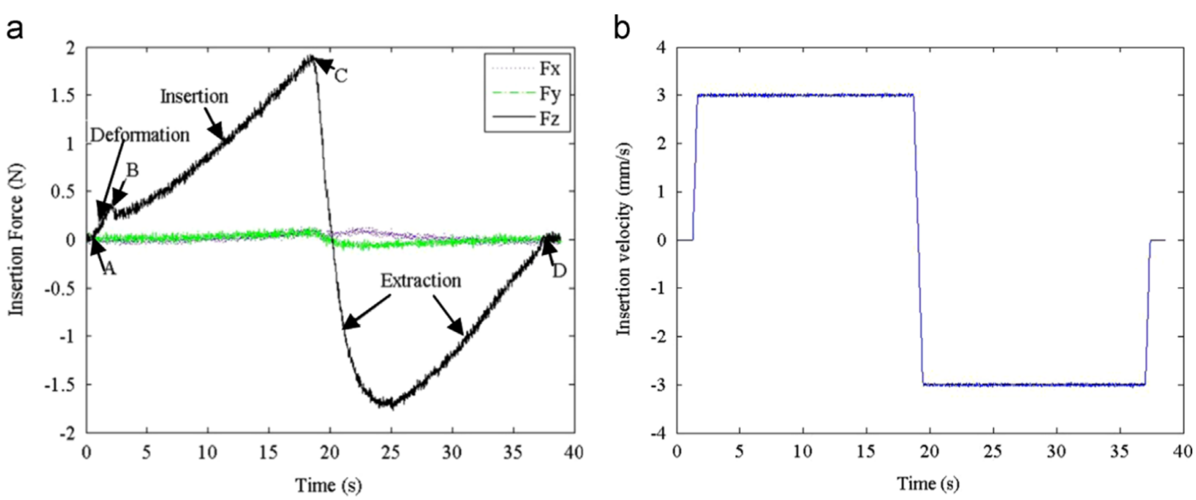

Figure 8: Force Profile of Needle-Tissue interaction Forces at 3 mm/s [22]

The force is seen reaching an initial peak when it maximally deforms the skin then drops off once the skin is pierced, followed by a relatively linear increase in force. This information is very useful for novice nurses since it can give them a better understanding of the dynamics they will experience. This data can also be useful in correlating force to required velocity, "Mahvash and Dupont (2010) showed that increasing the velocity of needle insertion will reduce the force of rupture event when it increases the energy release rate" [22] which can be seen in these graphs:

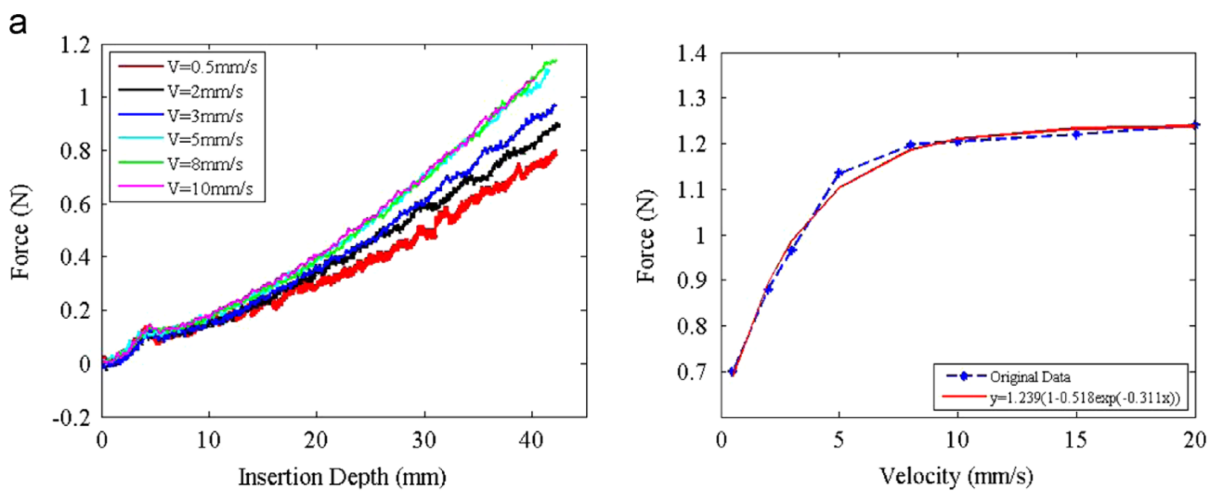

Figure 9: Force vs Insertion Depth and Velocity [22]

This velocity also becomes more critical once the needle has pierced the skin, since there is a higher likelihood of injury or irritation. Jiang et al. say that velocity and the "insertion process (interrupted and continuous)" greatly impact the insertion force.

Experimental Injection Training Methods

Research aiming to study the effectiveness of injection training has been limited to hands-off learning. A 2018 study compared the knowledge retained by 2 groups of nursing students after an experimental group was taken through a video presentation on subcutaneous injections while the control group received a 30 minute face to face lecture. Vicdan reported, "the score of the experimental group was 10 points… and the score of the control group was 11.98" [7] meaning the face to face lecture was a more effective teaching method. A 2021 study was able to test out a more immersive learning experience by presenting learning material about IM, SC, and IV administrations in Augmented Reality (AR) through games and animations. The material covered injection sites, angle, and tool preparation. Kurt and Ozturk concluded that, "MAR applications reduced their fears about injection practices, increased their motivation and self-confidence, provided a solid, clear picture of the subject, and facilitated the identification of the injection areas and applications, resulting in an efficient laboratory process" [8]. The results of these 2 studies show that more immersive hands-on learning experiences produce more knowledgeable and skillful students in this practice. Making a learning experience more engaging has great benefits for the student.

Conclusion

The current background and state of injection practice has been outlined. Injection training instruction, guidelines, and practices are generally inconsistent. The severe lack of kinematic data of body parts and syringes during injection administration limits the conclusions that can be drawn about the practice and would be useful for many applications. Injections are also procedures that require precision and take time and effective training to execute correctly. Hands-on training has proven to be a superior method for nursing education. To this end, it has been hypothesized that kinematic parameter data would be useful for feedback to those learning how to administer injections.

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