Research Journal of Applied Sciences, Engineering and Technology 14(2): 56-60, 2017
DOI:10.19026/rjaset.14.3989
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: May 7, 2015 Accepted: June 22, 2015 Published: February 15, 2017

Research Article

Low Cost Negative Pressure Wound Healing Device System

[1]Tian-Swee Tan, [1]Kee-Gang Ng, [2]Kasim Johari, [1]Kah-Meng Leong, [3]Zaharil Arman and [4]Chong-Keat Teoh
[1]Medical Device and Technology Group, Faculty of Bioscience and Medical Engineering,
[2]Faculty of Electrical Engineering, Universiti Teknologi Malaysia,
[3]Reconstructive Sciences Unit, Universiti Sains Malaysia,
[4]Department of Computer Science, Faculty of Computing, Universiti Teknologi Malaysia, Malaysia

Abstract: Negative Pressure Wound Therapy (NWPT) has been successfully used in treating acute and chronic wound by promoting wound healing. Many medical techniques like NPWT are available in this world but not approachable for many patients due to high in cost and lack of devices. In order for most of the patients accessible to NPWT, an inexpensive NPWT system is explored in this study. Aim of this work is to design a prototype of NPWT system that can generate negative pressure and the negative pressure can be regulated within the range. A NPWT system consists of vacuum pump, drainage tube, wound dressing, fluid collecting canister and adhesive film dressing. In this study, a miniature vacuum pump, canister and Arduino microcontroller were used in order to build up a functional NPWT system. The system has been designed to supply negative pressure from 0 mmHg to 200mmHg and negative pressure which can be controlled. To sum up, this system is able to function according to the require specification and suitable for home healthcare wound healing device with safety precaution implement and system stabilization is improved in future.

Keywords: Chronic wound, feedback system, microcontroller, negative pressure wound therapy, vacuum pump

INTRODUCTION

The basic suction method of negative pressure therapy used for treatment originated from the cupping therapy which has been used in China for thousand years (Cao *et al*., 2010). Cupping therapy is used to cure the diseases by circulating the blood flow was recorded earliest in *Bo Shu* (an ancient book written on silk) which was discovered in an ancient tomb of the Han Dynasty in 1973 (Chirali, 1999). In 1908's, Bier's Hyperemic Treatment using vacuum suction apparatus and method was introduced (Meyer *et al*., 1908). Since then, the technique of using Negative Pressure Wound Therapy (NPWT) has been triggered and began to draw attentions of many researchers. The more advanced use of NPWT has been studied by Chariker and Fleischmann in late 1980's and early 1990's (Chariker *et al*., 1989; Fleischmann *et al*., 1996). The method of using NPWT for open wounds arose in Germany and United States and has been widely spread throughout Europe, North America and other parts of the world. Normally equivalent words used for NPWT are Vacuum Assisted Closure (VAC) therapy, vacuum therapy, vacuum sealing therapy, topical negative pressure therapy and sub-atmospheric pressure therapy. Nowadays, NPWT has become a vitally important part of modern wound treatment and is implemented in most of the surgical discipline (general surgery (Baharestani and Gabriel, 2011), gynaecologic surgery (Altman *et al*., 2011), plastic surgery (Scherer *et al*., 2002), orthopaedic surgery (Bollero *et al*., 2007), thoracic surgery (Sjögren *et al*., 2005), trauma surgery (Kaplan *et al*., 2009) and pediatric surgery (Gutierrez and Gollin, 2012) throughout the world. Treatments of acute, chronic and complex wounds routinely have been using NPWT in hospitals. NPWT became commercially available in the 1990s and the market significantly expands into both United State and international healthcare systems. There are many products of NPWT are being fabricated by manufacturers and various kinds of devices like Stand Alone NPWT Devices, Portable NPWT Devices and NPWT Disposable Devices are being rented or sold to consumers. The NPWT devices in the market are high in cost. Based on McGill University Health Centre (MUHC), the average cost of NPWT in fiscal year 2009 to 2010 was US$36.30 per treatment day or US$254.13 per week. The NWPT product of KCI Company is cost US$20-30 per day for rental and available for purchase that cost about RM70000 per unit in Malaysia. The demand of using NPWT has been raised for promoting wounds healing in hospital due to the increase in the number of

Corresponding Author: Tian-Swee Tan, Medical Device and Technology Group, Faculty of Bioscience and Medical Engineering, Universiti Teknologi Malaysia, Malaysia

diabetes, cardiovascular diseases and peripheral vascular diseases and caused the NPWT devices inaccessible for most of the patients who need the NPWT. In addition, the price of NPWT device is high in market give rise to hospital inability to supply the treatment for most of users and the cost of therapy is also much costly that cause middle or low income family unable to receive the therapy. The concept of Physics mechanics has been applied in NPWT by controlling the sub-atmospheric pressure that induces mechanical stress to tissues. The division of cells (Mitosis) is stimulated, new blood vessels are grown and the wound is drawn closed (Lizarov, 1989). The level of pressure to the wounded tissue is small, but when whole parts of the wound press in an effort to close toward the center point, the effect of negative pressure becomes impressive and results in faster healing and resolution. NWPT aids in wound healing by increasing blood flow rate at wound, promoting the growth of granulation tissue, providing a humid, shielded surrounding, decreasing interstitial oedema, contracting wound edges and reducing bacterial and infectious. There are various types of settings of negative pressure device and wound fillers are well established but there are no strong evidences to prove the optimise magnitude for negative pressure and the most beneficent of wound filters used. The range of negative pressure from 0 mmHg to more than 200 mmHg that give impact to the effectiveness of wound healing has been used to study for many years ago. Most of the commercial NPWT device has the default pressure setting of -125 mmHg. The earlier wound control and treatment has been studied by researcher and found out for the -125 mmHg pressure setting was significantly enhance the growth of granulation tissue (Morykwas *et al*., 1997). Another study determined the granulation tissue formation at the pressure level of -25, -125 and -500 mmHg have been discovered that -125 mmHg is the optimal pressure to be used as effective therapeutic pressure level (Morykwas *et al*., 2001). There were no effects were seen at -25 mmHg and detrimental effects at -500 mmHg on granulation tissue. Theadvocated therapeutic range of NPWT from -40 mmHg to -150 mmHg can be beneficial (Malmsjö *et al*., 2012). Basically there are three types of mode delivery of negative pressure between continuous, intermittent and variable. In some vivo studies, the intermittent and variable NPWT showed greater result in wound contraction and formation of more granulation tissue than continuous NPWT (Malmsjö *et al*., 2012; Borgquist *et al*., 2010). In addition, both intermittent and variable NPWT increase the blood flow rate that known to facilitate oxygenation and nutrient supply, but there are no much different in results between intermittent and variable NWPT. Consequently, intermittent NPWT is unpopular than it used to be because it causes patient discomfort. Thus,
variable NWPT may be superior to be used as it provides smooth cycling between two different levels of negative pressure (Borgquist *et al*., 2010). Therefore, in this study, a low cost NPWT system is being design that can be functioned according to the beneficial negative pressure range.

METHODOLOGY

This section describes the overview of the NPWT system alongside its specifications. Figure 1 shows the schematic diagram of NPWT system design with consisting of vacuum pump, Arduino microcontroller board, pressure sensor, fluid collection canister and drainage tube. The negative pressure is generated via the vacuum pump which is connected to fluid collecting canister with drainage tube. The vacuum pump can supply negative pressure up to -600 mmHg or -80 kpa which is higher than the design specification of -200 mmHg with objective to give an adequate negative pressure supply.

The value of negative pressure is controlled through pressure sensor and Arduino board, so that a desired level of negative pressure is obtained. By varying the speed of motor pump using analog output Arduino board of Pulse Width Modulation (PWM) can generate different level of negative pressure. The negative pressure generated by vacuum pump was tested. Vacuum pump was controlled using PWM Arduino microcontroller board and negative pressure generated was detected using pressure sensor. PWM

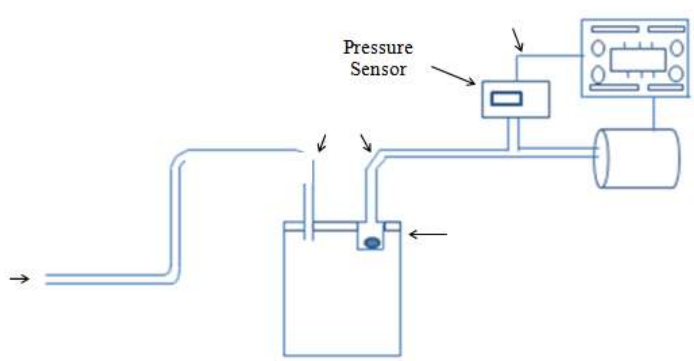

Fig. 1: Schematic diagram of NPWT system

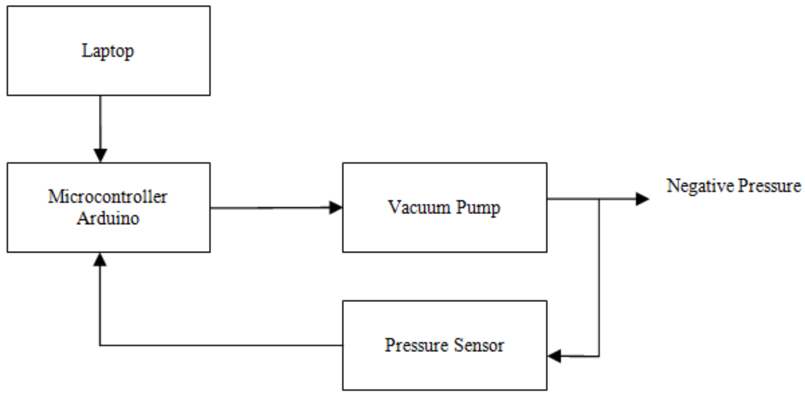

Fig. 2: Block diagram of NPWT system

Fig. 3: NPWT system with negative pressure generated

signal turning a digital output line on and off that produced duty cycle to control the output power level which supplied to the vacuum motor pump. The pressure sensor is used to detect the negative pressure level supplied by vacuum pump in order to regulate the negative pressure to the desired value. Besides that, the fluid collecting canister used should able to withstand the negative pressure within the range for maximum durability. There is also a ball float design inside the canister to prevent overflow of fluids into the vacuum pump.

Figure 2 illustrates the NPWT control system by using Arduino Uno microcontroller board to control the speed of dc motor vacuum pump. The vacuum pump will generate negative pressure to the wound. If the pressure level is not in the range of the value set, the pressure sensor will detect the current value and send signal to the Arduino Uno and regulate back the negative pressure level that set at the beginning by increasing or decreasing the speed of motor pump. The negative pressure values will display on the LCD screen.

Figure 3 shows the NPWT is being set up and negative pressure generated by vacuum pump is being measured. In this study, different levels of negative pressure generated were tested and control within a range of value was recorded. The cost of the hardware that used to build up this system was being calculated.

RESULTS AND DISCUSSION

This section presents the results for the negative pressure generated with varying PVM. Figure 4 showed that the different level of negative pressure generated by vacuum pump when varying the PWM to change the speed of motor. From the graph above, it indicated that the negative pressure was not linearly changed with altering the PWM. The negative pressure level increased exponentially when PWM changed from 140 to 250 or voltage supplied from 5.8V to 10.3V. The -75 and -125 mmHg of negative pressure can be reached when the PWM adjusted to 175 and 208 respectively. There was 2.5V of voltage drop within the motor driver circuit which used to drive the vacuum pump. This caused the vacuum pump unable to generate negative pressure linearly with speed change.

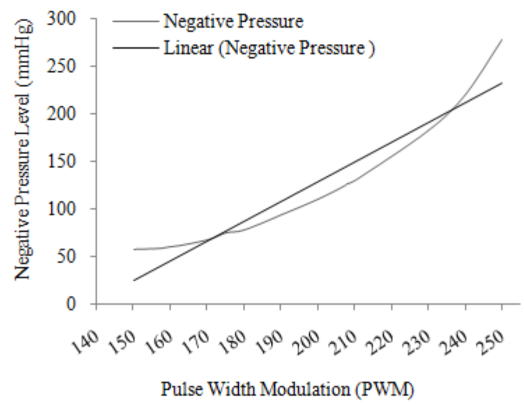

Fig. 4: Real time negative pressure generated with varying PWM

The negative pressure generated by vacuum pump was tested. Vacuum pump was controlled using PWM Arduino microcontroller board and negative pressure generated was detected using pressure sensor. PWM signal turning a digital output line on and off that produced duty cycle to control the output power level which supplied to the vacuum motor pump. The equation used to calculate the output power generated to run the motor pump was $\boldsymbol{V_{output}} = \frac{\boldsymbol{PWM}}{\boldsymbol{255}} \times \boldsymbol{V_{source}}$.

Table 1 shows the negative pressure measurement different between analog vacuum gauge and pressure sensor. There was averaging of -6 Kpa different of negative pressure detected by pressure sensor comparing with vacuum gauge at the same time.

Table 1: Negative pressure measurement difference between vacuum gauge and pressure sensor

PWM	Vacuum gauge (Kpa)	Pressure sensor (Kpa)	Differences (Kpa)
150	-11	-6	-5
160	-13	-7	-6
170	-14	-8	-6
180	-15	-9	-6
190	-16	-10	-6
200	-18	-12	-6
210	-20	-14	-6
220	-24	-17	-7
230	-27	-20	-7
240	-30	-24	-6
250	-35	-30	-5

Table 2: Comparison specification of NPWT system in market

Manufacturer	Product name	Specification
KCI	V.A.C.® Freedom	Negative Pressure: -50 to -200 mmHg Operation Mode: Continuous and Intermittent
Smith and Nephew	V1STA	Negative Pressure: -40 to -200 mmHg Operation Mode: Continuous and Intermittent
Prospera	PRO-II	Negative Pressure: 0 to -200 mmHg Operation Mode: Continuous, Intermittent and Variable
This System		Negative Pressure: 0 to -200 mmHg Operation Mode: Continuous and Variable

Besides that, the negative pressure generate will not fix exactly to a value, it vary within the range of ±3 mmHg which detected by pressure sensor. The difference in negative pressure and pressure changed within range is due to pressure loss via the fittings between tubes and resistance or friction with the tube. Besides that, the negative pressure different caused by the 2.5% maximum error over 0 degree Celsius to 85 degree Celsius of the pressure sensor according to the datasheet. In addition, the readings in analog vacuum gauge are not precise enough when the values were taken directly.

Table 2 shows the comparison of different type of products for the specification of NPWT system. From the comparison, the NPWT system designed is able to generate the negative pressure from 0 to -200 mmHg which has the wider range of pressure than V.A.C.® Freedom and V1STA but same pressure range as PRO-II. The wide range of negative pressure provides user more negative pressure levels to be adjusted according to the need of patient. Moreover, a wide range of negative pressure eases the varying of pressure level between two different levels that provide a smooth transition. In this system, it only operates in continuous and variable modes of negative pressure without intermittent mode compare with other products because intermittent mode will cause pain to the patient. The hardware or components used for this NPWT system are DC micro vacuum pump, Arduino Uno R3 board, 1mL fluid drainage canister, pressure sensor IC, silicon tube and tube connector and others. The total expenses spend on this NPWT system cost about RM731.79 without fully packaging and much lower than the other products in market which cost RM70000 per unit in Malaysia. This designed system gradual reduces the cost and can be afforded by all patients that need the treatment and reduce the hospitalization days due to faster healing of using this NPWT system.

CONCLUSION

In this study, a prototype of NPWT system is being designed and the cost is lower compared to other NPWT market product price. The negative pressure generated by this system is able to supply from 0 to -200 mmHg which is in the beneficial range of treatment. For future work, safety precaution is required to implement and system stabilization is need to improve to reduce pressure loss.

ACKNOWLEDGMENT

This research is a collaboration between Universiti Teknologi Malaysia (UTM) and Hospital Universiti Sains Malaysia (HUSM). The authors gratefully acknowledge the research grant provided to this study by Research Management Centre sponsored by Ministry of Education, Malaysia. GUPVot: 10H93 (Research University Grant), Universiti Teknologi Malaysia, Johor Bahru, Malaysia.

REFERENCES

Altman, A.D., G. Nelson, J. Nation, P. Chu and P. Ghatage, 2011. Vacuum assisted wound closures in gynaecologic surgery. J. Obstet. Gynaecol. Can., 33(10): 1031-1037.

Baharestani, M.M. and A. Gabriel, 2011. Use of negative pressure wound therapy in the management of infected abdominal wounds containing mesh: An analysis of outcomes. Int. Wound J., 8(2): 118-125.

Bollero, D., R. Carnino, D. Risso, E.N. Gangemi and M. Stella, 2007. Acute complex traumas of the lower limbs: A modern reconstructive approach with negative pressure therapy. Wound Repair Regen., 15(4): 589-594.

Borgquist, O., R. Ingemansson and M. Malmsjö, 2010. The effect of intermittent and variable negative pressure wound therapy on wound edge microvascular blood flow. Ostomy Wound Manag., 56(3): 60-67.

Cao, H., M. Han, X. Li, S. Dong, Y. Shang, Q. Wang, S. Xu and J. Liu, 2010. Clinical research evidence of cupping therapy in China: A systematic literature review. BMC Complem. Altern. M., 10: 70.

Chariker, M.E., K.F. Jeter, T.E. Tintle and J.E. Bottsford, 1989. Effective management of incisional and cutaneous fistulae with closed suction wound drainage. Contemp. Surg., 34: 59-63.

Chirali, I.Z., 1999. The Cupping Procedure. In: Chirali, I.Z., (Ed.), Traditional Chinese Medicine Cupping Therapy. Churchill Livingstone, London, 3.

Fleischmann, W., E. Lang and L. Kinzl, 1996. Vacuum assisted wound closure after dermatofasciotomy of the lower extremity. Unfallchiirurg, 99(4): 283-287.

Gutierrez, I.M. and G. Gollin, 2012. Negative pressure wound therapy for children with an open abdomen. Langenbecks Arch. Surg., 397(8): 1357-1357.

Kaplan, M., D. Daly and S. Stemkowski, 2009. Early intervention of negative pressure wound therapy using vacuum-assisted closure in trauma patients: Impact on hospital length of stay and cost. Adv. Skin Wound Care, 22(3): 128-132.

Lizarov, G.A., 1989. The tension-stress effect on the genesis and growth of tissues: Part II. The influence of the rate and frequency of distraction. Clin. Orthop. Relat. R., 239: 263-285.

Malmsjö, M., L. Gustafsson, S. Lindstedt, B. Gesslein and R. Ingemansson, 2012. The effects of variable, intermittent and continuous negative pressure wound therapy, using foam or gauze, on wound contraction, granulation tissue formation and ingrowth into the wound filler. Eplasty, 12: e5.

Meyer, W., V. Schmieden and A.K.G. Bier, 1908. Bier's Hyperemic Treatment in Surgery. W. B. Saunders Company, Philadelphia and London.

Morykwas, M.J., L.C. Argenta, E.I. Shelton-Brown and W. McGuirt, 1997. Vacuum-assisted closure: A new method for wound control and treatment: animal studies and basic foundation. Ann. Plast. Surg., 38(6): 553-562.

Morykwas, M.J., B.J. Faler, D.J. Pearce and L.C. Argenta, 2001. Effects of varying levels of subatmospheric pressure on the rate of granulation tissue formation in experimental wounds in swine. Ann. Plast Surg., 47(5): 547-551.

Scherer, L.A., S. Shiver, M. Chang, J.W. Meredith and J.T. Owings, 2002. The vacuum assisted closure device: A method of securing skin grafts and improving graft survival. Arch Surg., 137(8): 930-933; Discussion 933-934.

Sjögren, J., R. Gustafsson, J. Nilsson, M. Malmsjö and R. Ingemansson, 2005. Clinical outcome after poststernotomy mediastinitis: Vacuum-assisted closure versus conventional treatment. Ann. Thorac. Surg., 79(6): 2049-2055.