A Review of Externally Aided Syringe Retraction Techniques for Needle Thoracostomy

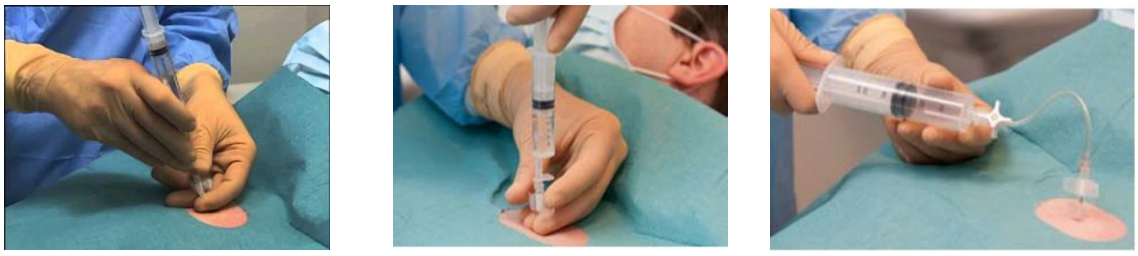
Nitin Sharma, Sukhdeep Singh Dhami
Department of Mechanical Engineering, National Institute of Technical Teachers Training & Research, Chandigarh, India

Abstract— Needle Thoracostomy, which is an aspiration procedure, is frequently used in critical conditions. Conventional syringes are usually used for the aspiration procedure and their usage requires two hands. However, syringesfacilitating single hand usage are very much required for needle thoracostomy so that the second hand may be utilized for video assisted procedures like ultrasound for assisting the aspiration procedure. The presnt work presents a review of various syringe designs and concepts reported in the literature for externally aided operation of syringes. Different methods have been reported for aided actuation of the plunger for single hand operation.The features of various types of syringes reviewed in the present work may guide the user in deciding the suitability of the device for aspiration as well as in designing a new device for aspiration.

Keywords– *Needle Thoracostomy, Air aspiration, Epidural space, Reciprocating Procedure Device, Actuating mechanism*

INTRODUCTION

A thoracostomy is a small incision of the chest wall for drainage. When air, blood, or other fluids accumulate in the pleural cavity it may be drained by thoracostomy. Needle Thoracostomy, which is an aspiration procedure, is frequently used in critical conditions [1]. The present work is focused on air aspiration procedure devices for facilitatingsingle hand usage, while the second hand may be utilized for video assisted procedures like ultrasound for assisting the aspiration procedure. Motivation for the review is to determine non-electrically powered simpler mechanisms for retraction of the plunger of a thoracostomy syringe such that one hand operation of syringe is easy. Figure 1depicts the aspiration procedure.



(a) (b) (c)

Figure 1: Needle Thoracostomy.(a) External precision grip on barrel and Inter-digital grip at needle, (b) Internal precision grip at plunger and External precision grip at needle, (c) power grip at the plunger and Internal precision grip at barrel. [2]

REVIEW OFASPIRATION AND OTHER SIMILAR DEVICES

Various types of devices reported in the literature for injection and aspiration are discussed. The literature review provides a peek into the differenet types of mechanisms proposed by researchers for aided actuation of the syrine plungers.

Aspiration Syringes

Singer [3] discussed a device for treating pneumothorax, tension pneumothorax, pleural effusion, and hemothorax in neonates. The syringe plunger needs manual hand force for ingression and egression. Device requires two hands for effective operation of syringe but may be operated by single hand. The author also describes and claims different configurations of assembly arrangements according to requirement. Hub containing one way valve can be connected to syringe where three way stopcock could also be attached in line for controlled suction of fluid. Syringe used is simple hypodermic syringe and basically designed for treatment of neonatal pneumothorax. Hub containing one way valve could be attached to skin or insertion site through vacuumed suction effect.

Fojtik[4] introduced an aspiration syringe having a gun-like grip (power grip). Actuator mechanism members are pivoted at the point where it acts lever mechanism. Pressing the proximal actuation ends makes the mechanism to do distal actuation of syringe and plunger distal connecting ends. Syringe was specifically designed for aspiration.

Haber et al. [5] proposed a syringe barrel consisting of a plunger guide attached toand extended axially from the flanges of the barrel. Plunger guide had been provided with axial groove for stabilised movement of plunger assembly. Plunger assembly consists of ribs to slide through axial guide grooves and flanges (distal to piston end) for aspiration or retraction force. The plunger ribs can slide within the guide groove by locking the distal end of the plunger guide with inbuilt locking mechanism. It was claimed that the syringe could be operated by single hand for stabilised aspiration and injection of fluids. During aspiration, Index and middle fingersare placed under the flanges of the plunger and thumb on the distal end of plunger guide to aspire fluid into the syringe.

Tao [6] described a device for aspiration through syringe in which conventional syringe of certain size can be mounted. The syringe can be fitted into the port for the syringe barrel and the plunger is attached to the spring actuated holding rod within the device.A sliding member through which spring-actuated holding rod is passing, is set up in a way that it will act as a catch or stop for the spring actuated rod, which is trying to retract plunger for aspiration. Catch is arranged in such a way that it can also be released for further aspiration motion of the plunger. Spring actuated rod can be latched at withdrawal position into the syringe barrel and near the needle hub base,such that on releasing latch, springe actuated rod will retract plunger up to the slider catch. It was claimed that syringe can be operated with one hand in a pencil grip.

Lee [7] presented an aspiration device which could be operated with one hand. The device can fit conventional syringe into it at the place for barrel fitting. Device had a sliding memberwhich can attach to the plunger flange for displacing the plunger in backward direction. Part of the device which is attached to syringe barrel had a pistol grip like shape. It is attached at the barrel flange and acts as a grip support for retracting the sliding member along with the plunger.

Sibbitt et al. [8] discussed the quantitative measures of control and performance characteristics of eight different suction biopsy devices including conventional syringeThe clinically approved quantitative needle-based displacement method model was utilized to gauge syringe and needle control by the individual doctor hand.Reverse aspiration syringe (RAS)was operated with single hand, which was neither FDA approved nor commercially available. Two types of reverse aspiration syringes were compared, both having different actuation mechanisms for plunger displacement. One RAS (BioSuc-

C7)syringe, consists of a long barrel having approximately double length than the plunger. It has sliding groove in it from flanged end up to thefull length displacement of plunger into the barrel. Plunger flanges are ribbed and plunger can be operated with one hand. Whereas the other RAS has plunger flanges elongated axially along the barrel length up to the needle hub. While aspiration, middle finger and index finger holding the barrel at the flange of plunger nearer to needle hub and thumb will hold the barrel flange. During aspiration, plunger mechanism allows proximal movement of involved fingers (digits) force. A three-ringed control syringe which is FDA approved and commercially available from multiple manufacturers, was prototyped from similar 10-mL BD syringes by replacing the conventional straight flanges on the barrel and plunger with the ringed flanges. Study showed that three-ringed control syringe has better single hand control as compared to conventional one. However, all RAS devices were observed to have quite high LOC. Further, it was concluded that syringe pistol was the most poorly controlled concluded device, followed closely by the conventional syringe used with one or two hands.

Reciprocating Procedure Devices

Sibbitt and Sibbitt[9] presented a Reciprocating Procedure Syringes (RPD) device consisting of two syringe barrels mounted on a frame. This invention allows single hand operation and rare use of second hand and has features like auxiliary actuator which can be connected with respectiveplunger and the flexible linepassing over pulley arrangement, joins both the plunger in a way that there would be relative movement of the plungers in opposite direction. Invention claimed major benefits such as rapid high pressure injections. The index and middle fingers are placed on the flange of the Syringe and the thumb is placed on the thumb rest of the plunger. The finger grips are brought together resulting in a powerful injection due to contraction of the powerful flexor muscles of the hand and forearm. The single hand operation allows second hand to perform other useful work. The invention can deliver necessary power and maintain fine control as compared to single handed use of standard syringe.

Chavez et al. [10] presented a one-needle-two-syringe RPD device in which the first syringe is used to anesthetize, aspirate effusion, hydro dissect and dilate the joint space, and the second syringe is used to inject the intra-articular therapy. Study suggested accurate intraarticular injection of the knee by using RPD syringe, by allowing the both hands usage for both anesthesia and intraarticular injection.Single hand control of the syringe has been shown by allowing second hand to check the accuracy of needle placement by sonographic imaging.

Haseler et al. [11] compared theuse of conventional syringe and a Reciprocating Procedure Device (RPD),used for aspiration procedures. The maximum vacuum achieved was −517±12 Torr for 20 ml conventional syringe as well as for RPD. Smaller diameter needle took larger time for vacuum generation as compared to larger needle. However, force required to generate vacuum is high for large diameter needle as compared to smaller one. It was far easier to generate a certain vacuum with one hand using RPD than with the conventional syringe because of the mechanical advantage provided by the pulley mechanism. The results indicated that that both syringe and needle control was better with smaller syringes and the RPD during aspiration than large conventional syringes.

Nunez et al. [12] compared the performance of reciprocating procedure device (RPD) with the conventional syringe for injection purpose. RPD was used in one-handed fashion for local anesthesia of the knee before a deep joint aspiration procedure. Outcome was measured on the basis of administration time, anesthesia pain, procedure pain, and operator satisfaction. RPD significantly reduced anesthesia administration time by 49%, reduced anesthesia pain by 27%, reduced significant procedure pain by 74%

and improved physician satisfaction by 63%. It was concluded that the RPD is superior to and significantly more effective than the conventional syringe for the administration purpose.

Sander [13] compared RPD and conventional syringe (CS), by measuring procedural pain and duration. Results showed that RPD group had less procedural pain on Visual Analogue Scale (VAS), shorter procedural duration and had greater physician satisfaction than the conventional syringe group on Visual Analogue Satisfaction Scale (VASS). The RPD group had fewer procedures (17%) in which patients had moderate to severe pain than the conventional syringe group (55%) with a confidence level of 99%.

Other Devices

Sibbit and Sibbit [14] presented a one hand operated syringe which can be used in multiple applications like biopsy, epidural space and local anesthesia etc. Syringe can be held with pencil grip and consists of control valve which is mounted forwardly nearer to needle hub, and can be operated with thumb or finger of the same hand. Syringe can be controlled better with one hand, and are less difficult to operate than conventional syringes for fluid aspiration, while performing ultrasound probe with the other hand. Syringes designs are claimed to be multipurpose, automatic and semiautomatic for ingress or egress of fluid. Plunger locking mechanism is present to restraint the plunger motion. Spring circumference the plunger and inscribe into the syringe barrel such that the patterns on the plunger can be locked on the perforated locking mechanism on barrel top. Patent also claimed different locking mechanisms for plunger. Working of the syringe is such that when plunger is retract backward by keeping the valve closed and locked on the locking mechanism, will causes vacuum or suction within the barrel for aspiration and upon pressing the valve it will suck fluid into the barrel. For injection purpose compressed spring apply force on releasing plunger from lock to ingress fluid into the body or out of syringe barrel.

DeLunaet al. [15] designed Suh precision syringe (SPS) having improvedstabilized control for precise injection. Study compared the accuracy and precision and found out that SPS serves better as compared to conventional syringe. SPS consists of a modified plunger in which plunger flange isextended on barrel length direction nearer to needle hub such that syringe can be held in pencil grip (between thumb and middle finger) and index finger can be used to apply plunger injection force. PCR tube and a sheep eye were injected with water by both the syringe. Video recorded results were analyzed and found out that SPS reduces overall injection risk by decreasing forward-reaction movement while operating the device. SPS also provide improved injection depth and drug delivery volume control.

Ulbrich et al. [16] discussed the usage of a syringe adapter for reduced muscular strain and fatigue during repetitive fluid draws. Repetitively used syringes have an increased risk for musculoskeletal disorders. The adapter has a compartment for holding the syringe where barrel is attached to fixed body and plunger is attached to moveable mechanism such that an in-built ratchet mechanism will make it to displace to a desired range. Ratchet is operated by means of lever action and it sucks 3ml of fluid at every actuation of lever. This device is suitable for effectively repetitive drawing fluid into the barrel by single hand.

There are injection syringes where spring actuation allows easy single hand operation. Injection displacement of the plunger is acquired by spring action. Similarly spring reaction mechanism for aspiration could be used if spring is allowing aspiration displacement of the plunger. Menes and Menes [17] used elastomeric bandas injection actuation mechanism. Elastic restoration force is used to develop a positive pressure inside the barrel which is favorable to restrict dural puncture.Riley [18] discussed the use of spring loaded syringe for detecting epidural space where clinician uses both the hands to insert

touhy needle. It was found out that springs with different stiffness coefficientsgive desired effect of outcome and suggested to use spring of having low spring constant. Joseph et al. [19] reported that with spring-loaded syringe (Episure syringe) much lower number of attempts are required to identify the epidural space and also lesser time taken to identify the epidural (31.63 ± 9.4 s) as compared to Glass syringe (39.0 ± 14.3 s). Further it was stated that during the trials, glass syringe caused 5 cases of dural puncture and 5 cases of failed epidural analgesia whereas spring-loaded syringe had reported none. Srinivas et al. [20] proposed a syringe in which a compression spring is mounted on the plunger outside the barrel. It is usually developed for Mesotherapy i.e. multiple injections of small quantity of the drug over a large area.

DISCUSSION

Based on the review of literature, a summary of features of various types of syringes is given in Table 1. These features may guide the user in deciding the suitability of the device for aspiration as well as in designing a new device for aspiration.

Table 1: Features of Various Types of Syringes

Type	Purpose	Single hand / double hand operation	Plunger Actuation Mechanism	Suitable for aspiration	Display or indication for plunger motion	Remarks
CONVEN-TIONAL SYRINGE	Simple standard hypodermic syringe [8]	Single hand	• No aided actuation mechanism • Hand actuation and pressure gradient	Yes	• Visual • Haptic	• Aspiration may require two hands • Smooth retraction of plunger at low resistance
ASPIRA-TION SYRINGE	Syringe for Pneumothorax treatment [3]	Single handed	• No aided actuation	Yes / possible	Visual	• Specifically designed for fluid or air aspiration from thoracic cavity. • Best to be used by both the hands • Non-return valve between needle and the syringe for one directional flow • Easy for creating suction in syringe barrel
	Aspiration Apparatus and Methods [4]	Single hand	• Lever mechanism for plunger actuation	Possibly	Visual	• Gun grip holding

Type	Purpose	Single hand / double hand operation	Plunger Actuation Mechanism	Suitable for aspiration	Display or indication for plunger motion	Remarks
	Aspirating Syringe Having a Plunger Guide [5]	Single hand	• Modified axially plunger guide and hold outside it.	Yes	Visual	Inter digital grip during injection
	Pencil-Grip Fine Needle Aspiration Syringe Holder [6]	Single hand	• Spring actuated aspirating	Yes	Visual	Stabilized pencil grip while operating
	Single-Hand Controlled Fine Needle Aspiration Device [7]	Single hand	• Aided mechanism for actuation	Yes	Visual	• Extended plunger flange along barrel length • Gun grip (i.e. power grip) • Plunger displacement actuated by hand force
	Reverse aspiration syringe (RAS) [8]	Single hand	Aided mechanism for actuation	Possible	Visual	• Extended plunger flange along barrel length • Syringe grip is interdigital between thumb, index and middle finger.
	RAS BioSuc-C7 syringe [8]	Single hand	Aided mechanism for actuation	Possible	Visual	• Extended barrel length with groove for easy plunger retraction. • Syringe grip is interdigital between thumb, index and middle finger.
	Three-ringed control syringe [8]	Single hand	Aided mechanism for actuation	Yes	Visual	Straight flanges of barrel and plunger replaced with ringed flange
	Syringe pistol [8]	Single hand	Aided mechanism for actuation	Possible	Visual	Syringe with gun grip

Type	Purpose	Single hand / double hand operation	Plunger Actuation Mechanism	Suitable for aspiration	Display or indication for plunger motion	Remarks
RECIPRO -CATING PROCE- DURE DEVICE (RPD)	Reciprocating Procedure Syringes [9]	• Single hand	• Modified Reciprocating actuation of the Interdependen t plungers	Yes	Visual	• Inter digital grip while operating • Syringe adaptor • Easy for creating −ve and +ve pressure in syringe barrel
	The highly accurate anteriolateral portal for injecting the knee [10]	• Single hand	Same as above	Yes	Visual	Second hand is used to carefully introduce the needle
	Syringe and Needle Size, Syringe Type, Vacuum Generation, and Needle Control in Aspiration Procedures [11]	• Single hand	Same as above	Yes	Visual	Comparison of conventional syringe and (RPD)
	A Randomized, Controlled Trial of the Reciprocating Procedure Device for Local Anesthesia [12]	• Single hand	Same as above	Yes	Visual	Free hand used to stabilize the needle
	Intra-articular corticosteroid injections with the reciprocating procedure device [13]	• Single hand	Same as above	Yes	Visual	Reduced procedural pain and duration andimproved physician satisfactioncompa red to conventional syringe
LOSS OF RESISTA NCE BASED SYRINGE	• Resistance Syringe for Epidural Anesthesa [17]	• Single hand	Aided injecting mechanism	No	• Visual • Loss of Resistance (LOR)	Elastomeric band for aiding motion of the plunger

Type	Purpose	Single hand / double hand operation	Plunger Actuation Mechanism	Suitable for aspiration	Display or indication for plunger motion	Remarks
S	A Novel Loss of Resistance Syringe for Locating the Epidural Space [18]	• Single hand	Aided injecting mechanism	No	• Visual • LOR	• Spring actuation force plunger movement • Effective use by both hands.
	Comparison of episure syringe with glass syringe [19]	• Single hand	Aided injecting mechanism	No	• Visual • LOR	• Spring actuation force for plunger movement
OTHER RELATED -ART- OF-THE-WORK	Automatic Syringes [14]	Single hand	Spring actuated mechanism	Possible	Visual plunger displacement	• Manual hand force for plunger actuation
	Suh Precision Syringe (SPS) [15]	Single hand	Modified	Possible	Visual plunger displacement	• Manual hand force and pencil grip
	Syringe adapter for reduced muscular strain [16]		Lever mechanism for actuation	Possible	Visual and measured	• Sucks 3ml of fluid at every actuation • Manual hand force by power grip
	Syringe for Multiple Rapid Injections [20]	Single hand	Spring actuated mechanism	No	Visual	• Plunger moved by spring action

From the above discussion,it is observed that various syringe designs and concepts are reported in the literature for externally aided operation of syringes. Different methods have been reported for aided actuation of the plunger for single hand operation. However, some designs are suitable for injection,some are suitable for aspiration, while others are suitable for epidural space detection. Single hand hold syringes are generally required because second hand is needed for sonographic or CT scans operation simultaneously. For aiding the plunger movement, in some cases the actuation mechanism were provided by using slacking elements like spring and elastomeric band, and some mechanisms are provided without slacking elements. Without spring or elastic band, manual hand force would be required for actuation. From dexterity and stability points of view, reciprocating procedure devices and aspiration syringes are most suitable

CONCLUSIONS

Needle Thoracostomyis an aspiration procedure, which is frequently used in critical conditions and therefore requires specially designed syringe facilitating single hand usage, while the second hand may be utilized for video assisted procedures like ultrasound for assisting the aspiration procedure. The use of conventional syringes is not always suitable for different requirements. It is preferred to use syringesdesigned specifically and ergonomically for different tasks. Different types of mechanisms

reported in the literature may be utilized with modifications for needle thoracostomy. Devices and designs based on epidural space detection are mostly favorable for injecting medicament or medication into the body. Epidural detection based designs could be useful if upon modifications it could be designed for aspiration biopsy. Reciprocating Procedure Devices are reported to be better on the basis of ease of use and satisfaction by the medical staff as well asbeing less painful to the patient.

REFERENCES

[1] *L. Weichenthal, D. C. Do, and L. R. Do, "Needle Thoracostomy in the Prehospital Setting: A Retrospective Observational Study",PREHOSPITAL Emerg. CARE, vol. 3127, no. March, pp. 1–5, 2016, doi: 10.3109/10903127.2015.1102992.*

[2] *M. Pasquier, O. Hugli, and P.-N. Carron, "Needle Aspiration of Primary Spontaneous Pneumothorax," N. Engl. J. Med., Vol. 368, no. 19, pp. 1–3, 2013, doi: 10.1056/NEJMvcm1111468.*

[3] *H. Singer, "Device fortreating pneumothorax, tension pneumothorax, pleural effusion, and hemothorax in neonates", US 2009/0227987 A1, Sep. 2009.*

[4] *S. P. Fojtik, "Aspiration Apparatus and Methods", US8491539B2, 2013.*

[5] *T. M. Haber, W. H. Smedley, and C. B. Foster, "Aspirating Syringe Having a Plunger Guide for a Reciprocating Plunger Assembly", US5582595, 1996.*

[6] *L.-C. Tao, "Pencil-Grip Fine Needle Aspiration Syringe Holder",US5830152A, 1998.*

[7] *P. F. Lee, "Single-Hand Controlled Fine Needle Aspiration Device",US5115816A, 1992.*

[8] *R. R. Sibbitt, W. L. Sibbitt, S. E. Nunez, L. G. Kettwich, S. C. Kettwich, and A. D. Bankhurst, "Control and Performance Characteristics of Eight Different Suction Biopsy Devices", J. Vasc. Interv. Radiol., Vol. 17 (23), pp. 1657–1669, 2006,*

[9] *W. L. Sibbitt and R. R. Sibbitt, "Reciprocating Procedure Syringes", US7967793B2, 2011.*

[10] *Chavez-Chiang C. E., Sibbitt W. L. Jr, Band P. A., Chavez-Chiang N. R., DeLea S. L., Bankhurst A. D.,"The highly accurate anteriolateral portal for injecting the knee", Sports Med Arthrosc Rehabil Ther Technol, 2011 Mar 30;3(1):6. doi: 10.1186/1758-2555-3-6*

[11] *Haseler L. J., Sibbitt R. R., Sibbitt W. L. Jr, Michael A. A., Gasparovic C. M., Bankhurst A. D.,"Syringe and needle size, syringe type, vacuum generation, and needle control in aspiration procedures", Cardiovasc Intervent Radiol, 2011 Jun;34(3): pp. 590-600.*

[12] *S. E. Nunez, E. J. Bedrick, S. C. Kettwich, L. G. Kettwich, A. D. Bankhurst, and W. L. Sibbitt, "A Randomized, Controlled Trial of the Reciprocating Procedure Device for Local Anesthesia," J. Emerg. Med., Vol. 35 (2), pp. 119–125, 2008*

[13] *Sander O., "Intra-articular corticosteroid injections with the reciprocating procedure device reduced procedural pain and duration more than the conventional syringe", Evid Based Med.,2007 Aug;12(4):106. doi: 10.1136/ebm.12.4.106.*

[14] *W. L. Sibbitt and R. R. Sibbitt, "Automatic Syringes" US 2011/0087173A1, 2011.*

[15] *D. DeLuna, A. Netzel, J. Dietze, B. A. Begley, J. K. Ndulue, and D. W. Suh, "A comparison in precision and accuracy of the conventional syringe to the Suh precision syringe",Clin. Ophthalmol., Vol. 13, pp. 1833–1839, 2019, doi: 10.2147/OPTH.S211485.*

[16] *Ulbrich J., Swader R., Petry G., Cox B. L., Greene R. L., Eliceiri K. W., Radwin R. G., "A syringe adapter for reduced muscular strain and fatigue", Appl Ergon., 2020 May;85:103061. doi: 10.1016/j.apergo.2020.103061*

[17] *Cesar M. Menes and Cenon M. Menes, "Resistance Syringe For Epidural Anesthesa", US5024662A, 1991.*

[18] *E. T. Riley, "The Episure Syringe : A Novel Loss of Resistance Syringe for Locating the Epidural*

Space",Anesth. Analg., Vol. 105 (4), pp. 1164–1166, 2007, doi: 10.1213/01.ane.0000281935.78144.82.

[19] E. J. Joseph, M. Muthukrishnan, and D. K. Kannan, "Comparative study of Episure AutoDetect syringe versus glass syringe for identification of epidural space in lower thoracic epidural",Indian J. Anaesth., Vol. 59 (7), pp. 406–410, 2015, doi: 10.4103/0019-5049.160933

[20] C. Srinivas, A. Somani, C. Shashidharan Nair, and T. Mylswamy, "Spring-loaded syringe for multiple rapid injections",J. Cutan. Aesthet. Surg., Vol. 10 (1), pp. 49–50, 2017, doi: 10.4103/0974-2077.204584