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Experimental study of the POP technique: focus on the physical basis of the process

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Abstract

Introduction: Central or peripheral vascular access devices have been in use for many decades. However, despite adequate care and maintenance, complete occlusion may occur, and its impact cannot be overlooked. A new procedure using a percussion technique has been published and referred as ‘the POP technique’.

Methods: A hydrodynamic bench was used permitting both the recording of the movement of the piston with a fast camera and the pressure variations in the polyurethane and silicone catheters while connected to 2- and 3-piece syringes.

Results: The results are twofold. First the upward movement of the piston leads to the installation of a saturation vapour pressure in the body of the syringe. During this sequence, the clot is submitted to a force of aspiration. Then the release of the plunger leads to a pulse pressure whose dynamics and intensity are dependent of the types of syringes and catheters.

Conclusions: The experiments bring to light the importance of practical features such as the orientation of the syringe and the nature of the polyurethane or silicone catheters. Then the analysis enables the definition of practical rules for safe practice of the POP technique. This study will impact clinicians as many may be tempted to use the technique in hope to resolve the occlusion safely, in a timely manner.

Keywords

Nursing, techniques and procedure, oncology access, intensive care, nutrition

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Introduction

Central or peripheral vascular access devices have been in use for many decades. They allow repeated vascular (venous, arterial) accesses for drugs administration, parenteral nutrition, blood transfusion, as well as blood sampling. Insertion of peripheral or central venous access devices is performed regularly following medical orders of intermediate or long-term intravenous infusions. In all cases, from a practical point of view, the patency of the catheter is a required condition to ensure the safe delivery and efficacy of the intravenous treatment. Several guidelines, on care and maintenance, are available giving both the so-called ‘good practices’ and recommendations for the prevention and treatment of the occurrence of occlusions.^{1–5} However, despite adequate care and maintenance, complete occlusion may occur, and its impact cannot be overlooked. There is existing literature

on management of complete occlusion⁶; however, the technique required to unblock the catheter is time-consuming, costly, and not always successful.^{2–5} In some cases, the permeability of the catheter can be re-established by increasing the pressure in the catheter by connecting a syringe to the catheter lumen and performing a manual flushing. This process can be successful if the clot is

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recent or weakly attached to the wall of the catheter. However, the increase of pressure in a non-power injectable catheter can lead to mechanical damage of the catheter and is not recommended by most manufacturers. In 2001, a new procedure using a percussion technique⁷ has been described and referred as 'the POP technique'. This procedure was summarised in the following way: the syringe is attached to the blocked lumen and placed vertically pointing downwards. The piston is pulled to the very end of the barrel and released briskly. The procedure is repeated every 2 seconds until patency is restored.

This article described a practical *in vitro* experimentation of the POP technique. This study had been performed⁸ using peripheral inserted central catheters (PICC) clotted with human blood. The authors concluded that, in the framework of their experiment, the percussive POP technique permitted to restore patency in 86% of the occluded catheters. Such results are clearly of interest, but they remain difficult to adapt to various medical situations in which a variety of material (silicone (SI) or polyurethane (PUR)), length of catheter, localisation, size and nature of the clot and degree of aging co-exist. The analysis of clinical and pharmacological data⁹ permits to highlight the possibility for the POP technique to be an inexpensive alternative to the use of thrombolytic for restoring the patency of occluded catheters: it is often not possible to locate merely the position of the clot, the introduction of urokinase or alteplase or new thrombolytics (alfimeplase, reteplase, etc.) near the clot is made difficult for practical physical reasons (convective and diffusive processes).

The work presented in this article proceeds in a different step. Keeping in mind that in the POP technique the ultimate cause of detachment and ejection of the clot is a mechanical process monitored by pressure forces, we aim at performing a thorough examination of the different physical elements possibly involved in the process, namely: type of syringe, movement of the plunger, geometrical and physical (elasticity) characteristics of the catheter.

It is expected that this experiment will enable to describe the favourable conditions for the potential effectiveness of the POP technique. Moreover, numerical simulation will be conducted permitting a better comprehension of the role of the different parameters involved in the breakage of the clot (such as the plunger mass or its friction in the body of the syringe).

Material and method

The experiments are conducted on a hydrodynamic bench permitting both the recording of the movement of the piston and the pressure variations in the catheter while connected to the syringe. The recordings are synchronised permitting to connect the movement of the piston to the pressure variations in the catheter.

The material retained corresponds to classical therapeutic practices: 2-piece 10 mL BD Discardit[®], 3-piece 10 mL syringes BD Plastipak[®] and BD Emerald[®] (Becton Dickinson France) and catheters 5 F SI (silicone) and PUR (polyurethane) and 7 F PUR (TIVADs Polysite[®] Vygon France). A comparative analysis is made difficult because for a same denomination of the available material (e.g. 5 F), the catheters do not have the same geometrical characteristics (due to the different mechanical properties of PUR and SI). Then the experimental results will be presented side by side with catheters 5 F PUR vs 5 F SI (same external diameter and different internal diameter) on one hand and 5 F SI vs 7 F PUR on the other (nearest thickness of material).

For the experimentation, the catheter was attached to the syringe by means of a T-piece, which was connected to a pressure transducer.

The initial position of the plunger corresponded to the nominal volume of the syringe, namely 10 mL, and is referred to 'Up' in the following. The final position of the plunger is referred to 'Uw' corresponding to the residual volume of liquid in the syringe, namely 2 mL.

Because of the rapidity of the movement of the plunger, a fast camera (Photron Fast Cam SA3) was used for acquiring images at a frequency of up to 5000 fps. The pressure is recorded by a high-frequency piezoelectric pressure sensor (pressure transducer type CTN/4F-1 LP, GAELTEC) connected with the syringe for recording the pressure variation during the fall of the piston.

Preliminary data

As mentioned previously, the so-called 'POP technique' results from a double process. First an upward movement of the piston followed its brisk release. The first part of the process involves a basic physical process mainly operator non-dependent and material non-dependent. The upward movement of the piston (on an occluded lumen) leads to the installation of a saturation vapour pressure in the body of the syringe. In the following, the vapour pressure will be noted as P_{sv} . For the experimentation, the catheter and the syringe were filled with an aqueous solution. At ambient temperature, the saturation vapour pressure value is approximately $P_{sv} = 3000$ Pa or 0.43 psi (pound per square inch). This pressure value, 0.43 psi, remains the same regardless of the diameter of the syringe. The vapour pressure (1) is installed as soon as the plunger begins to move, (2) is independent of the size and diameter of the syringe and (3) independent of the dynamics of the movement of the plunger. A major key difficulty associated with this process is the possible occurrence of gas bubbles in the body of the syringe or in the catheter as seen in Figure 1.

From the clinician perspectives, gas bubbles may be misinterpreted as a leak air within the syringe and/or catheter. Nevertheless, the gas bubbles may have an incidence on the

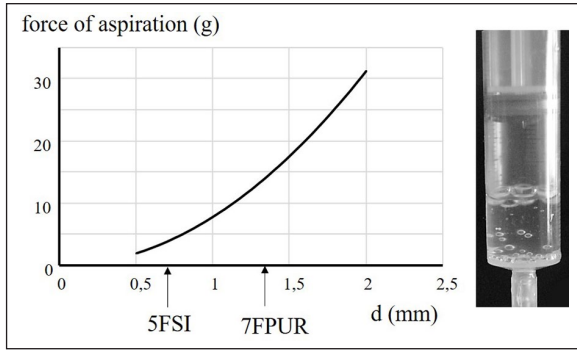


Figure 1. Mechanical incidence due to pressure depression: force of aspiration (converted in gramme) on a clot as a function of the internal diameter of the catheter and photography of the body of a syringe showing the formation of bubbles due to pressure depression.

global efficiency of the POP technique. The bubbles being deformable, they modify the global compliance of the catheter, thus leading to a greater attenuation of the pressure impact. This point will be considered in the discussion. The depression in the barrel of the syringe leads to a force of aspiration on the clot occluding the catheter. Denoting P_{atm} the atmospheric pressure and S the internal section of the catheter, the force of aspiration acting on the clot can be estimated by $f = S(P_{atm} - P_{sv})$. Figure 1 shows the dependence of f as a function of the internal diameter d of the catheter (in absence of gas bubbles in the catheter). For simplicity, the forces are given in equivalent gramme-force. The forces applied on the clot remain low and their effect on the clot will be strongly dependent of the adhesion of the deposit within the catheter. In accordance with the observed clinical practice, we consider here that the aspiration pressure is instantaneously installed in the set including syringe and catheters. The movement of the plunger being sufficiently low the whole process of pressure variations is quasi stationary. This point can be questioned when the catheter includes deformable elastic components. In this case, the pressure drop can induce a deformation of the wall of the catheter inducing a displacement of the fluid. A rough dimensional analysis can provide valuable insight on this point. Two classical parameters are relevant for the description of the process: first, the compliance defined by $C = (\epsilon \text{ compli})$ relating the variation (δS) of the cross section of the catheter submitted to a variation (δP) of pressure; second, the hydraulic resistance (cf. Poiseuille flow) denoted R_h associated with the fluid movement possibly induced by the variation of cross section of deformable parts of the line. By using these two parameters, it is possible to give an estimation τ of a time scale for the establishment of the pressure variation at a distance l of the syringe. Because of the dimensions of the different parameters, $\tau = R_h C l^2$. For example, $l = 20 \text{ cm}$ is possibly representative of the distance of the clot from the syringe connected to 5 F or 7 F catheters. Taking $E = 4 \times 10^6 \text{ Pa}$ as a

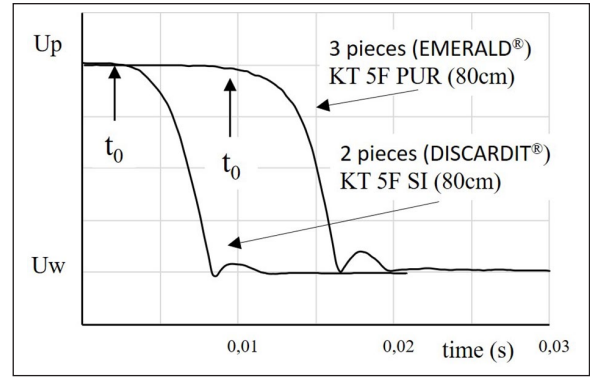


Figure 2. Recording of the movement of the plunger as a function of time: 3-piece EMERALD®-KT5 F-PUR and 2-piece DISCARDIT®-KT5 F-SI.

representative value of the Young modulus of the SI, the estimation of τ is $\tau \approx 0.3 \text{ s}$. While for the PUR, the time scale is one or two orders of magnitude lower. These are clearly rough estimates; nevertheless, a precautionary principle must be applied to introduce a time delay at the end of the upward movement of the plunger to achieve a time release of any elastic component even for the clot itself in a PUR catheter.

Experimental results

The first part of the experimentation concerned the recording and analysis of the movement of the plunger during the return movement. The movement was recorded by the camera. Then the images were digitised leading to a representation of the movement as a function of time. Among the data recorded, the results reported in Figure 2 were chosen as representative of the overall results. The initial time of the movement is noted t_0 in the figure. Globally, the results indicate that the dynamic of the plunger is quite similar in all cases. The return time of the plunger was very short, in the order of 0.07s. One noteworthy point was the occurrence of a rebound effect. These different points will be extensively discussed.

The second part of the experimentation concerned the recording of the pressure, at the extremity of an occluded catheter of different lengths. Figure 3(a) and (b) shows two typical examples of recordings for 7 F PUR and 5 F SI for the measured pressure jump resulting of the return movement of the plunger. The preliminary findings show that in all cases, the pressure pulse generated by the piston hammering induced an oscillatory decreasing variation of the pressure. Both amplitude and frequency of these oscillations were different for PUR and SI due to the different mechanical properties of the materials. In other words, the SI is more deformable, characterised by a Young modulus significantly lower than the PUR Young modulus, thus leading to a greater attenuation of the pressure variations.

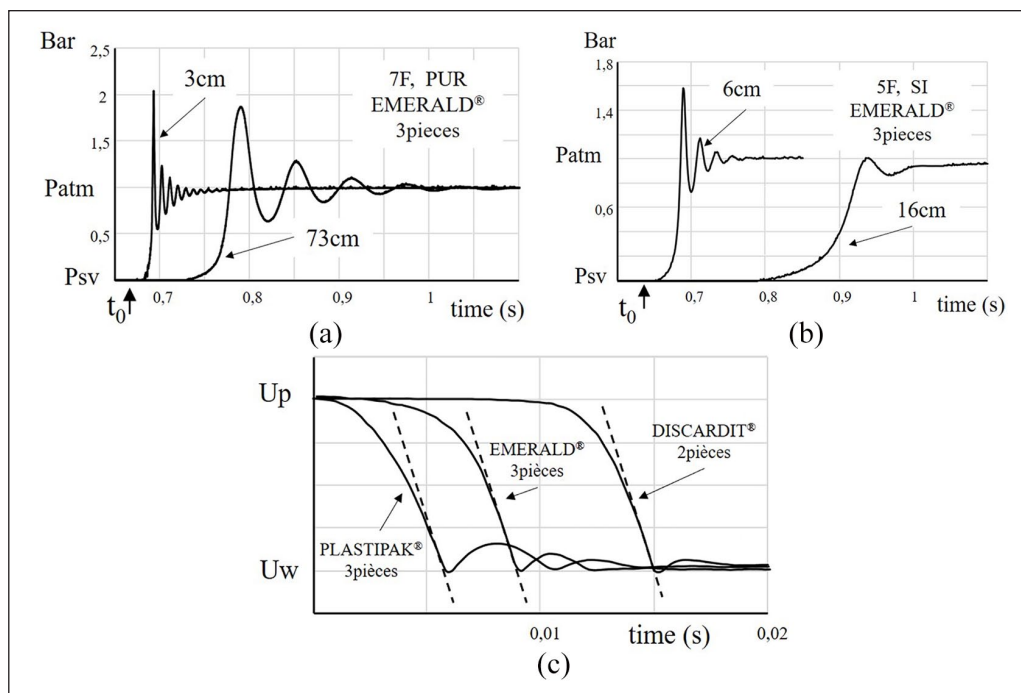


Figure 3. Time dependent recording: (a) pressure for two lengths of a PUR catheter; (b) the pressure for two lengths of a SI catheter; (c) movement of the plunger showing the impact velocity of the plunger for 2-piece and 3-piece syringes.

Discussion

The experimental data reported above have now been observed in the general framework of the so-called ‘POP technique’ namely potential efficiency and for some authors, questionable danger of this method. Following the aspiration phase, the dynamics of the plunger is the key point for the generation of a pressure pulse in the catheter. Two mechanical parameters were involved in the motion of the plunger: the mass of the plunger and the friction factor within the syringe barrel; then the plunger is set in movement by the restoring force proportional to $Patm - Psv$. Figure 3(c) illustrates the dynamics of the plunger for the 2-piece and 3-piece syringes under consideration. The velocity is represented by the slope of the curves in dotted line on Figure 3(c). We noted a similar impact velocity for the 2- or 3-piece syringes. However, the effect of the impact was greater with the 3-piece syringe due to the plunger’s greater mass.

The results vary when the syringe is set in the horizontal position. Figure 4 shows the syringe in horizontal position with the 2-mL residual liquid. In this situation, the plunger was slowed down by the liquid leading to a lower impact velocity as shown in dotted line in Figure 4. Taking the numerical values of the recorded data, we found that the impact velocity was reduced by 30% compared with the impact speed in vertical position (Figure 4). This illustrates that the reduction of the impact velocity has a limiting effect on the pulse of pressure associated with the impact of the plunger.

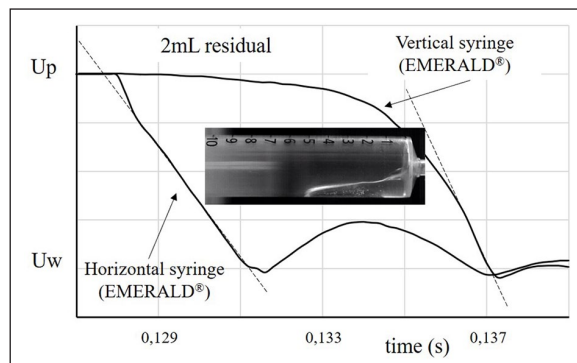


Figure 4. Consequence of the horizontal position of the syringe: recording of the time dependent movement of the plunger showing the impact velocity of the plunger for vertical and horizontal syringes and photograph of the horizontal position showing the residual liquid in the body of the syringe.

The key feature of the induced pulse of pressure can be seen in Figure 3(a) and (b). In any cases (operator, material, whether or not aqueous fluid is present), the impact of the plunger leads to a pulse pressure at the entry of the catheter. The situation can be referred to a general classical rheological problem. The catheter as an elastic material characterised by a Young modulus filled by a viscous liquid is solicited at the entry by a series of decreasing pressure pulses caused by the impact of the plunger as shown in Figure 2. Then the coupling between the entry conditions and the response of the catheter leads to a decreasing

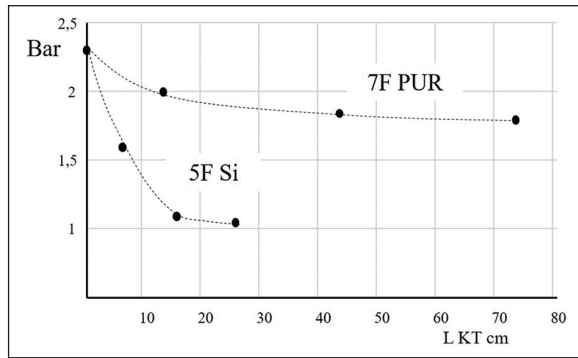


Figure 5. Experimental data obtained for the dependence of the maximum of the pressure pulse for the 7F PUR and 5F SI as a function of the length of the occluded catheter.

pulse pressure with amplitude frequency and attenuation that are strongly dependent on the elasticity of the material. Following the results reported in Figure 3(a) and (b), the responses of the catheters vary greatly depending on the catheter material. When using a SI catheter, the amplitude of the pulse pressure is strongly attenuated on a short distance (a few centimetres) while with PUR the amplitude is weakly attenuated. Figure 5 shows the experimental data obtained for the dependence of the maximum of the pressure pulse for the 7F PUR and 5F SI as a function of the length of the occluded catheter. Two major points must be mentioned. First, in any cases, the increase of pressure does not exceed 2.2 Bar (32 psi) which make the POP technique safe and without risks: the resistance of epicutaneous catheters (also known as peripherally inserted central catheters used in neonatology), standard and high pressure is, respectively, 87,150, 300–360 psi. Second, we observed that the induced pressure exhibits a series of oscillations. This is an original finding with important practical applications. The consequence of such an alternative time dependent behaviour is that the clot will be submitted to back and forth stresses potentially facilitating the detachment of the clot. It can be noted that the possible efficiency of an alternative stress for the detachment of a clot is to be compared with the efficiency of an intermittent flow for flushing a catheter.¹⁰

Concluding remarks

The use of the ‘POP technique’ is based upon the idea that the sudden return of the plunger may induce a convenient pressure pulse permitting the detachment of a possibly obstructive material. Keeping in mind that the return movement of the plunger is the preliminary key for the possible efficiency of the process, the question arises of the best choice for the syringe. This experiment enabled to describe that the maximum of input momentum at impact is obtained with both the maximum velocity and mass of the plunger. The impact velocities being the same, the

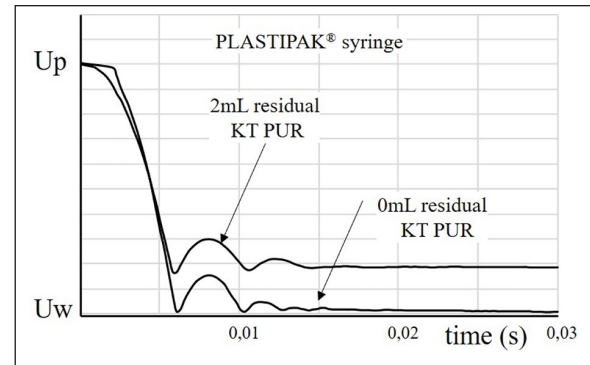


Figure 6. Time dependent recording of the movement of the plunger with and without residual fluid in the body of the syringe (for this case, Uw is referred to 0 mL residual).

3-piece syringes are then to be recommended with the initial position of the plunger at the upper position in the barrel (namely 10 mL). A related issue to this is to recommend or not the presence of a residual liquid in the syringe. Figure 6 shows the return movement of the plunger without and with 2 mL of residual liquid. The dynamics of the plunger is not affected by the presence or absence of residual liquid in the barrel. Nevertheless, we consider that the presence of residual liquid is necessary to ensure the continuity of the liquid phase between the catheter and the syringe. The absence of residual liquid may permit the presence of a small gas bubble at the entry of the catheter. Such a gas bubble should have an attenuating effect on the possible efficiency of the POP technique due to additional compliance in the catheter. In addition, during the experimentation process, we observed that the impact of the plunger without residual liquid may lead to a mechanical rupture of the syringe barrel. Therefore, a 2 mL fluid volume is recommended.

The expected efficiency of the POP technique can be assessed from the data reported in Figures 3(a) and (b) and 5. Clearly, the imposed pressure pulse at the entry of a SI catheter is rapidly attenuated and will have no marked effect on an obstruction (thrombotic, precipitate or combination) in a catheter. On the contrary, the use of PUR catheter appears to be well adapted to the application of the POP technique. In other words, the application of the POP technique appears more suitable with PUR catheters than SI catheters. The pulse pressure is transmitted along the catheter (with low attenuation). Then the efficiency of the method is only dependent of the adhesiveness of the obstructive material. It is to be noted that all these results are obtained with a free movement of the plunger. Any manual accompaniment of the plunger may have undesirable effects: either a slowdown of the plunger leading to a weakening of the generated pressure pulse, either a manual acceleration of the plunger leading to a sharp increase in the internal pressure in the catheter with possible mechanical damages such as breaking.

The POP technique as described above with syringes in permanent vertical position provides only relatively low pressures: aspiration 0.46 psi, pulse pressure <2.5 Bar or <36.3 psi, well below the resistance of a new catheter. However, the resistance of some standard catheters is lower than these values (25 psi). It is therefore prudent to record this limit pressure in the protocol of use of this catheter.

It is expected that this experimental study will permit the establishment of a detailed protocol for the implementation of the POP technique.

Conclusion

It is expected that this study will have an impact on the clinical practice as clinicians may be tempted to use the technique in hope to resolve the occlusion safely in a timely manner. In that context it is useful to recall some relevant points. The depression caused by the traction on the plunger, followed by a stopping time then by the release of the plunger, may resolve the obstruction; however, more studies are needed to determine the effectiveness of the intervention, in relation to the time of the occlusion, its size or its nature (thrombotic or precipitation). The authors would like to reiterate that despite being simple to realise, some elements must be respected. These are: holding the syringe at a vertical angle and holding that position for the whole procedure, pulling to the 8–9 mL mark, not beyond that point, and having a volume of solution in the syringe to ensure that neither the syringe nor the catheter ruptures during the procedure. Clearly, the different protocols, using the POP technique, must mention the strict observation of all the modalities to prevent any deviance and ensure safety of the procedure.

This last remark gives the opportunity to mention alternative possible techniques to restore patency, such as instillation of a thrombolytic (e.g. recombinant tissue plasminogen activator (rt-PA), urokinase) which remains a partially open question and is the subject of a forthcoming study.

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Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical statement

Ethical approval was not required as the study, strictly made in a physics laboratory, did not involve human subjects or biological data.

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