Investigation of Needle Bevel Face Up and Down Orientation on Pediatric Intravenous Access

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In the pediatric intravenous (IV) procedures, needles with small diameters are selected to access the patient's small and fragile vessels. The most common type of needle used for IV access is the lancet hypodermic needle. In the pediatric community, there is currently a divide in opinion on the best practice with the bevel face up or down in needles insertion into thin vessels. In this study, a 24-gauge needle (0.56 mm outside diameter) with a lancet tip was inserted into a soft PVC phantom with a 1.27 mm vessel to compare the performance of these two approaches. The insertion force of the needle and the deformation of virtual blood vessel were measured. The peak insertion force in bevel-down insertion is 33% lower than that of the bevel-up insertion. The vessel width change before needle tip cut into the lumen with needle bevel face down is 14% smaller than that in bevel up insertion. The bevel down insertion has 13% and 75% smaller peak deformation of the vessel anterior wall and posterior wall than bevel up insertion. This study shows the bevel down needle insertion, a procedure less utilized by medical professionals, has advantages over bevel up in accessing the fine vessels for pediatric IV procedures.

1. Introduction

Intravenous (IV) access is a common medical procedure in pediatrics. During pediatric IV insertion, a small size needle (22-24 gauge, 0.71-0.56 mm OD) with lancet tip is usually used to pierce into the vessel of the pediatric patient [1-3]. Because the veins of children are very thin, IV insertion is usually difficult. If the patient is very young or with other medical complex conditions, for example, high body mass index (BMI), the needle insertion is more difficult and time consuming [4-10]. Clinical observations showed that multiple insertions are usually required for successful IV access [11]. Additional needle passes increase the time as well as pain and other problems of children. The pain and fear of the needle procedure also has a long term negative effect on pediatric patients, who may have a lifelong fear of needles [12-14]. There are several ways to increase the success rate in pediatric IV access, such as developing novel needle design and insertion tool [15, 16], training for pediatric residents and nurses to improve their skills and techniques [17-20], using ultrasound or infrared light guiding equipment to assist insertion procedure [21-24]. Among these methods, improving the needle insertion technique is an effective, economic and practical approach to increase the success rate and reduce the pain of pediatric patients. Needle bevel face orientation is an important but often overlooked factor to be considered in needle insertion techniques [19]. There are two accepted insertion techniques according to bevel face orientation: bevel up and bevel down. Figure 1 shows the schematic of these two insertion techniques. The goal of IV access is to connect the inside of needle tube to the lumen of the vessel without causing the needle tip over-penetrates the posterior wall of the vessel wall. In bevel down insertion orientation, the needle whole bevel face of needle tip has a better orientation to access inside the vessel lumen and result for a successful insertion. In comparison, bevel up insertion, some part of the needle tip is still prone to over-penetrate outside the vessel and may be more likely to results a failure needle IV insertion access. However, bevel down is less popular due to the lack of training and difficulty to visually unable to see the needle bevel face and tip at the penetration point on the skin. In theory, compared to the bevel up technique, the bevel down technique should may have higher insertion success rate. Some pediatric textbooks [1] recommend using the bevel down technique especially in small and dehydrated patient. However, most medical centers professionals adopt the bevel up technique while only a few pediatric care training centers teach bevel down technique. There is no definite conclusion on which technique is better than the other. Black, et al., [19] made a research to compare these bevel up and down two IV insertion techniques in a pediatric clinical trial on 63 nurses and 428 patients. The results showed that the bevel up technique has higher success rate than the bevel down technique (Fig 1(b)). Because most of nurses in the research were familiar with the bevel up technique and never tried the bevel down insertion approach before. The study could not make the conclusion that bevel up insertion is better than the bevel down insertion.

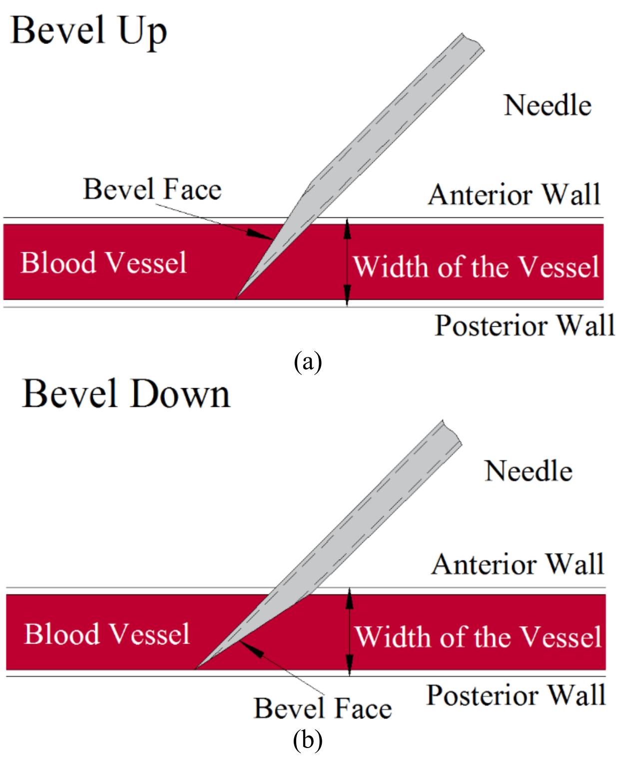


Figure 1. Schematic of two IV insertion techniques with needle: (a) bevel up and (b) bevel down

In this paper, a transparent tissue-mimicking polyvinyl chloride (PVC) material is used to make a cube phantom with a straight hole inside to simulate the vessel under skin. The insertion force and deformation of the virtual vessel during the insertion are both measured to compare the performance of bevel up and bevel down techniques.

2. Experimental Setup and Procedure

The overview of the experimental setup, including the needle, phantom, linear stages, optical microscope, and dynamometer, is shown in Figure 2(a).

2.1 Preparation of the Samples Made of Transparent Soft Tissue Mimicking Material

To achieve repeatable and consistent needle insertion force and deformation, homogeneous tissue mimicking soft PVC was used to make the phantom samples with vessel [25]. Besides the appropriate mechanical properties of this material, this soft PVC is also optically clear, which enables the optical tracking method to measure the deformation of the vessel lumen during needle insertion. The tissue-mimicking soft PVC was made by mixing two liquids: liquid plastic (66.7 wt%) and plastic softener (33.3 wt%). The liquid mixture was heated to 150°C to polymerize and became transparent. The liquid mixture was poured into a cubic mold with an 18 gauge (1.27 mm OD) tube inside. The phantom was secured inside the mold after it was cooled to the room temperature. After the soft PVC cured, the tube was extracted, leaving a 1.27 mm diameter hole inside the phantom to mimic the blood vessel. The phantom and the mold are shown in Figure 2(b). Six phantoms were made: three for bevel up and the other three for bevel down insertion tests. The values of insertion force discussed in this paper were calculated as the average values of three tests.

2.2 Experimental Setup and procedure

A 24 gauge (0.559 mm OD, 0.406 mm ID) AISI 316 stainless steel needle was used in this study. The lancet needle tip geometry was grounded with a vitreous bond cubic Boron Nitride (CBN) grinding wheel in the Chevalier surface grinding machine (Model Smart-B818) [26], which is shown in Figure 2(c). The needle was fixed on the needle fixture on a stack of three linear stages (Model 200cri, Siskiyou Instrument, Grants Pass, Oregon), which were utilized to control the position and movement of the needle in x, y and z direction. The PVC phantom and the mold are mounted on top of a piezoelectric force dynamometer (Model 9256C1, Kistler, Winterthur, Switzerland) to measure the force during needle insertion. The angle between the needle insertion direction and the virtual vessel is 45° [19, 24]. The speed of the needle during insertion was 1 mm/s. The insertion distance is 12 mm. Three bevel down insertions were conducted in three phantoms, followed by three bevel down insertions into three phantoms.

During the insertion, a microscope eyepiece camera (Model MU035, AmScope, Irvine, California) was used to record the video of the insertion procedure with a WF 10x lens at 24 frames per second rate. The video images were converted to binary images and processed with a MATLAB code to get the deformation of the blood vessel. The profile of the posterior and anterior wall of the vessel were identified and deformation of the blood vessel was evaluated by the deformation of anterior wall and posterior walls of the vessel during the insertion procedure, which is the displacement of the points on the anterior and posterior walls from the original to deformed position in the direction perpendicular to the axis of the vessel. The width of the vessel is another factor to be considered, which was obtained by calculating the distance between anterior and posterior wall. The deformation of the vessel at two time instances were used to compare the performance of these two insertion techniques: one was the moment when the needle tip touched the anterior wall of the tube and the other was the time when the largest deformation happened. The deformation of the vessel before the needle cutting edge entering the vessel showed the probability of the situation in which the needle slid over and missed the vessel.

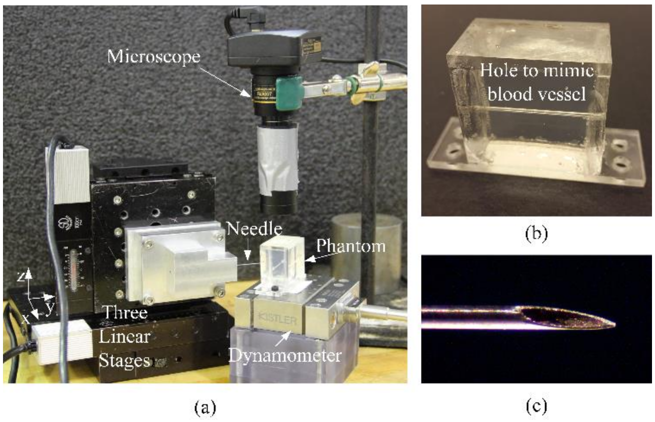


Figure 2. Experiment setup of the needle insertion test: (a) overview; (b) the vessel mimicking phantom and (c) the close-up view of the needle tip

3. Results and Discussions

3.1 Insertion Force

The force profiles of the two insertions with bevel up and bevel down techniques are shown in Figure 3. The force profiles for bevel up and down insertions are similar: the insertion force increased with the insertion distance after the needle tip cut into the phantom sample which exhibits a large deformation. The peak insertion force (at about 12 mm insertion distance) varies significantly: 0.20 N for bevel up and 0.14 N for bevel down. The bevel face down insertion has 33% lower peak insertion force than that of the bevel up needle insertion. The insertion force consists of the cutting force at the tip and the friction force on the contact surface between needle wall and phantom material. The friction force increased with the contact surface area. The contact surface areas and the friction force of the two bevel orientations are the same. The difference of the insertion force is in cutting force and the configuration shown in Figure 4. The angle θ between the phantom surface and the needle bevel face of the needle with bevel up and down is:

$$\theta = \beta + \xi \quad \text{(for bevel up)} \qquad (1)$$

$$\theta = \beta - \xi \quad \text{(for bevel down)} \qquad (2)$$

where β is the angle between the axis of the needle and the phantom surface and ξ is the bevel angle of the needle tip.

Under the same angle β and ξ, the bevel down has smaller θ. The smaller θ can help to reduce the insertion force for the bevel down orientation.

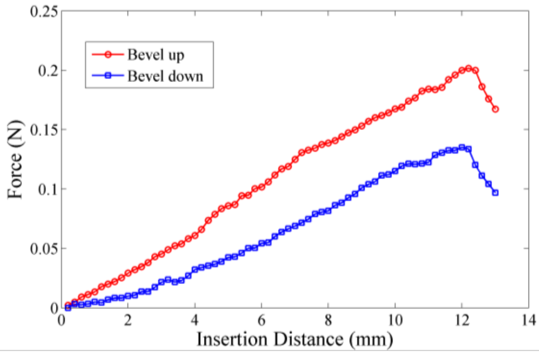


Figure 3. The measured force of the bevel up and down insertion procedures

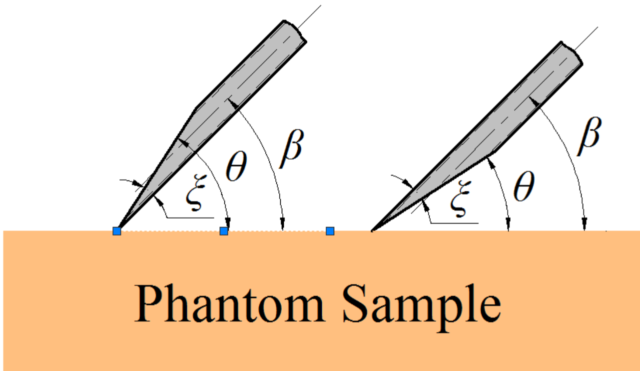
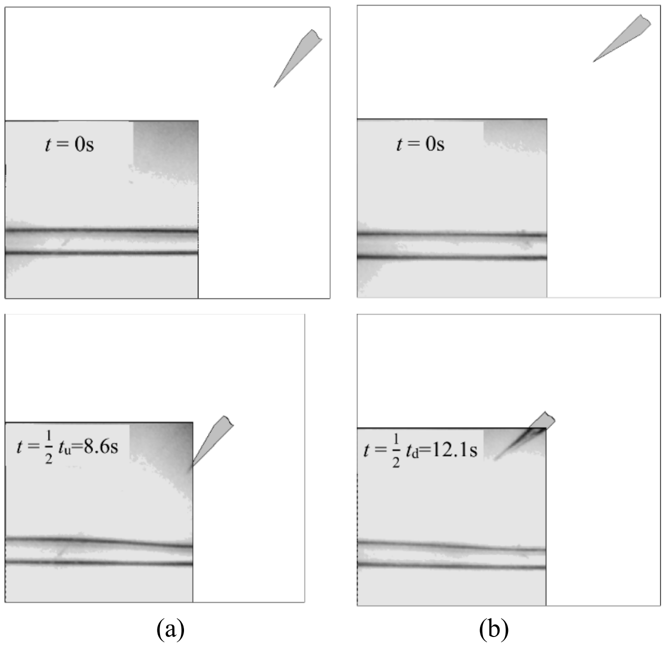
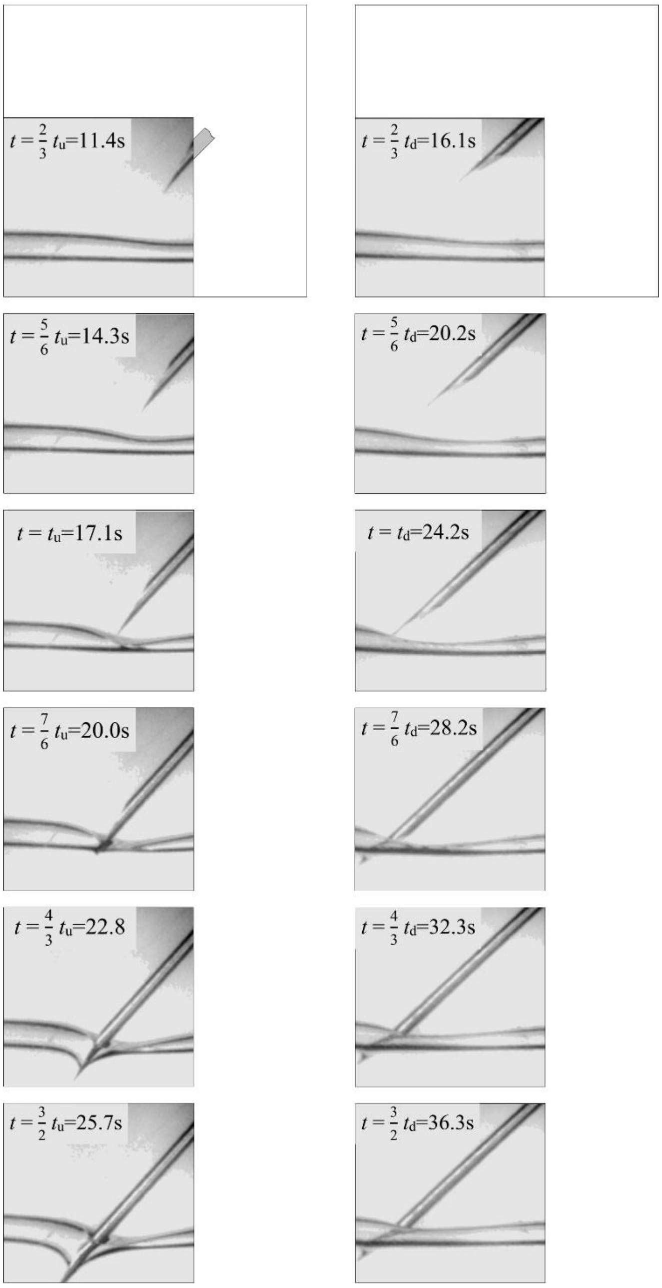


Figure 4. The schematic of angles on the needle tip in bevel up and down insertion

3.2 Deformation of the vessel phantom

The deformation process of the vessel during the whole needle insertion with bevel up and bevel down is shown in Figure 5, where t_u (17.1 s) and t_d (24.2 s) are the time when needle point touched the vessel in IV access with bevel up and bevel down, respectively.



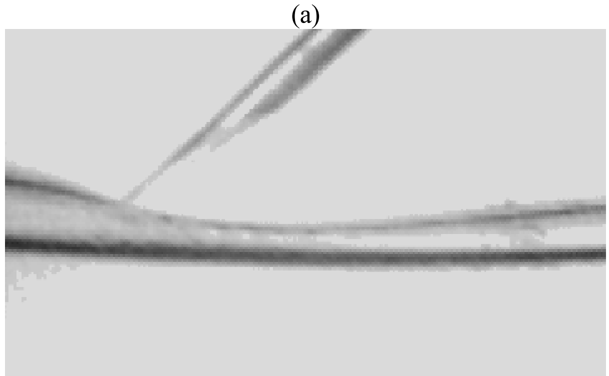


(a) (b)

Figure 5. The whole deformation process of the IV access with: (a) bevel down and (b) bevel up.

The deformation of the blood vessel before piercing by the needle tip may affect the success rate of the IV procedure. If the deformation of the vessel before penetration is large, the vessel may change its position and make the needle to miss the blood vessel. The deformation of the vessel at the point where needle tip began to touch the vessel wall before the penetration is shown in Figure 6. The bevel down exhibits much smaller vessel deformation and narrowing of the lumen than the bevel up insertion. Using the imaging processing code, the minimum width of the vessel lumen inside at the point where needle tip touched the vessel vs. insertion time are shown in Figure 7. The needle tip in bevel up insertion touched the anterior wall of vessel first, the change of the vessel width in bevel up insertion starts earlier (t_u = 17.1 s) than that of the bevel down (t_d = 24.2 s) insertion. When the needle tip touched the vessel wall (the last point of the Figure 7), the width of vessel at the touching point before needle penetration in bevel down insertion (0.79 mm) is larger than that in bevel up insertion (0.68 mm). Since the original width of the vessels in these two insertion is the same, the change of the vessel width is smaller in bevel down insertion than that in bevel up insertion. The smaller deformation and larger width of vessel before needle entering the vessel in bevel down insertion may could help to avoid the situation where the needle slides over the vessel.

(a)



(b)

Figure 6. Deformation of the mimicked blood vessel before the needle entering into the lumen of the vessel in: (a) bevel up and (b) bevel down

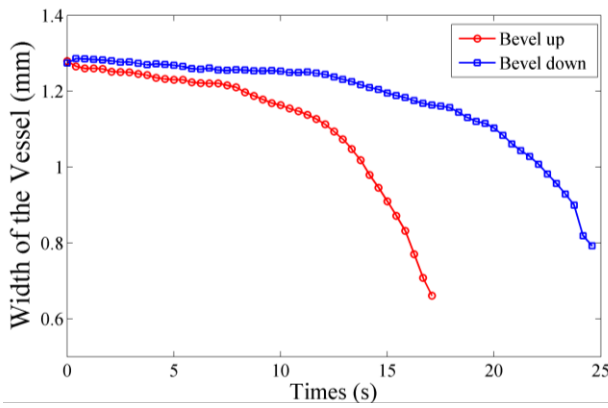


Figure 7. The widths of the lumen inside the vessel at the point where needle tip touched the vessel from the beginning to the touch moment in two insertion methods.

Pictures of the vessel phantom with the largest deformation during the bevel up and bevel down insertions are shown in Figure 8. The deformation and the damage of the vessel are clearly different between these two insertion approaches. The deformation of the vessel is evaluated by the largest displacement of the points on the anterior and posterior wall from the original position to the deformed position in vertical direction respectively. In bevel up insertion, the whole needle tip penetrated outside the vessel. Point A and B are the lowest point on the anterior and posterior wall after deformation in bevel up insertion respectively. The deformations of the anterior and posterior wall at point the point A and B respectively were 1.47 and 1.16 mm, respectively. Point C and D are the lowest point of the anterior and posterior wall of vessel after deformation in bevel down insertion respectively. In bevel down insertion, the deformation of anterior (at the point C) and posterior wall (at the point D) is 1.28 mm and 0.29 mm respectively, which are both smaller than those of the bevel up insertion. Bevel down insertion also has a smaller portion of the needle tip punched out of the vessel than that of bevel up insertion. In bevel up insertion, point A on anterior wall touched the posterior wall and resulted a zero vessel width. The largest change of the vessel width is 1.27 mm. Similarly, in bevel down insertion, point C touched the posterior wall. The largest vessel width change in bevel up insertion is also 1.27 mm. According to the geometry relationship of the needle and vessel, the bevel up insertion can penetrate the vessel easier than the bevel down insertion and may cause complication. The results of the experiment proves the difference of the bevel up and down insertion technique in geometry relationship analysis. The larger deformation of the vessel in bevel up insertion may lead to more severe damage to vessel and lower success rate of IV procedure.

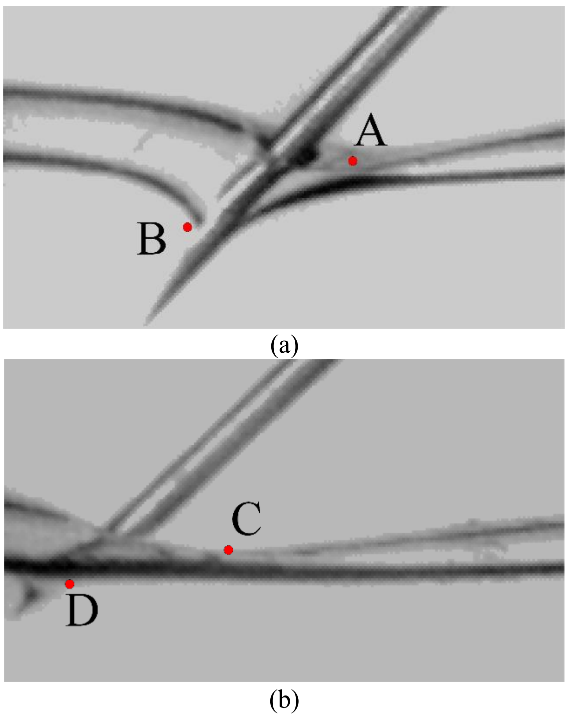


Figure 8. Largest deformation of the mimicked blood vessel in: (a) bevel down and (b) bevel up

4. Conclusions

In this paper, the insertion force and the deformation of the simulated vessel in bevel down and bevel up insertion were measured. The peak insertion force of the bevel down insertion is 33% smaller than that of the bevel up insertion because of the high rake angle. The width change of vessel before the needle pierce the vessel in bevel down insertion was 14% smaller than that of the bevel up insertion. The largest deformation of the anterior wall and posterior wall in bevel down insertion were 13% and 75% smaller than that of the bevel up insertion. Needle in bevel down insertion punched out of the vessel with a smaller distance than that of the bevel up insertion. The lower insertion force and smaller deformation in bevel down insertion showed the advantages of this needle orientation over the bevel up insertion. In the future, the influence of insertion angle, needle speed and bevel angle on the pediatric IV procedure will be investigated.

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