Feasibility Study on Applying the Principle of Gas Gun for Needle Free Jet Injection

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Abstract

This study aims to investigate the feasibility on applying the principle of gas gun as the power source for the needle free jet injector. This study focuses on the gas gun modification and level of impact pressure to penetrate the porcine skin. This gun has been modified for generating high speed liquid jet to penetrate the tissue. The injector is the high pressure gas system used on driving the object for the impulse.

Form momentum tests, the injector releasing high pressure gas at pressure range of 10–20 bar to launch the projectiles. In the current study, nozzle diameters are varied as from 0.1, 0.2 and 0.3 mm. The calibration between the signal in voltage by PVDF film and values of impact pressure are performed to indicate the same injecting conditions in the experiments.

Preliminary results reveal that the impact pressure values of 10–38 MPa can be achieved from the injector. However, it is found that only the impact pressure values more than 18 MPa is able to penetrate the skin. This study therefore confirms that the modified gas gun is feasible to apply for the needle free jet injection. Nevertheless, some improvements of a jet generation mechanism and a jet delivery system are needed to improve to achieve the best injection characteristics.

Keywords*:* gas gun, needle free jet injection, impact pressure.

1. Introduction

High speed liquid jets have been widely used for appropriate applications in many fields of engineering technology such as cutting, automobile, combustion, and medical engineering [1]. In the medical engineering, a jet injector is a type of medical injecting syringe that uses a high-pressure narrow jet of the injection liquid instead of a hypodermic needle to penetrate the epidermis. It can be powered by voice-coil, gas cartridge, or compressed spring [2].

Voice-coil is a form of electromagnet power that can generate the intense force, pressure, and stroke length required by jet drug delivery. Their inherent bi-directionality allows the applied pressure to be controlled and even reversed when necessary. However, commercially, available voice-coil actuators that meet the power demands of this application are typically too large, heavy and expensive to apply for a portable hand-held device [3].

A gas cartridge or pressurized gas is used to advance a piston and forcibly expel injectable fluid out through an injector orifice. When a gas cartridge is used, the gas cartridge may be moveable from an initial position to an actuating position in which gas is released to drive the injector, and a recoil inhibiter may be employed to prevent the gas cartridge from moving back to the initial position. This may be difficult to control the inconstancy of the gas cartridge expand [4-5].

A compressed spring needle-free, including a plunger and a spring coupled with the plunger is another possible power source. The plunger is disposed within a fluid chamber and is retractable to draw injectable fluid into the fluid chamber through an injection orifice. The spring is configured to be compressed during arming of the injection device, and decompressed during discharge to forcibly advance the plunger within the fluid chamber. Nevertheless, a spring fatigue caused an inconsistency of injection was found when it was used in a number of times [6-8].

This study therefore aims to investigate the feasibility for applying the principle of a gas gun as the new power source for needle free jet injection or the injector. It is modified to co-operate with the previous medical jet needle free injection system or "Med-jet NFIS", which is very bulky and complicate to handle shown in "Fig. 1". The modified gas gun becomes the power-air injector that co-operates with high pressure air generator from the "Med-jet NFIS" hydraulic power [9]. This success provides the experimental apparatus for further study on characteristics of the liquid jet.

Fig. 1 Prototype of power-gas injector: Med-jet NFIS

2. Operation of apparatus assembly

2.1 Generation of high pressure gas

The high pressure air is built-up by compressing the initial air in the closed system chamber comprised of the hydraulic-cylinder and hydraulic piston as shown in "Fig. 2". The piston is movable, by the forward-backward controllable, along the hydraulic-cylinder. The power unit, as shown in "Fig. 2(a)" enables to control the piston movement by hydraulic power system, thereby contributing the controllability in the higher pressure level. Hydraulic power unit consists of a hydraulic pump coupled to the single-phase motor, a reservoir tank with oil level gage, a ¾ control valve, a hydraulic pressure gage installed on the discharge of the pump, and hydraulic hoses connected to hydraulic cylinder. When the hydraulic power unit begins functioning, the pump pulls hydraulic fluid out and moves it black into reservoir. This process continues until the control valve is switched to allow the fluid flow into hydraulic cylinder. These cause the piston moves either forth or back, depending on which way of ¾ valve is opened.

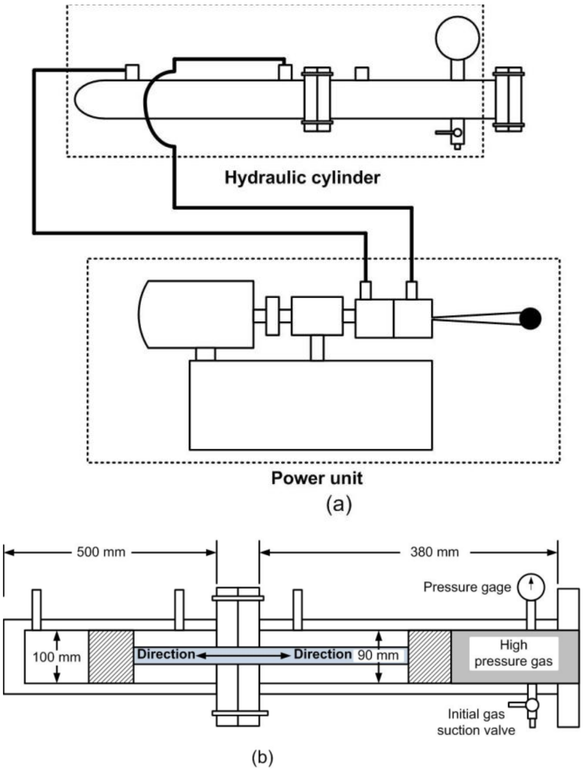


Fig. 2 Schematics of Med-jet NFIS: (a) three main parts of Med-jet NFIS (b) the hydraulic cylinder with the compressed air chamber

A single piston rod, both ends connecting a piston, is used together inside coupled cylinder barrel, as shown on "Fig. 2(b)". This cylinder is divided into two-part by the coupling. The first gets power from pressurized fluid through hydraulic hose connecting into both chambers, separated by one end piston. This enables that the piston inside the cylinder barrel can move forth and back when the fluid is filled into either. The inside of other part is also divided by other end piston into two chambers: fluid and air chamber. The fluid chamber is provided to allow the entrance of hydraulic liquid from power unit. It facilitates the forward movement of the piston and its rod to build high pressure of air in neighbor and allows the fluid to leave when such piston set such is moving backward. Other chamber is used as and initially is used as high pressure air reservoir and initially filed with the compressed air. The contraction of this chamber by the moving piston forward leads the high pressure creation. In addition, in order to fill the chamber with the air initially and release at the end of the operating procedure, a needle valve is provided and installed.

2.2 Jet injector with airsoft gun

The airsoft gun is modified to be the jet injector that utilizes the high pressure air from the hydraulic cylinder chamber as shown in "Fig. 3(a)".

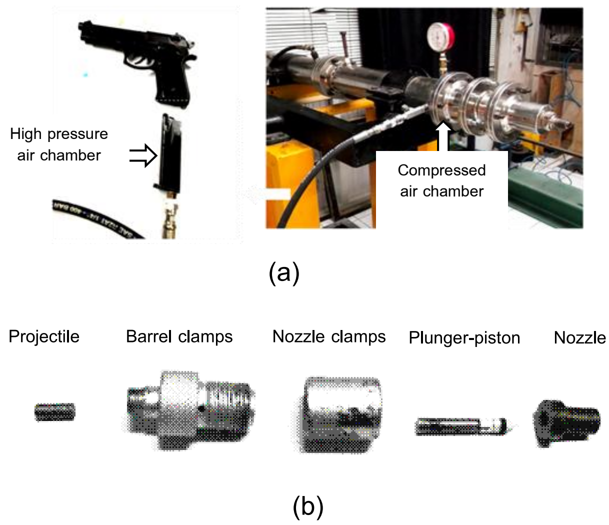


Fig. 3 jet generation parts: (a) the modified gun, (b) the new jet generation part

A high pressure air is filled into a magazine, working as reservoir of gas gun power source released by a trigger. The trigger of the gas gun is used as the quick released valve for fully releasing high pressure air into the barrel in which jet generation part, as shown in "Fig. 3(b)" is attached. When trigger is pulled, the projectile is driven along gun barrel, then impact the plunger-piston in jet generation part. The piston being attached to a nozzle in which the water is retained presses the water to expel through the tiny orifice nozzle. By this mechanism, a high speed liquid jet is generated and this is provided for feasibility study on applying the principle of gas gun for needle free jet injection.

3. Experimentation

In the experiment the pressure ranged from 10–20 bar was used to launch the projectiles. The nozzle diameters were varied, ranging from 0.1, to 0.3 mm. In this study, jet impact pressure was evaluated from piezoelectric voltage signal from PVDF film which was impacted. Therefore, calibration between such signal and certain values of impact pressure are performed. Thus details of the investigation step are followed.

3.1 Projectile velocity and momentum of plunger-piston after impact

Fig. 4 Velocity measurement by shooting through the shooting chronograph

To calculate the plunger-piston momentum, based on the momentum conservation approach, the weight and velocity of a projectile are firstly required. The projectile along a barrel goes through the shooting chronograph at the barrel exit. This measures the projectile velocity. In this study, the cylindrical projectiles, being 6 mm of diameter, 1.0 to 4.0 g of weight, and 5 mm to 20 mm of lengths, and the plunger-piston being 5.6 g are used. The momentum of the piston can be calculated by using "Eq. (1)" in which the assumption is that the projectile and plunger-piston initially resting at the end of barrel are attached after projectile impact on plunger-piston as shown in "Fig. 5". The experimental results, the projectile velocity and the estimated momentum, are shown in "Figs. 6-7." respectively.

$$m_A(v_A)_1 + m_B(v_B)_1 = (m_A + m_B)v_2 \qquad (1)$$

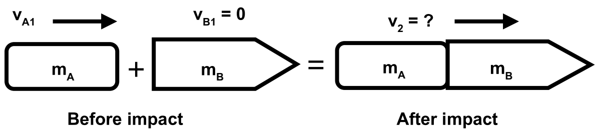


Fig. 5 Momentum conservation of plastic impact

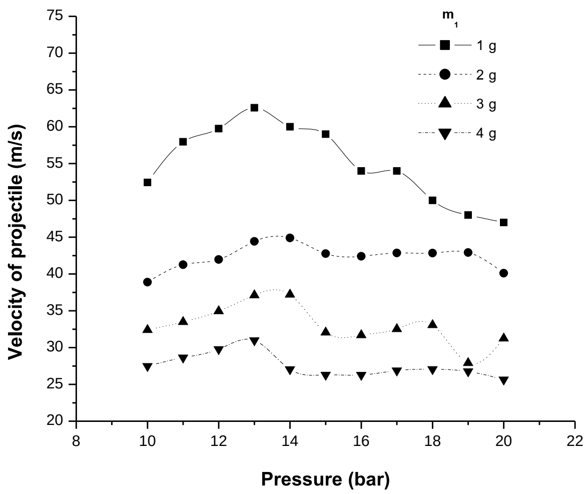


Fig. 6 Velocity of the projectiles before impact.

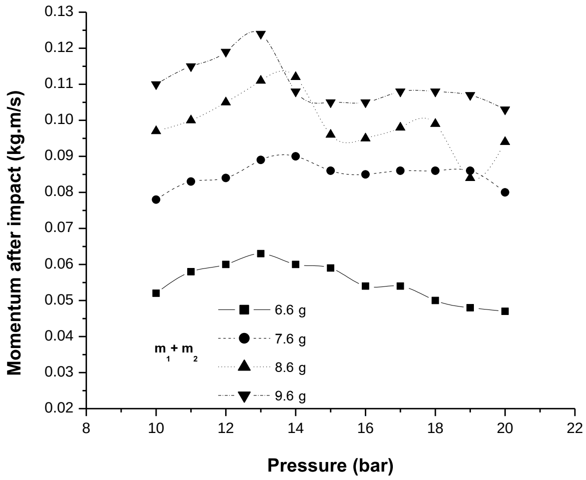


Fig. 7 Momentum after impact at various pressure ranges

3.2 Calibration of PVDF piezoelectric transducer

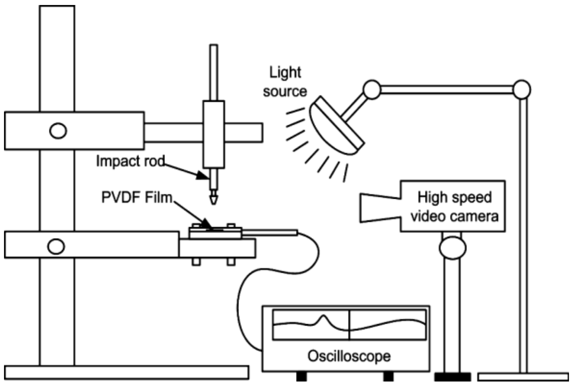


Fig. 8 Schematic of the calibration setup and data acquisition system

The calibration setup and data acquisition system are shown in “Fig. 8”. It was employed to finding out the calibration graph, relationship between piezoelectric voltage signal from PVDF film and dynamics pressures resulting from the rod impact. Those pressures can be calculated by the laws of conversion of energy and momentum as following analysis.

Originally, the impact velocity is varied by changing distance between the plunger tip and the target surface. The impact force, F, is a function of the initial velocity, v_1, and the final velocity, v_2, of rod plunger after rebound. By using the laws of conversion of energy and momentum, the impact force of the plunger can be calculated, following “Eq. (2)” [10].

$$F = C \times \frac{(1+e)\sqrt{h_1}}{T} \quad (2)$$

Where, m is the mass of plunger, T is the impact duration of the impact force, and C is of form

$$C = m \times \sqrt{2 \times g} \quad (3)$$

The gravity, g, is equal to 9.81 m/s^2, and e is the coefficient of restriction which can be computed from

$$e = \frac{v_2}{v_1} = \sqrt{\frac{h_2}{h_1}} \quad (4)$$

This leads the estimation of the typical impact force, F, that is developed when the rod plunger impacts the target surface at various impact heights which are varied from 10 to 40 mm. Thus the relation between those forces and the peak voltage output, V, can be plotted. In the estimation, Impact duration, T, was determined from the voltage with time signal that is displayed on oscilloscope, during rod impact on PVDF films. In addition, h_2, maximum rebound heights of the rod were determined using the high-speed photography. “Fig. 9”, shows the calibration graph of the PVDF piezoelectric film represented by impact force and voltage. A linear relationship between peak voltage and impact force is high voltage output achieved with increasing impact height (h_1) of the rod plunger. Then, the impact pressure, P, of rod plunger can be therefore computed from:

$$P = \frac{4F}{\pi d^2} \tag{5}$$

Where F is the impact force and A is the cross section-tip area of the rod plunger which has 1.0 mm of tip diameter, d, of 1.0. The impact pressure can be computed from "Eq. (5)" with experimental value of, F, in "Fig. 9" Thus, the calibration graph of the PVDF piezoelectric film is obtained as shown in "Fig. 10"

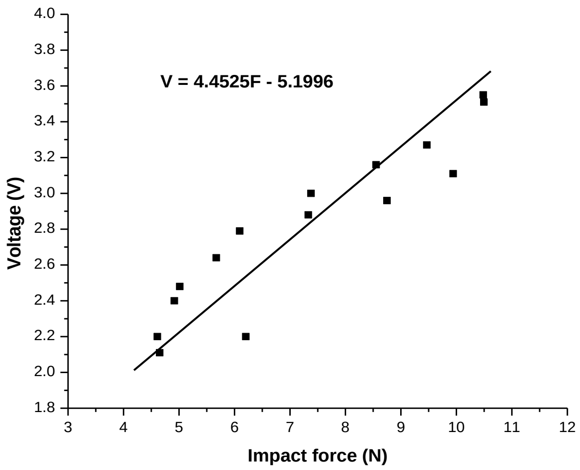


Fig. 9 Relationship between voltage and impact force

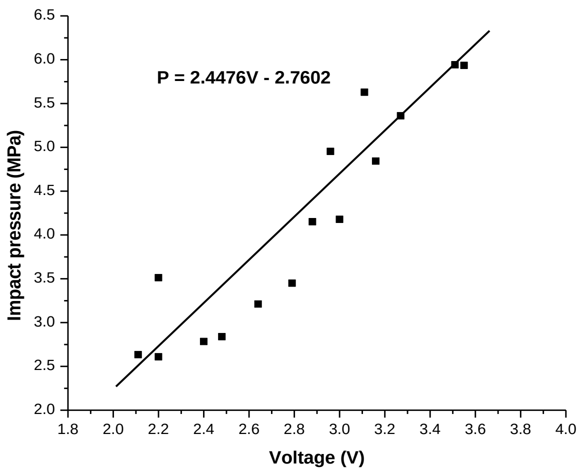


Fig. 10 Calibration curve of the PVDF piezoelectric film

3.3 Impact pressure of the jet

The high pressure air at ranging 10 bar to 20 bar, 20 mm in length and 4 g in weight were used to jet generation in experiment. The reasons why these conditions are used are that it provides the maximum peak momentum, given from "Fig. 7". The jets were generated through the nozzle orifice diameters of 0.2, 0.3 and 0.4 mm to impact horizontal on PVDF film, its voltage signal displayed on an oscilloscope. Using these signal values, it is translated to be the impact pressure by relationship from "Fig. 10".

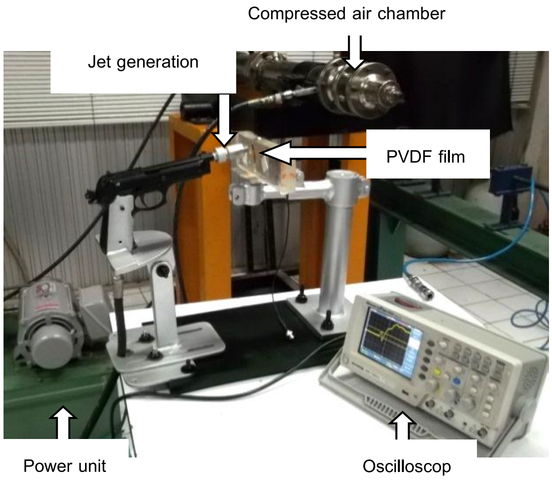


Fig. 11 Measurement of impact pressure of the jet produced by PVDF setup

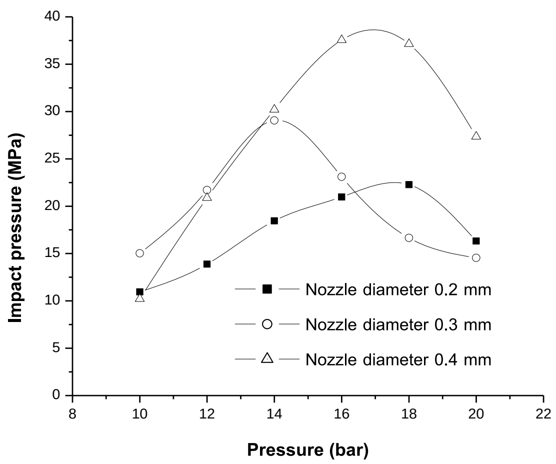
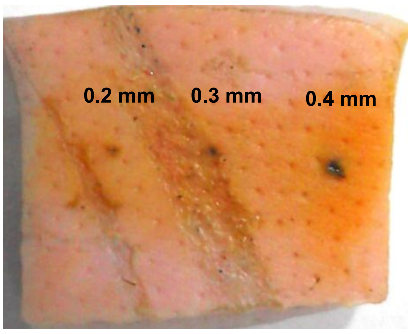


Fig.12 Impact pressure from various air pressure air

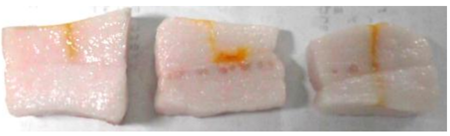
3.4 The penetration testing into the porcine skin

Investigation of the proper functioning of the injector with attached injections which the nozzle tip is attached to skin are performed on porcine skin, by use same injecting conditions in experiment of the jet impact pressure, in the previous section. The porcine skins are segmented from rear part of a porcine body. They were freezing for 10 hour before were shaped into hexahedral boxes, 50 x 50 x 20 mm. In the experiment, a jet injector is the liquid solution of 0.1 ml volumes, made up by yellow coloring and water in a proportion of 1 mg to 10 ml of water. It is injected into the porcine skin contained in a boxes socket "Fig. 13" shows the hole of penetration by the jet generated from nozzles having 0.2, 0.3 and 0.4 mm of orifice diameters.



(a)

0.2 mm 0.3 mm 0.4 mm



(b)

Fig. 13 (a) holes of penetration each diameter (b) Solution jet dispersing in porcine skin.

4. Result discussions

4.1 Velocity and momentum testing of the projectiles

The projectile velocity and momentum plunger-piston resulting from various pressures are shown in "Figs. 6-7." respectively. The high of these values are achieved by using 13 bar of pressure. This is resulting from limitation on performance of gas gun trigger in which the design condition of trigger nozzle hole is around 13 bar. When the higher pressures are used, chock flow phenomena limits air mass flow through a trigger nozzle hole. Afterward, the projectile velocity values and momentum are decreased until to 20 bar.

4.2 Calibration of PVDF piezoelectric transducer

Polyvinylidene fluoride or polyvinylidene difuoride (PVDF) was used as dynamics pressure sensor that employs the piezoelectric effect to measure jet impact pressure. The piezoelectricity is the charge that accumulates in materials and then response to applied mechanical stress from acting of the external force, as shown in "Fig. 14". Relation between the stress and either negative or positive voltage created is linear with large range. In addition, PVDF film is very thin, flexible, strong and cheap and it can generate high voltage with high responsible frequency by itself. Therefore, the PVDF films have been popularity applied to measure the impact pressure of a high-speed object.

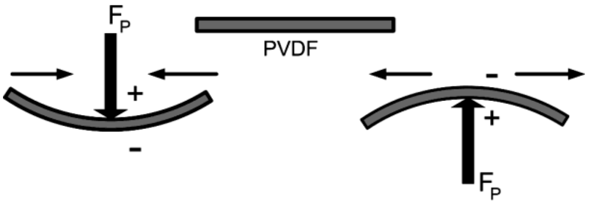


Fig. 14 Piezoelectric effect on PVDF

4.3 Impact pressure of the jet

"Fig. 12" shows the impact pressure created by impact of the jets varied with different nozzle diameters, which are varied from 0.2, 0.3 to 0.4 mm. The preliminary results reveal that the maximum peak impact pressure around 38 MPa by nozzle diameter of 0.4 mm. High jet momentum can be achieved when the appropriated pressure and projectile velocity are used and correspond to nozzle diameters, sometime being large size resulting in higher jet force. The Jet having impact pressure above 18 MPa is able to penetrate the skin.

4.4 The penetration testing into the porcine skin

In the jet penetration examined in porcine skin the projectile weight of 4 g and air pressure of 13 bar was used, due to this giving the maximum peak momentum as revealed in "Fig. 7 ".

"Fig. 13 (a)" shows the hole on the porcine skin from none impact injection, which have. The hole is large when large nozzle diameters are used, 0.4 mm diameter giving largest hole.

"Fig. 13 (b)" shows the yellow color shade corresponding to liquid jet dispersion resulting from the injection using 0.1, 0.2 and 0.3 mm of nozzle diameters. It was observed that the specimen having a large dispersed region and long penetrations, resulting from large nozzle diameter being used. This is because an ability of a penetration that dependent impact pressure of jet.

5. Conclusions

The injector is developed from a medical jet needle free injection system or "Med-jet NFIS", which is a hydraulic power system and was employed to operate the air-power jet injector. This study provides the fundamental study of needle-free injection utilizing the impact driven method for generating liquid jet.

Experimental results confirms that the modified gas gun is feasible to apply for the needle free jet injection. Nevertheless, some improvements of a jet generation mechanism and a jet delivery system are needed to improve to achieve the best injection characteristics.

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7. References

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