Compression Bandage Pressure Measurement

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A Thesis Presented in Application for the Degree of Master of Science at the University of Dundee

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Lastly, thanks to my family for their support and belief in me through out this project.

Declaration and Certificate

DECLARATION

I hereby declare that this dissertation has been composed by me. Work other than my own is clearly indicated by reference to the relevant researchers. This thesis has not been presented in any previous application for a higher degree.

Tao WU

CERTIFICATION

This is to certify that T. Wu has done her research under the supervision of Dr R.A. Lerski at the Medical Physics Department at Ninewells Hospital and Medical School in Dundee, and that she has fulfilled the conditions of the relevant Ordinance and Regulations of the University of Dundee. She is qualified to submit the following thesis in application for the Degree of Master of Science in Medical Physics.

Dr R.A. Lerski

Summary

Each year, approximately a quarter of a million of the UK adult population is affected by chronic venous insufficiency. The current annual cost of treating the resulting chronic leg ulcers is approximately £500 million.

The most effective method of treating chronic venous leg ulcers is by the correct application of pressure bandages. The incorrect application of pressure bandages results in failure to heal the ulcer which can lead to the amputation of the lower leg. In the UK, 70% of patients with chronic venous ulcers are treated by district nurses or general practitioners who receive little or no training in the technique of applying pressure bandages.

The aim of the thesis was to develop a simple and efficient training method for applying bandages by clinical staff, and to investigate the factors that influence pressure under such bandages, both theoretically and experimentally. This should enable correct treatment of leg ulcers, reducing treatment costs and improving healing rates.

To achieve the aim of this project (to produce a bandage training leg), the following work was carried out:

Firstly, review of the principles and history of bandaging. From this review it becomes very apparent that a stable bandage tension is very important to attain a reasonable pressure gradient when applying bandages.

Secondly, choosing sensors to measure the applied bandage force or pressure. These sensors had to be accurate and sensitive.

Next, a computer was programmed to monitor and analyse in the data from the sensors. Computers are in common use in hospitals and clinics and the computerisation the bandaging training device would make it easy to use and cost effective.

Finally, clinical staff tested the software and the training leg and the resultant feedback from these tests were used to improve the prototype.

Chapter 1

Introduction

1.1 Background

Leg ulcers are well known to occur between the knee and the foot. Leg ulcers affect 1% of population of 70 year olds. Every year, approximately a quarter of a million of the UK's adult population, and about 0.5% of the United States' adult population are affected by chronic venous insufficiency (Westerhof W., 1993). In the UK, it has been shown (Figure 1.1) that 80% of leg ulcers are due to venous disorders, 10% of them due to ischemia, 5% due to diabetic and the remaining 5% due to other reasons (Nursing times, 1999).

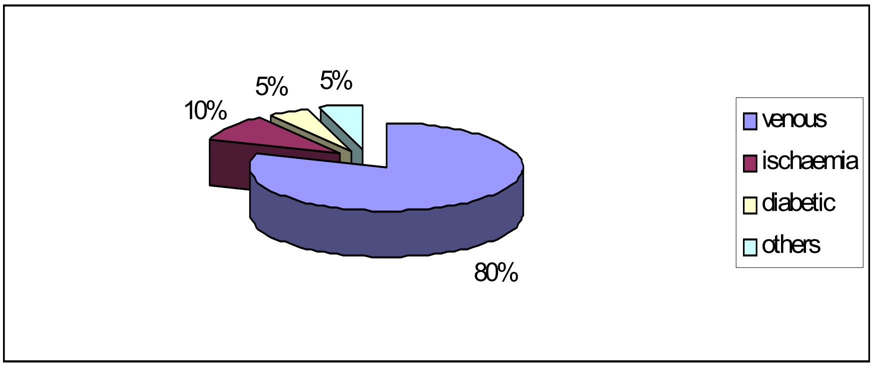


Figure 1.1 types of leg ulcers

 ‘Estimates of total cost of leg ulcer management in the UK range from £50 million to £600 million per annum, similar to the cost of tobacco-related diseases: it has been estimated that over sixty per cent of this cost is for community nursing services’ (Westerhof.W., The extent of the problem, 1993).

As long as a patient gets leg ulcers, the ulcers are very difficult to treat. The process of treating the disease normally takes at least six weeks. 50 % of patients with leg ulcers may present for up to one year, and 67 % of ulcers were recurrent (Westerhof, W., 1993). In addition, as people get older, they are more likely to develop leg ulcers. Maffeii and her colleagues found in a study, that the mean age of leg ulcer patients was 78 (52-91) years old. Meanwhile, women were more susceptible to leg ulcers than men. The ratio of occurrence in women to men was 2.2:1 (Westerhof, W., 1993).

According to figure 1.1, chronic venous leg ulcers account for the majority of leg ulcers. Bandage application on venous is currently known as the most effective way to treat chronic venous leg ulcers. However, chronic venous leg ulcers are mainly prevalent in the elderly and tend to be non-fatal conditions (Negus, D., 1995), so few studies of leg ulcers have been carried. Many clinical staff and nurses may make patients worse when treating them (Ryan,

T. J., 1987). Inadequate pressures will have little effect on healing, and incorrect bandaging techniques, where very high sub-bandage pressures are obtained, could have a detrimental effect on the patients' limb and result in pressure necrosis and amputation (Moffatt 1992, Moffatt and Dickson 1993).

1.2 Venous system of legs

The vessels are a blood reservoir. Almost two thirds of the body's blood flows in the venous system at any one time, and 300 to 400 ml of it is contained in the veins of the leg. (Ryan, T. J., 1987) There are two sets of blood vessel in human legs. One is the arteries, which transfer blood from heart to legs. The other is the veins, which collect venous blood from legs to heart. Only the legs' venous vessels have been reviewed here. (Figure 1.2) (McMinn R. M. H ET al., 1995).

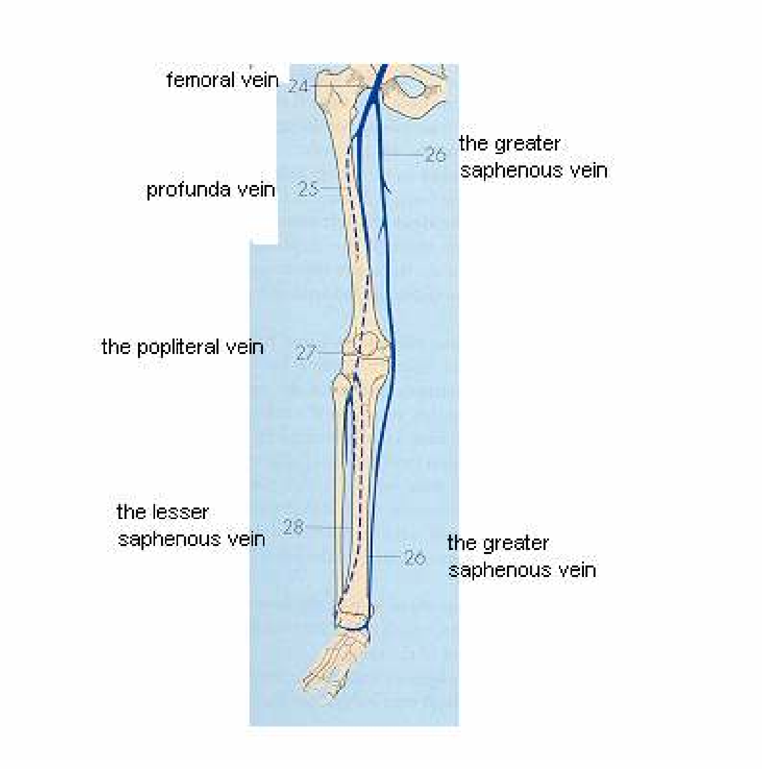


Figure 1.2 venous system of leg (adapted from McMinn R.M.H., 1995, P58)

In legs, there are two groups of veins: deep (27-the popliteal, 24-femoral and 25-profunda veins) and superficial veins (26-the greater and 28-the lesser saphenous veins). The deep veins accompany the arteries of the same name. They receive venous blood from the area surrounding them and the superficial venous vessels. The superficial veins, the greater saphenous and the lesser saphenous vein, collect venous blood and join the deep veins respectively at different points. At the same time, the greater and lesser saphneous veins communicate with each other by abundant, small, superficial venous vessels, and connect with the deep intermuscular veins via the deep fascia. (Palastanga, N., Field, D., Soames, R., 1994).

1.3 Distribution of pressures in legs

Due to gravity, the pressure varies from the top to the bottom of the leg. The effect of gravity on the flow of blood in the veins depends on leg posture (Nicolaides, A. N., 1975). When the leg is placed horizontally, there is little flow of blood through it. Figure 1.5, (Tibbs, D. J., Sabiston, D. C., Davies, M. G., Mortimer, P. S., Scurr, J. H., 1997), shows that the ankle pressure is obviously different when the subject is lying, rising, standing and walking. However, humans walk with an erect posture. So, when a normal person stands still, the pressure of venous blood in the leg increases from knee to foot because of gravity. As in Figure 1.3, the pressure profiles in the veins are 60, 70 and 90 mm Hg on popliteal fossa, calf and foot respectively.

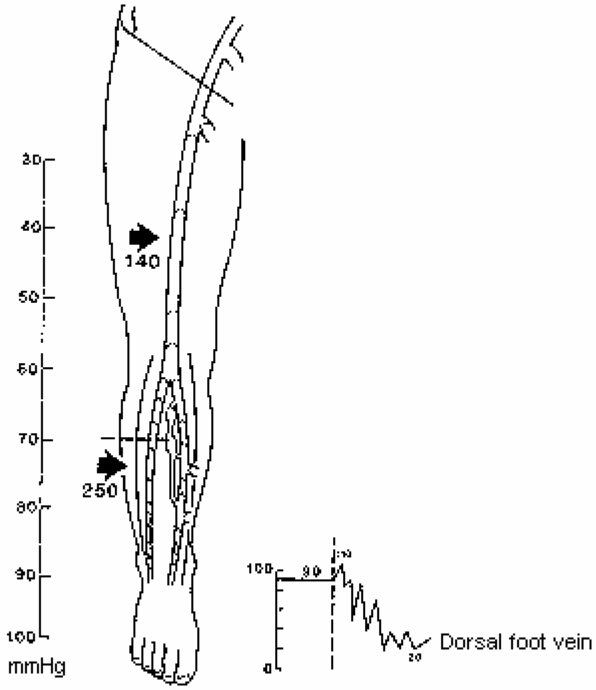


Figure 1.3 Contribution of leg pressures

“Pressure profiles in the veins of the foot, calf, poplliteal fossa and upper thigh at rest and on walking. Foot venous pressure is progressively reduced by contractions of the calf muscle pump whose excursions of pressure are significantly greater than those of the popliteal are or groin ‘pumps’. The heavy black arrows indicate intramuscular pressures.” (Adapted from Negus, D., 1995, P31)

When the leg is exercising, the pressure will change greatly. The calf pump may produce about 250 mm Hg intramuscular pressure (Tretbar, L. L., 1999**)**. A study showed that when the calf muscle pump contracted, it could reduce the pressure by 60-80 from 100 to 20 mm Hg within a number of seconds at the area of ankle. Consequently, the venous blood was pushed upward towards the heart. As the calf muscles relaxed, the venous blood falls due to gravity.

1.4 Functions of calf pump and valves

When venous blood is transmitted to the heart, it must overcome gravity. Firstly, the blood flow has to rely on muscle contraction (calf and foot muscles mainly), and then the valves in the veins functioning correctly to ensure correct direction of blood flow. Only when the pressure produced by the calf pump is stronger than gravity will the valves in leg veins opened, and hence venous blood will flow to heart.

Meanwhile, veins have inherent elasticity and have an important function to expand and contract. However, the deep veins are wrapped by fascia that is a thin, tough and inelastic envelope. The superficial veins exit on surface of muscles. So when muscle pumps contract, the forces will produce large pressure on superficial vessels. However, because there is the fascia surrounding the deep vessels, they are hardly affected. As a result, the venous blood is sucked from superficial to deep veins (Figure 1.4).

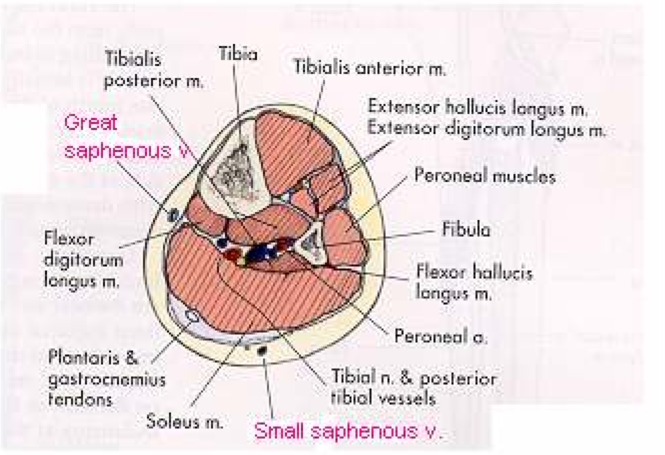


Figure 1.4 veins positions of lower leg (adapted from Mathers, L…1996, P693)

In fact, the muscle pumps only cause blood to flow when they contract, and valves play a very important role in directing the blood to back heart. The deep veins possess numerous valves, while there are about 14 to 32 bicuspid valves in superficial veins (Negus, D., 1995). All valves in veins should open in the direction of the heart. The reflux venous blood will push valves closed in normal legs. For illustrative purposes, these valves look like piston in an air pump. The piston opens when air is pushed into the tube. When the air ceases to be pushed in, the pressure of air inside the tube is higher than outside, so air in the tube flows back to close the piston. The same principle applies to the valves in the leg. The valves of veins can maintain venous blood flow to the heart. When the calf muscle contracts again the motion will repeat again and continue to push blood towards to the heart (Tretbar, L. L., 1999).

Thus, healthy venous valves are necessary for man to maintain normal leg vessel pressures. Figure 1.5 shows the different effect of exercise on venous pressure at the ankle with normal and defective venous valves. In normal people, when they are standing, the pressure at the ankles is 90-100 mm Hg. As the subjects move, the ankle pressure falls dramatically within a few steps to about 20 mm Hg and remains at this low value while the subjects keeps walking. As the subjects stop, the pressure reverts to 90-100 mm Hg over a period of 30seconds or more. In contrast, when a patient with defective valves starts to walk, the ankle pressure decreases slowly to over 80 mm Hg, and remains at this high level while walking. The pressure will increase quickly in less than 30 seconds to maximum once the subject stops the exercise.

There are two cases that could result in venous valve incompetence. One is that if veins are dilated too much, the valves will become too small compared to the swelling vessels, the other reason is if some valves are damaged by disease. In both of these two situations, there is a loss of the function of preventing venous flow away from the heart and therefore the venous blood refluxes.

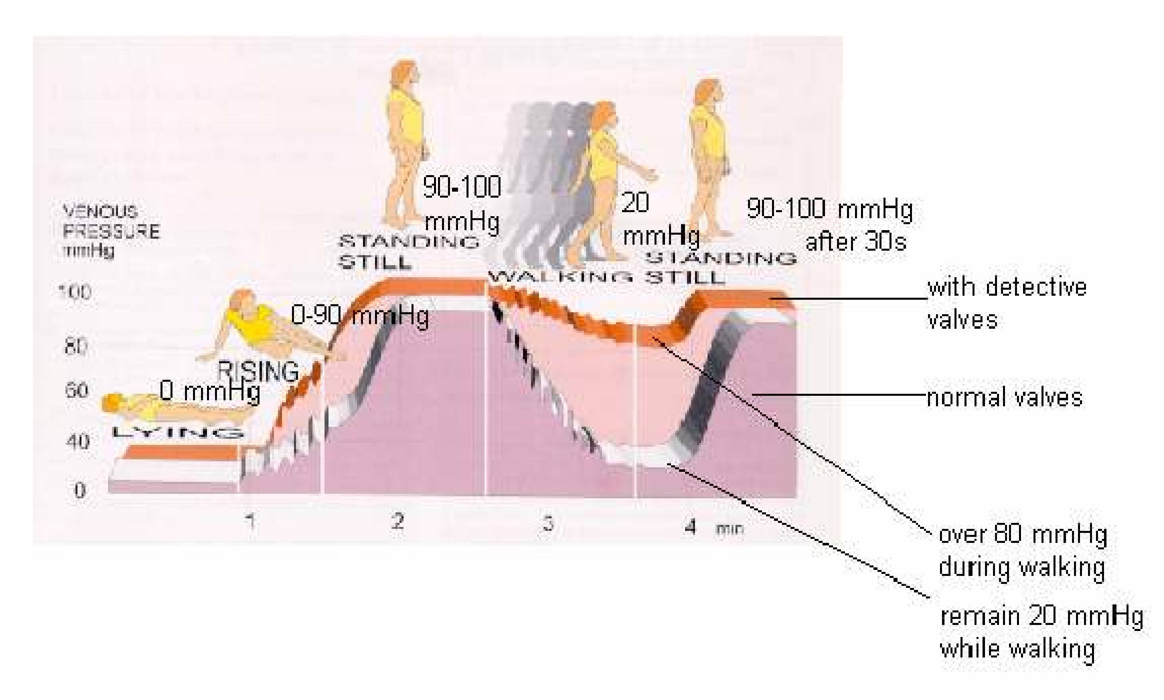


Figure 1. 5 Changes of ankle pressure at varying position and exercise causes of leg ulcers

"Changes in venous pressure with varying position and exercise, comparing normal behaviour with venous disorder. Changes in limb volume and degree of capillary filling run parallel with this, so that various forms of phlethysmography can be used to indicate the rate and extent of pressure changes in response to exercise and posture. Note how venous pressure in venous disorder is lowered inadequately with exercise and rapidly returns to high level. High venous pressures, unrelieved by movement when upright is damaging and causes the harmful effects of venous disorder; this is maximal on standing and minimal or absent when the patient is recumbent." (Adapted form Tibbs, D. J., et al, 1997)

1.5 Causes of leg ulcers

Although there are four most common causes of lower-extremity ulcers such as venous insufficiency, arterial insufficiency, neuropathy (often due to diabetes) and ischemia (Aranjo, T., et al). Patients with venous insufficiency ulceration may complain of limb aching and swelling that becomes worse at the end of the day, relieved by elevation of the limb (Phillips, T. j., 1999), and normally patients may have a history of long standing varicose veins, or a history of blood clots in either the surface or the deep veins of the legs (The Cleveland Clinic, 2003).

It is known that the blood of the capillaries plays a very important role in venous leg ulcers.

> “Measurement of femoral artery blood flows shows a decline of 60% in response to rising to the standing position from the supine position. Measurement of skin perfusion using laser Doppler fluxmetry shows a similar decrease in the cutaneous blood flow on standing. … Capillary microscopy studies which suggested that following ambulatory venous hypertension, fewer capillaries were visible in the skin of patients with venous disease than before ambulatory venous hypertension.” (http://www.ulc.ac.uk)

The positions of a leg cause blood flux to change dramatically. For example, upon putting the foot 30 cm above the level of the heart, there was mean 45% ($p<0.1$) blood flux increase, which was shown in the laser Doppler. (Abn-

Own A, Scurr JH, 2003). So far no reasons have been defined to explain why leg ulcers occur, especially why ulcers are always found at gaiter region. It is known that the foot pump also pushes venous blood from the feet to the legs when the subject moves (Tretbar, L. L., 1999). Thus it is the belief of this study that there are ‘two pumps’ in a leg. One is well known as calf pump, behind the lower leg, which is made of soleus and gastrocnemius muscles. The other is the foot pump, which is under the foot plantar. When a person walks, both of the pumps exercise, then the two pumps produce forces that go in opposite directions. The foot pump lies under the foot plantar; it produces force up to the leg. The calf pump produces two forces, a force up the leg and one down the leg. In a normal leg, because the leg veins’ valves are perfect, the downward force produced by the calf pump is effectively blocked by these valves. Hence in a healthy leg the upward forces of the calf pump and the foot pump will cause blood to flow (Figure 1.6).

However, in a leg with incompetent venous valves (Figure 1.7), such as valves damaged or veins dilated, the downwards-force is not blocked by the valves. Thus, the down-force from the calf pump will meet the up-force from the foot pump around the gaiter area and stagnant venous blood is accumulated at gaiter region because of these two opposing forces. As a result, haemoglobin from the red blood cells escapes and leaks into the extra-vascular space, causing the discoloration commonly observed. (www.medicaedu.com/venous.htm). Fresh arterial blood cannot fill the area fully, so the skin of gaiter cannot receive arterial blood with oxygen and nutrition replacement. As a consequent in time, it is easy to develop ulcers around this area, but more advanced work will need to be carried out to determine if this is a sound theory.

1.6 Current therapies for treating leg ulcers

There are different treatments adopted according to different types of leg ulcers. These include such treatments as systemic antibiotics, skin grafting, laser therapy (Fleming K., Cullum N., 2003) and compression bandages. For example, systemic antibiotics should only be used in the presence of cellulites or systemic infection. The drug Pentoxifylline appears to be an effective adjunct to compression bandaging for treating venous ulcers (Jull AB., Waters J., Arroll B., 2003). In some cases the usual treatments, such as simple dressings and compression bandages or stockings, are unsuccessful with large areas of ulcers remaining open for months or years. In these cases skin grafts may be taken from the patients own uninjured skin or they may be grown from the patient's skin cells into dressing, (autografts) or applied as a sheet of bioengineered skin grown from a donor cells (allograft) (Jones JE. Nelson EA., 2003). (Dermagraft from Smith and Nephew is such a Bioengineered product. This product is a cryopreserved human fibroblast derived dermal substitute.)

In recent years, the application of low intensity laser therapy (LILT) has emerged, but further clinical studies are required (Ashford R, Brown N, et al, 1998).

It has already been mentioned earlier in this thesis that the topic of this project was chronic venous leg ulcer, and compression is the cornerstone of therapy for venous ulcers. However, some patients with venous ulcers may have arterial insufficiency as well. It is therefore very important to conduct an investigation before commencing treatment. The ankle-brachial pressure index should always be measured before compression bandages are applied (see 1.7).

For patients with chronic venous leg ulcers, the following compression devices can be used (Phillips T. J., 1999):

- Elastic support stockings – use of these stockings at a pressure of 30 to 40 mm Hg is recommended in patients with ulcers caused by venous insufficiency.
- Elastic bandage – correct application is essential for effective compression.
- Non-elastic bandages – they protect ulcers from the environment, help control edema and are especially helpful in elderly or noncompliant patients because they can be left in place for 7 to 10 days.
- Multi-layer bandages – these bandages achieve uniform, sustained compression and can be left in place for a week.

- Pneumatic compression pumps – when a venous ulcer does not respond to treatment with standard compression dressings.

1.7 Principle of bandaging

Suitable compression bandaging is very important when applying elastic bandages to treat a patient with chronic venous leg ulcers, not only can it reduce patients' legs swelling but also produce gradient pressures which mimic the human's leg real pressure.

When a person stands still, their ankle's blood pressure is higher than rest of the leg. According to the figure 1.5, when a person stands still, the venous pressure in his leg decreases gradually from foot to knee and Dorsal foot veins, post-tibial vein and popliteal vein pressures are 90, 70 and 60 mm Hg respectively. When a nurse applies a bandage, the patient's legs should be put level, so that pressures in leg are almost same. If the nurse can keep bandaging at correct tension, the pressures to legs can be calculated according to Laplace's law (Mani, R., 1999):

$$\mathbf{P=}\ \frac{\mathbf{TN \times 4630}}{\mathbf{CW}} \qquad \text{(Equation 1)}$$

Where

P= sub-bandage pressure (mm Hg)

T= bandage tension (in kg Force)

C= circumference of the limb (cm)

W= bandage width (cm)

N= number of layers applied

From this, the sub-bandage pressure is in proportional to the bandage’s tension and number of bandage layers. Pressure decreases, however, as circumference of the limb and bandage width increase. Thus, according to the formula, given a certain type of bandage, only the bandage’s tension can be adjusted by the practitioner. That means if a nurse keeps the bandages at the same tension when applying the compression bandages, the bandages themselves will form a pressure gradient from foot to knee.

1.8 Conditions of bandaging

So far there is no effective drug treatment for leg ulcers, and a correct application of graduated compression is the single most effective means of healing venous ulcers (National Health Service in Scotland, July 1995 ISBN 0 7480 3026 3). It was also mentioned that ‘with a correct compression technique, it should be possible to heal more that 90% of venous leg ulcers’ (Noel, B., 2000).

There are two forms of bandages: inelastic and elastic. The elastic bandage, with compression, is the main treatment used in chronic venous leg ulcers. This project used compression bandaging.

It has been known for centuries that if medical nurses and staffs apply compression bandage correctly then this is a valid method to heal chronic venous leg ulcers. However, not all leg ulcers can be cured by compression bandage. There are many reasons for the occurrence of leg ulcers, such as failure of veins, or artery, or veins and artery mixed and others. If patients have leg ulcers from arterial causes, bandaging is counterproductive, because the pressure the bandaging produces will make patients’ arterial problems worse, even causing amputation.

Therefore, before applying bandages to a patient, it is necessary check whether the patient’s feet arterial pressures are normal. If the patient’s feet pulses cannot be felt, compression bandaging is forbidden. Currently the only equipment commonly used to measure foot arterial pressure is Doppler sonography. The result is known as ABI: (Mani, R., 1999)

$$ABI=\frac{ASP}{BSP} \quad \text{(Equation 2)}$$

ASP----Ankle Systolic Pressure (mmHg)

BSP----Brachial Systolic Pressure (mmHg)

ABI----Ankle Brachial Index

The result of ABI cannot be less 0.9. Only when ABI is equal to or greater than 0.9, may the application of compression bandage be considered as a treatment for patients with leg ulcers.

1.9 Bandaging History

It is known that the Greeks and Romans used bandaging to treat leg ulcers; to empty the ‘stagnant blood’ in the superficial veins (Leg ulcer care system, 1997). However, the therapy was misunderstood; their intention was just to drive out ‘evil humors’. Until recently compression bandaging therapy was not understood (Moffatt, C., Harper, P., P70). The type of compression applied has been studied in a number of tests, and the healing rate was nearly 70% at three months (Westerhof, W.). But its mechanism of action still remains unknown (Tretbar, L. L., 1999).

Chapter 2

2.1 Objective:

The aim of this project was to develop a simple and efficient training method for applying bandages by nurses, and investigate the factors that influence pressure under such bandages, both theoretically and experimentally. This should enable correct treatment of leg ulcers, reducing treatment costs and improving healing rates.

There are a number of devices available, which can be used to measure the pressure applied to the skin by a compression bandage. These include:

1. The Salzmann Medico Sub-bandage Pressure Monitor (Produce by MESH; a Salzmann AG subsidiary). This device consists of a monitor and thin plastic sleeve with four paired electrical contact probes, which is laid on the leg surface and bandaged over. The sleeve is inflated with air until the contacts are broken when the pressure exerted by the air is greater than the pressure exerted by the outer compression layer. (Cost of this device is in the region of £7500 including sensors making it rather expensive as a general teaching aid. Also it is not designed as a teaching aid)

2. The Oxford Pressure Monitor Mark 2 (Was manufactured by Talley) measures pressure by observation of the pressure flow characteristics of small pulses of air (Swain et al, 1992). It has 12 plastic sensors that inflate with air and can simultaneously record pressures at up to 12 individual sites in a range of 1300mmHg with an accuracy of ±4mmHg. The pressure readings are displayed on a liquid crystal display screen and can also be printed out. The probes can be taped together or are available as a sheet. (This device is no longer manufactured)

These two kinds of devices, although they use different sensors, both make measurements directly. They do not store the results and cannot guide trainers in keeping stable compression bandage tension. We know that constant bandage tension is very important and effective in treating venous leg ulcers. The desired outcome of this project is to design a cheap and effective in vitro, under bandage pressure monitoring devices using different sensors and software written in Visual Basic 6.0. As the results of measurement are visible, and the device should also function as a recorder, clinical staff can not only compare the results of there own bandaging attempts but also compare these to other staff's work. Hence improvement in their technique will be visible and staff will be able to develop optimum bandaging technique. The project makes use of common personal computers to make the monitoring training system cheap and effective.

2.2 The principle of training device:

It is now well known than an important theory behind the application is Laplace's Law:

$$\mathbf{P} = \frac{\mathbf{TN \times 4630}}{\mathbf{CW}} \quad \text{(Equation 1)}$$

According to this Law, if the bandaging tension (T) can be kept constant, a gradient pressure (P) will be applied from the foot to the knee as the leg's circumference increases. In a whole process of applying bandage, the bandage's width is fixed, and the layers of bandaging (N) also can be taken as stable number as the pressures will be compared on the same bandaging layer.

To compare different pressure points the following mathematical calculation is required:

There are two positions to be chosen as measurement points, their pressures being P1 and P2 respectively. Firstly,

$$\mathbf{P}_1 = \frac{T_1N_1 \times \mathbf{4630}}{C_1W_1} \quad \text{(Equation 3)}$$

$$\mathbf{P}_2 = \frac{T_2 N_2 \times \mathbf{4630}}{C_2 W_2} \quad \text{(Equation 4)}$$

If tension is supposed to be constant, $T_1=T_2$. With same layer of bandage ($N_1=N_2$), the width of bandage is fixed, $W_1=W_2=W$. Thus, P1 divided by P2 is equal to P1/P2=C2/C1. A training device has been designed to monitor the bandage tension while the bandage is being applied. The monitoring device consists of a dummy leg connecting to a computer. Having a computer, a practical computer language, Visual Basic 6.0, was used to write code to make the job easier and simpler. In the meantime, the user can record the results they make so that different data can be compared. This would improve the skill of bandaging by the analysis of the results obtained by either user or another colleague.

Chapter 3

3. Research Process:

3.1 Determine suitable sensors to use

In this project, the key point was to measure the pressure produced by the compression bandages. Sensors were used to convert the pressure to a digital value for processing by a computer.

At the beginning of the project, there were two types of sensors suggested for use in this project, namely Air Sensors (Figure 4.1) and Force Sensors (Figure 4.2).

Through the tests, a series of results were obtained (See Table 5.1, 5.2; Figure 5.2, Figure 5.3).

From these results it was decided to use the Force Sensor to measure the pressure of the applied bandage. The Force Sensor has a linear output, is more reliable, does not suffer from air leaks, is simple to interface to other electronic devices and is very robust.

3.2 Determine effectiveness of chosen sensors

Firstly, the precision of the Force sensors was tested (See Table 5.2, Figure 5.2).

Secondly, it was checked whether force sensors worked properly after they are fixed onto the surface of the dummy leg.

3.3 Determine positions and numbers of sensors

A. Determine positions of sensors.

The shape of the human leg varies (is not a perfect circle), and everybody has different shape of legs. Hence it was required to determine if there was a "best" position for the sensors.

B. Determine numbers of sensors

To show the gradient pressure, at least two points of pressure measurement needed to be used. It was decided to use four sensors to allow greater flexibility.

3.4 Produce computer interface and software

To enable the output from the force sensors to be used by a computer program they would need to be digitised. This was done using a PICO ADC-16 high-resolution 8-channel analogue to digital converter. To make it work, some necessary support software for the ADC-16 data logger from Pico technology had to be downloaded, and the computer language-Visual Basic 6.0 used to write code for the program. In this computer interface, the display was designed to be more active and interesting, and this makes manipulating of the training easier. (See the code and window display)

3.5 Produce prototype dummy leg

To function correctly the bandage training device had to have a realistic dummy leg. The manufacture of a hollow dummy leg was undertaken by the local orthopaedic rehabilitation centre. The final leg was modelled on the shape of an "average" leg.

To ease the assembly of the sensors and wiring the leg was made hollow. With the dummy leg there were four holes that are made on the surface of the leg. Four sensors were put on the holes. The diameters of positions of the four holes were ∅26.5, ∅30.5 mm, ∅32.2 mm, and ∅39.5 mm respectively.

3.6 Trial of completed prototype

Once the prototype bandage training device (Figure 6.1, Figure 6.2) was completed clinical staff would try out the device to see if it functioned correctly. During this trial users would be encouraged to record their "training" results and any comments regarding the training device. This data would be used in the analysis phase of the project.

3.7 Evaluation of trial results

According to data that would be obtained from the tests changes to the device would be made, some helpful advice re: “bandaging technique” may be included in the program, required improvement to the device made, etc.

Chapter 4

4. Tools and devices:

4.1 Air and Force sensors

The sensors used to measure bandage pressures would need to be accurate, reliable, robust and small. The precision of the sensors was also very critical for acquiring pressures. Prior to commencing the design of a prototype-training device it was necessary to choose a sensor to detect the bandage pressure.

Two kinds of sensors were been considered for use in the project at first. One was an air sensor; the other was a Force sensor.

The air filled sensor tested was a small air filled device normally used in paediatrics for apnoea monitoring. The sensor has a sponge filling used to maintain the shape of the device and reduce discomfort to the patient.

Figure 4.1 Apnoea pneumatic pressure sensors

The solid-state force sensor chosen was a Honeywell FSG 15 NIA device (Brief specification given in Appendix D for full details see http://content.honeywell.com). It has many advantages (See 5.2.3).

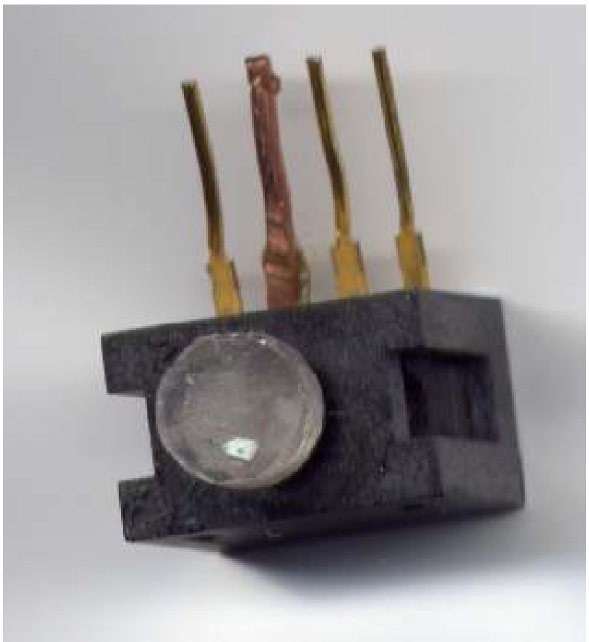


Figure 4.2 Honeywell Force Sensor

4.2 Testing Air Sensor

4.2.1 A cylinder

To test the accuracy, reliability and usability of the air sensors, a plastic cylinder 50-mm diameter and 1500 mm height (See figure 4.3) was used. The air sensors were placed in the bottom of the cylinder and water was poured over them (see section 5.1 for test method and results).

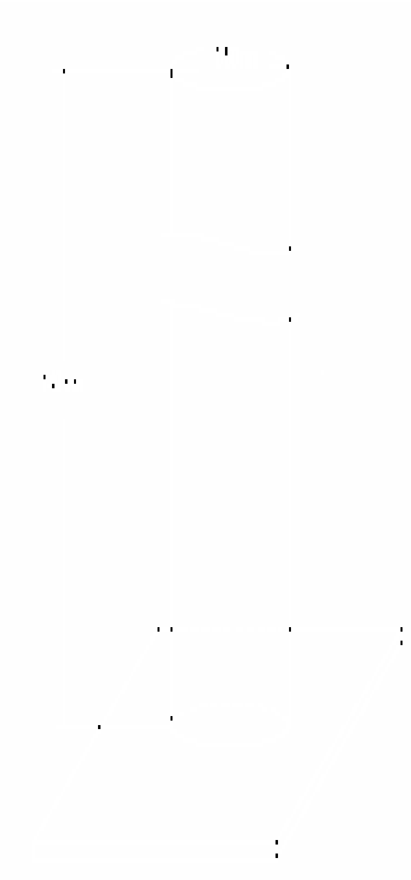


Figure 4.3 a ∅ 5omm X 150omm Plastic cylinder

4.3 Pressure transducer system

To monitor the output of the air sensors, a 4 channels pressure transducer system made by the R&D section of Medical Physics was used. This displayed the output of the air sensors in mmHg.

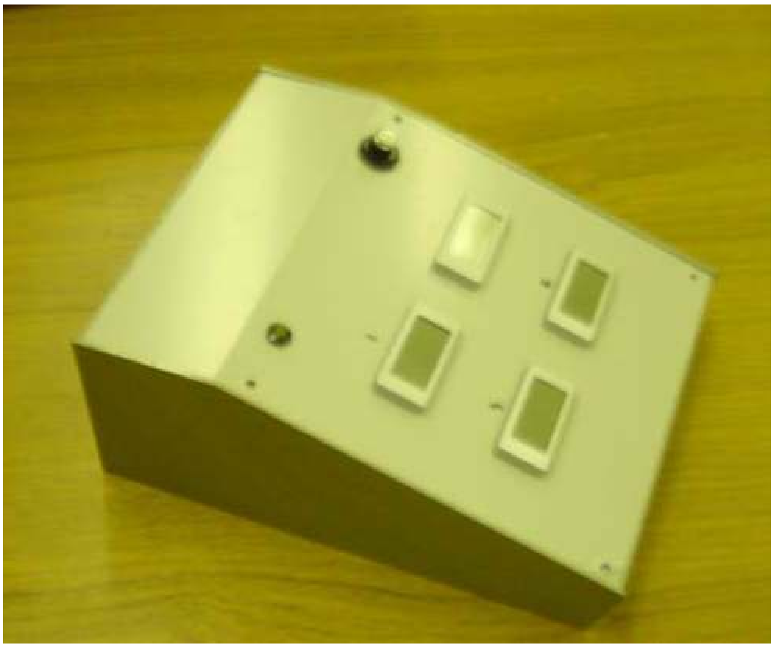


Figure 4.4 Pressure transducer system with four displays

4.4 Metric weight

A set of metric weight units from 1g to 30g were applied to the force sensors. These were to check the relationship between real pressures applied on the Force sensors and their electrical output.

Figure 4.5 Metric Weights

4.5 A dual display

This is another device made by the R&D section of Medical Physics to display the output from two Force Sensors.

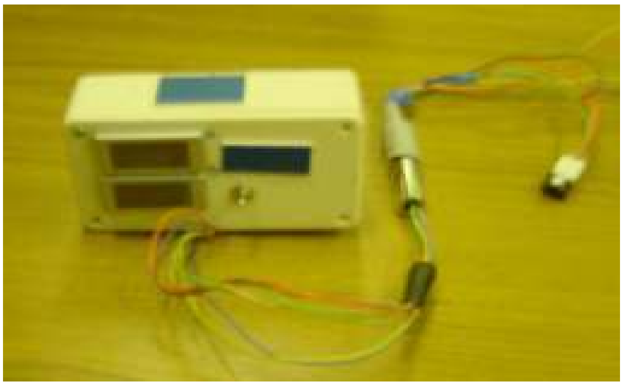


Figure 4.6 A dual display

4.6 A plastic column with different radius

This was used to test the output of the force sensors due to differing leg radii and bandage tension.

Figure 4.7 plastic column with different radius

4.7 Sphygmomanometer and bladder

To check the effect of different radius of column, a Sphygmomanometer and bladder were used to apply an even pressure around the column.

4.8 DC battery

The final sensor and interface electronics would have to be powered from a battery. For economic reason, during the process of working with the project, a laboratory DC power supply was used to supply a stable power of 5 volt instead of a battery.

Figure 4.8 A laboratory DC power

4.9 ADC-16 data logger

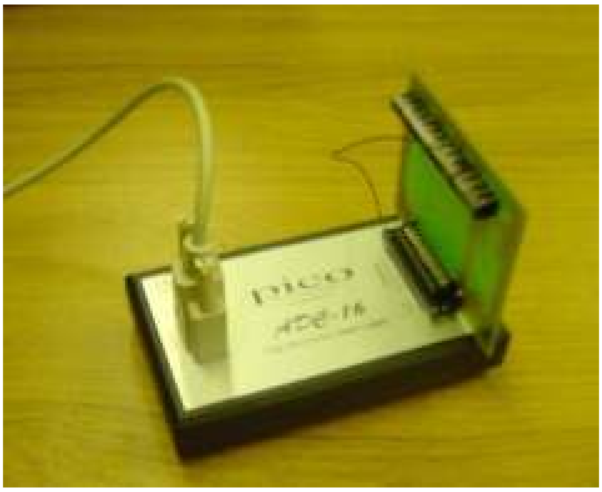


Figure 4.9 ADC-16 high-resolution data logger

The picture in figure 4.9 shows a multi-channel electronic data logger, Pico Technology's ADC-16 high-resolution data logger, which has 8 input channels. It converts the electronic signals from the sensors into a 16 bit code for use by a computer.

Before connecting with this device to a personal computer, support software from Pico Technology had to be installed (Appendix B).

4.10 A dummy leg

This was a normal dummy leg used in the prototype training device; four Force Sensors are put onto the leg's surface. This has already been described on page 22.

Figure 4.10 a dummy leg

4.11 Compression bandage

A long stretch, elastic bandage with a series of many identical squares marked along its length. This was used to do tests on the dummy leg. When the bandage stretches, if the widths of squares on the bandage are equal, the bandage tension is regarded as approximately constant.

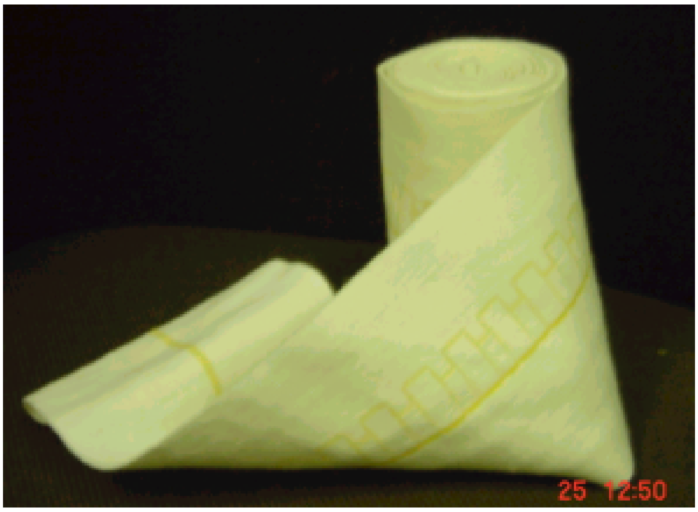


Figure 4.11 Compression bandage

4.12 Computer

To get a display for the sensor readings and to develop the required training interface a personal computer is required. To install Pico software and run visual basic 6.0 properly, the requirement of a personal computer was a 486 processor or above.

Chapter 5

5. The methods, results and analyses:

To check whether pressures obtained on the monitor really reflected the pressures produced by the air sensors. If so, this would mean that the air sensors were viable in this project.

5.1 To test the air sensors

To test that the air sensor are robust and reliable and that they can measure pressures with repeatable accuracy the sensors were placed in a long cylinder (see figure 4.3) and water poured over them to varying depth to simulate varying pressure.

5.1.1 The methods

First, the air sensors (Figure 4.1) were connected with the electronic device with four screens display (Figure 4.4). Then the air sensors were put into the bottom of plastic tube (Figure 4.3). Finally, water was poured in step by step, noting taking the readings shown in the four displays as the height of water rose. The process was repeated with the remaining sensors.

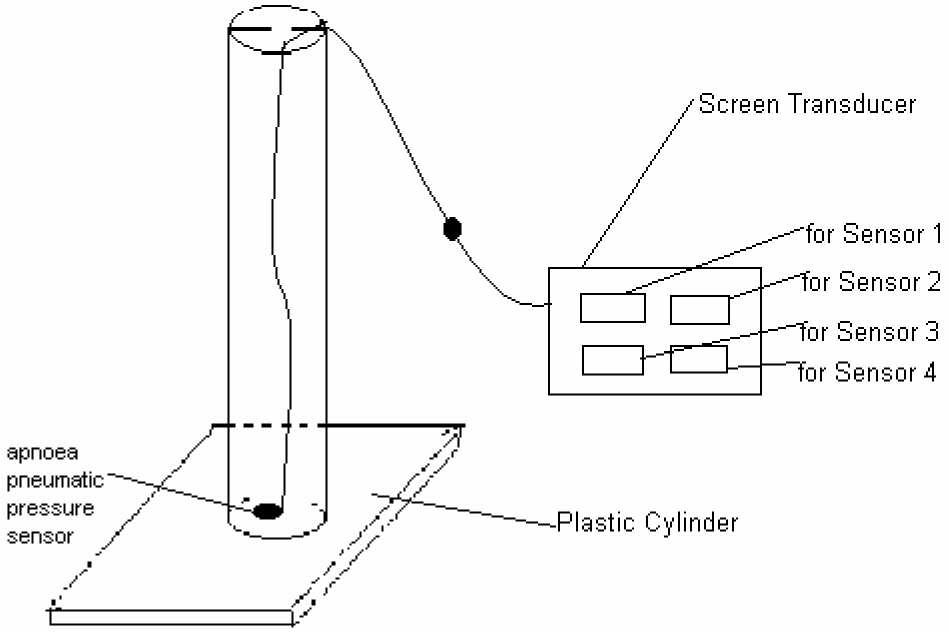


Figure 5.1 Drawing of air sensors test.

5.1.2 The results

H2O (cm)	Sensor 1 (mmHg)	Sensor 2 (mmHg)	Sensor 3 (mmHg)	Sensor 4 (mmHg)
0	-5.8	4.2	0.1	0.2
10	0	10.3	0.1	0.2
20	4.0	16.7	1.4	2.6
30	7.4	19.7	4.7	5.3
40	10.4	22.7	7.9	7.8
50	14.5	25.8	11.3	10.3
60	17.6	29.0	14.3	14.5
70	21.7	33.1	19.1	18.1
80	26.1	37.6	23.1	22.2
90	31.4	41.4	28.4	27.3
100	36.4	47.3	33.2	32.5
110	35.4	45.9	32.9	33.5
120	35.0	44.0	31.8	31.0
130	33.6	42.1	29.7	28.8
140	31.9	41.0	27.5	26.2

Table 5.1 Pressures of air sensors are measured by adding water into cylinder.
(Units are voltages displayed on computer)

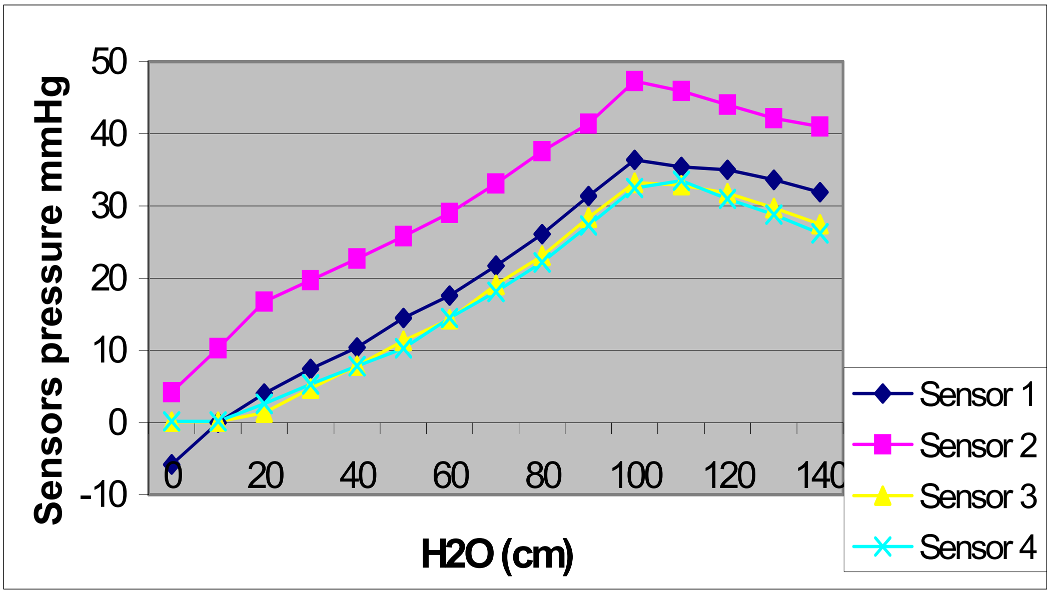


Figure 5.2 The variation of the four air sensors with the height of water increases in cylinder

From the figure (6.1), it can be seen that pressure increases as height of water in cylinder raises until 110 cm, then the pressure falls down dramatically. In addition, it was found that the measured pressures fell down slowly with time.

5.1.3 The analysis

Through the test, it was found that there were many problems when it was used (Figure 5.2, table 5.1):

A. The pressures did not change linearly as applied water height increases. Although pressures increased steadily first, they dropped suddenly at a water height of around 100 cm.

B. There should be a suitable volume of air in the air sensors before they are used. The quantity of air in the sensors affects the measurement results, as the sensor needs air to transfer the pressure. For example, if there is no air in it, data cannot be obtained. Otherwise, if it accepts too much air, the existing air pressure will result in large change.

C. Testing was very difficult due to air leaking out of the measuring system. Numerous attempts were made to stop these air leaks but none proved totally successful and that the problem of air leaks would need to be solved if these types of sensors were to be used in the final system.

D. Due to the above unrepeatable tests, measurements were very difficult to make.

E. The sensors are made of soft plastic surface and are easily damaged.

5.2 To test the Force sensors

5.2.1 The methods

The first step was similar to the test of the air sensors, connecting the force sensors with the dual display. The weight pieces were then put on the surface of the Force sensors one by one from 10 g to 100 g (Figure 4.5), recording the data each time.

5.2.2 The results

Applied Weight (g)	Sensor 1	Sensor 2
0	14	0
1	15	2
2	16	3
3	18	4
4	19	5
5	20	6
6	21	7
7	22	8
8	23	10
9	24	11
10	26	12
11	27	13
12	28	14
13	30	15
14	31	16

Table 5.2 The measured pressures of the Force Sensors under an applied weight
(Units are just numbers which are related to the sensor output)

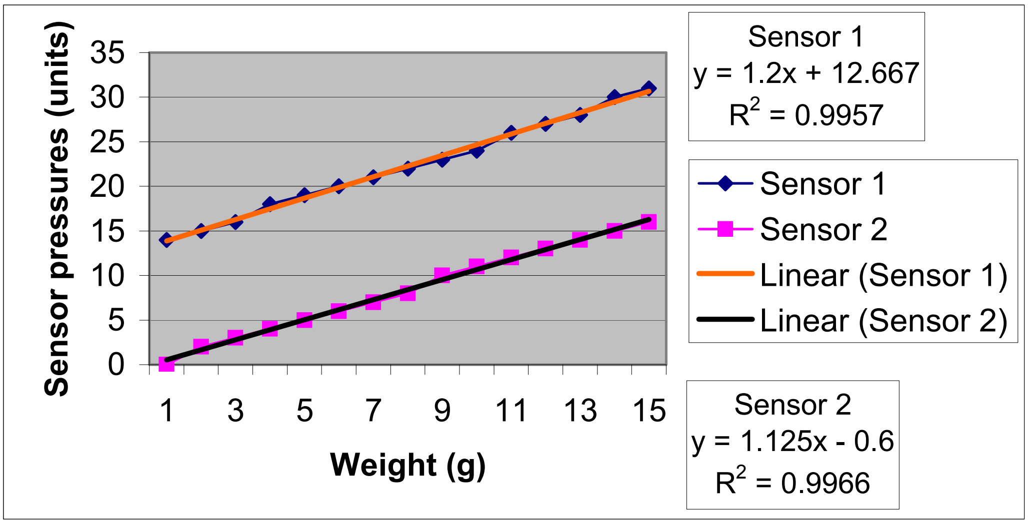


Figure 5.3 the tendency of pressure as applied weight increases
(Units are just numbers which are related to the sensor output)

5.2.3 The analysis

From the figure 5.3, (liner (sensor1): y=1.2x+12.667, R2=0.9957; liner (sensor2): y=1.125x-0.6, R2=0.9966), taking into account experimental error, the pressure increases linearly with the applied pressure.

By comparing to the above tests, it appears that the Force sensors have many advantages:

- Good linear relationship between sensor pressure and applied weight.
- Sensitivity to pressure changes.
- Reliable and not be easily broken.
- High output signal, which means the sensors output will not need to be amplified.
- Simple to use and calibrate.

Finally, the Force sensors were chosen for use in the project.

5.3 The effect of different radius on leg pressures

5.3.1 The methods

Firstly, three Force sensors were put onto the surface of the column randomly, at radii of 5.85 cm, 6.15 cm and 6.30 cm respectively. The sensors were connected to the monitor, recording each of the three sensor readings without any pressure on the sensors.

Then the column was wrapped with the bladder of the Sphygmomanometer. Air was applied into bladder. Three readings of pressure from the three sensors were obtained from the monitor.

Finally, repeating above process and getting 10 sets of data from the monitor as applying more air into bladder by 10 mmHg each time.

5.3.2 The results

Sphg (mmHg)	Position 1	Position 2	Position 3
0	2	0	0
10	11	9	11
20	21	22	19
30	30	31	29
40	39	41	39
50	51	49	51
60	60	58	62
70	71	70	71
80	81	81	79
90	89	91	91
100	98	101	102

Table 5.3 Pressures in three points with different radius
(Units are voltages displayed on computer)

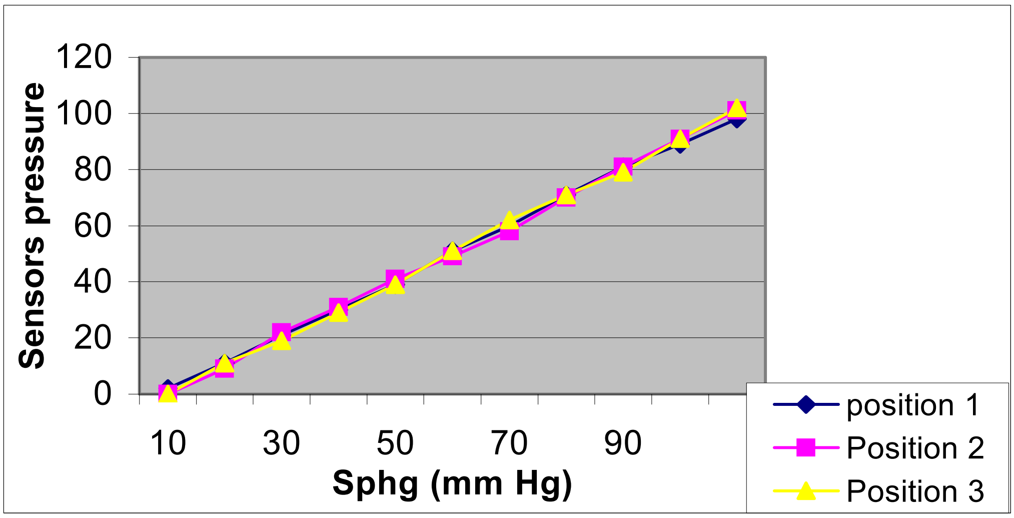


Figure 5.4 pressures in three points with different radius

5.3.3 The analysis

The result given in table 5.3 shows that, as expected, the diameter/curve of leg does not affect applied pressures.

5.4 Connecting the sensors with a computer

The materials and ideas for the project were now ready. Before writing any software, the sensors, ADC-16 high-resolution data logger and a computer had to be connected.

First of all, to obtain the values from sensors, the ADC-16 data logger was used. Its support software therefore had to be installed.

Secondly, the sensors and the computer were connected through the ADC-16 data logger and its correct operation checked.

Another piece of software (Visual Basic 6.0), was installed on to computer. This software could be used to build up a visual computer interface that user could control easily.

Finally, the computer codes were written.

5.5 Writing code by Visual Basic 6.0

Using Visual Basic 6.0, the codes were completed (see 5.5). There is also CD containing this code attached to this thesis (see Appendix C).

The abundance of computers in the modern work place, and the common knowledge of their operation by most educated people, makes computerization of certain tasks some work easier and more convenient.

This project employed a computer to perform the function of measuring the compression bandage pressure applied by medical staff, show the results and draw its picture, so the medical staff could compare the results they or others have obtained.

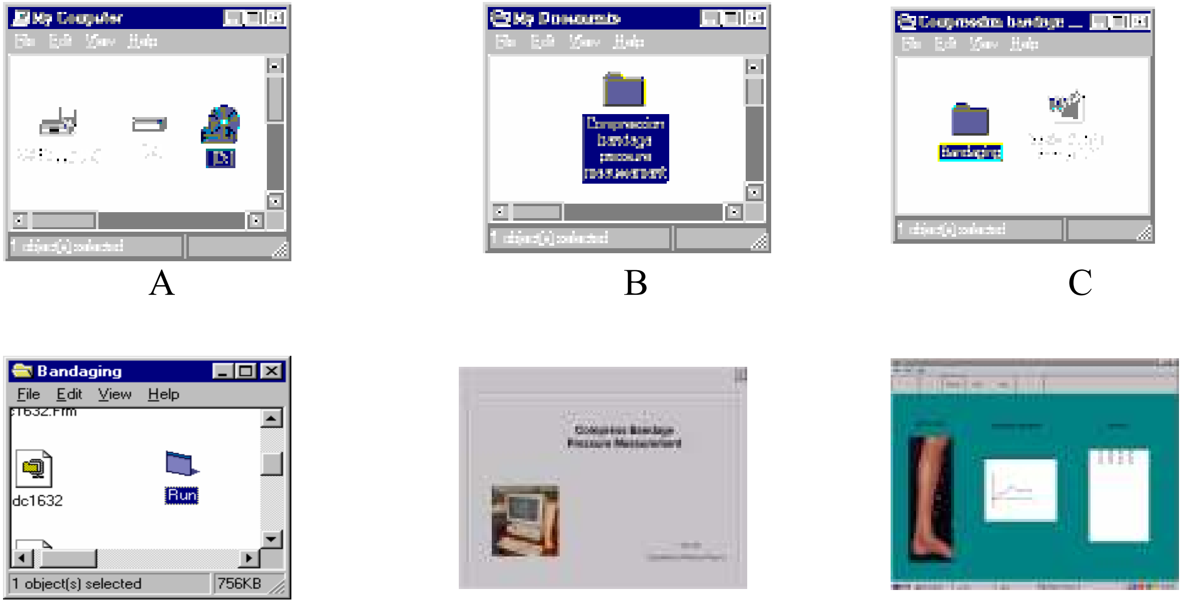
To practise this idea, first some material or machines to connect the sensors on the dummy leg with the computer had to be used. The ADC-16 high-resolution data logger (Figure 4.9), produced by Pico technology limited, was chosen (see Appendix E). Through the logger, electrical signals were transferred to data information from sensors to a computer. In addition, the software of Pico Technology was downloaded to support the function.

The largest and most important task was how to get a computer to accept and analyse these signals. This meant a reasonable amount computer programming was required. Computer experts may advise that there are many sorts of computer software programmes available to carry out this task, however the lack of any software programming experience meant that some programming had to be learnt. This was useful for the job at hand and was not too difficult. The end program had to be easy and simple to use by people without extensive programming knowledge. The process took approximately three months, learning to set up computer interfaces and write codes. Visual Basic 6.0, How to program (Deitel, H.M., et al), has been proved as a very efficiency and simple computer program for this task.

In this program, window interfaces were setup and related codes written. There were two interfaces that could be seen and operated by the users. First one was the Entry form of the software (Figure 5.4), which shows the name of the project, producer and the department. The next, and main one, was the Monitor form (Figure 5.5, Figure 5.6). In the middle of this interface, pressures obtained from the dummy leg were shown with a picture. Pressure graph (labeled as “pressure graphic” on the screen) was drawn according to the pressures obtained. In addition, there was a record list for users recording the results. On the top of this there are two rows of buttons. The upper was very common, like those in any software windows. There were File, View and Help. The second was a set of control buttons, six in total, which were Run, Start, Record, Clear, Stop and Exit.

For running these interfaces, programming codes were shown following the interfaces (Page 48 - 67). In addition, there is a CD attached on the back of the thesis, which is an electronic copy of my project.

So far, everything was ready. The following figure (figure 5.5) gives a simple introduction to run the software. First, put the CD into D driver of the computer, then double click the label of My Computer in a computer, picture A will be shown, next open the labels with deep coloured from picture A to D one by one. Finally, the main windows, E (figure 5.6) and F (figure 5.7, figure 8) are opened. A to D show the normal way to open a file or software in computer. The next stage of this project is described in detail in E and F.



A B C

D E F

Figure 5.5 Introduction for running the software

Compress Bandage
Pressure Measurement

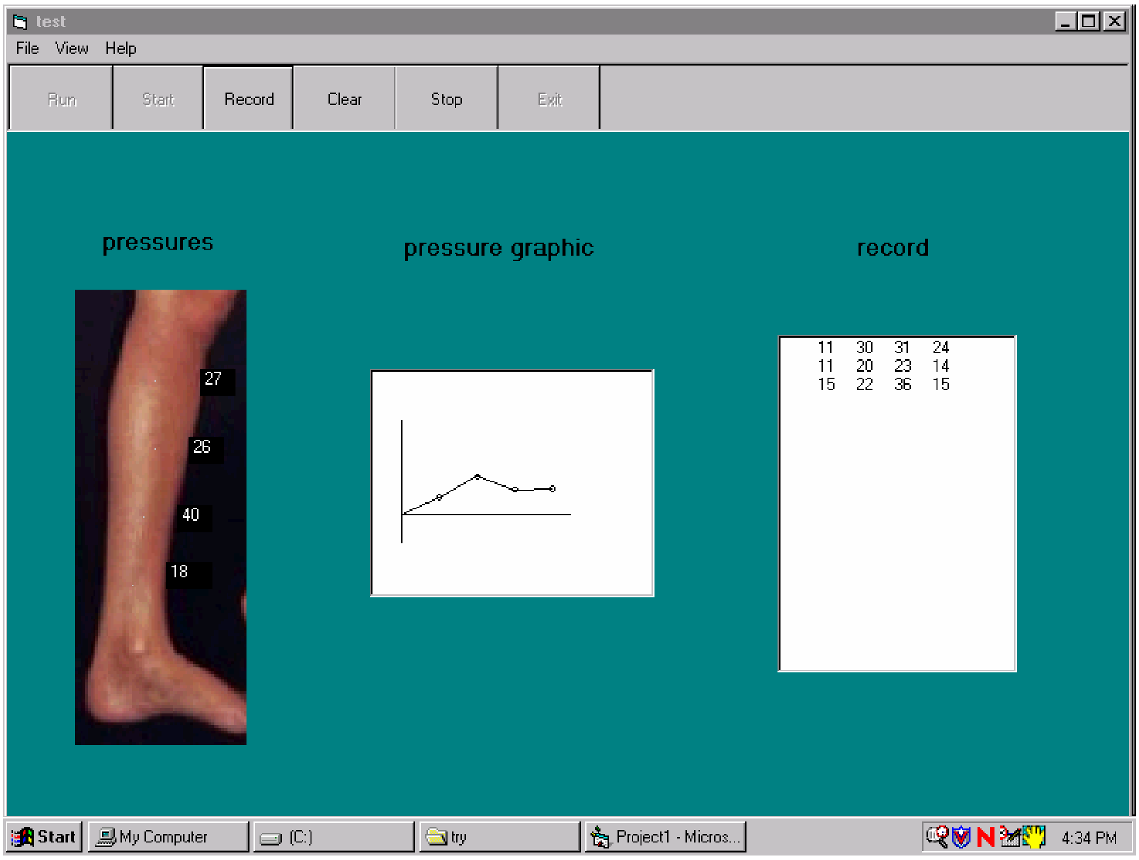
Tao WU

Department of Medical Physics

Figure 5.6 Entry form of the software

The above screen is shown upon opening the Compression Bandage Pressure Measurement program. It includes the name of the project – compression bandage pressure measurement (for chronic venous leg ulcers), the name and the department of a producer and a photo.

Double clicking on the photo on the screen, main control screen (F), monitor form of the software, is followed by the screen shown in Figure 5.5.



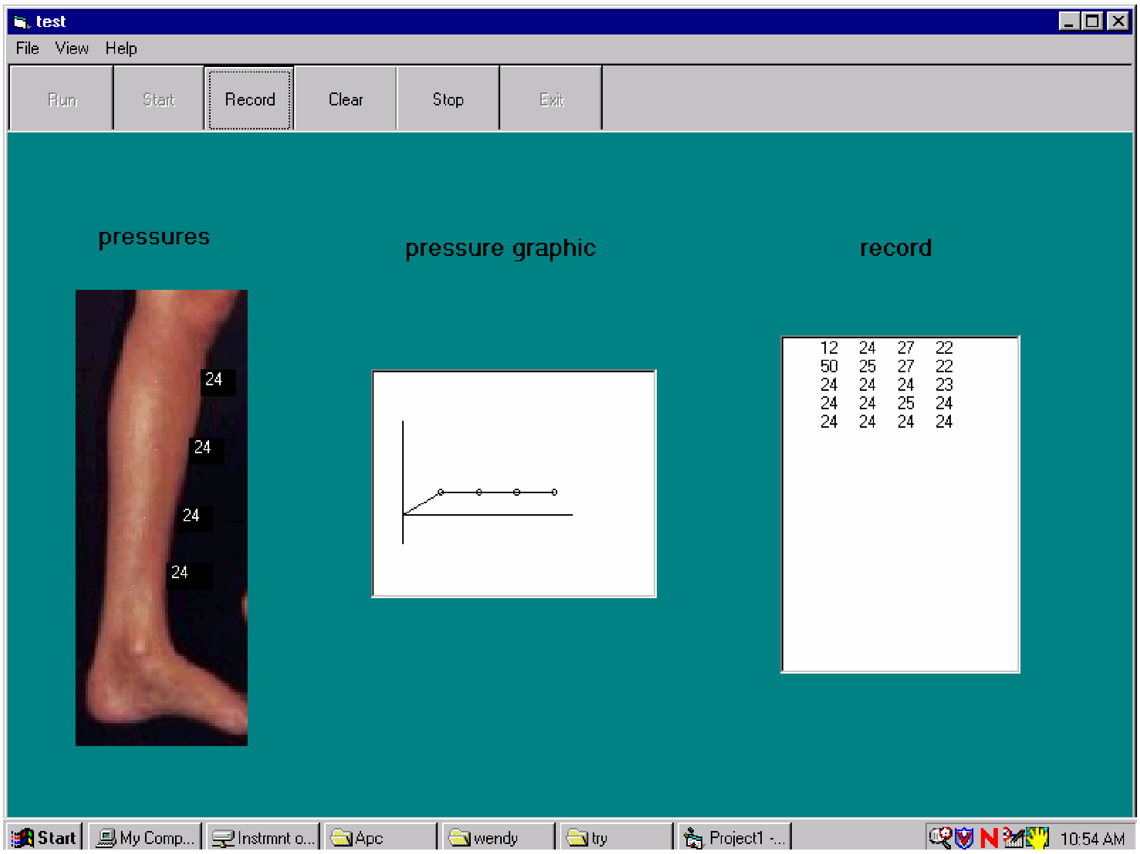
```
11  30  31  24
11  20  23  14
15  22  36  15
```

Figure 5.7 Monitor form1 of the software

For figure 5.7 and figure 5.8, in main areas (blue colour), there are three parts, which are called pressures, pressure graphic and record.

In the pressures along the leg, the four pressures form the ankle to the knee reflect the real bandage pressures on the dummy leg as time changes when applying compression bandages on it. The pressure graphic gives related four data in axis system in real time, which makes it easy to compare the value. For the record, it can record every measurement when a bandage is applied. For instance, after a trainer applies the first layer of bandage, he or she can record it. They may then record again after second, third layer or more layers as desired. Or else a few people can receive training and record the results at same time. This is helpful for comparison of their results.

In figure 5.7, the program recorded three groups of data obtained by one person who applied bandages three times with one layer, while the pressures and pressure graphic sections showed latest result (the third row in record). In the first row, the pressures change from 11 to 31, form 11 to 23 in the second one and 15 to 36 in last one.



```
12   24   27   22
50   25   27   22
24   24   24   23
24   24   25   24
24   24   24   24
```

Figure 5.8 Monitor form2 of the software

In figure 5.8, the record stored five groups of pressures obtained by 5 users, while again in pressures and pressure graphic last results obtained by last person were shown. Obviously, of these, only the last row is ideal pressure, because the pressures are same in each measurement point of the leg (The value being 24).

Chapter 6

6.1 Trial of completed prototype:

The foundation of compression bandage pressure measurement was now ready. After each piece of equipment had been connected properly (Figure 6.1, Figure 6.2) and supported software was installed and tested with it started.

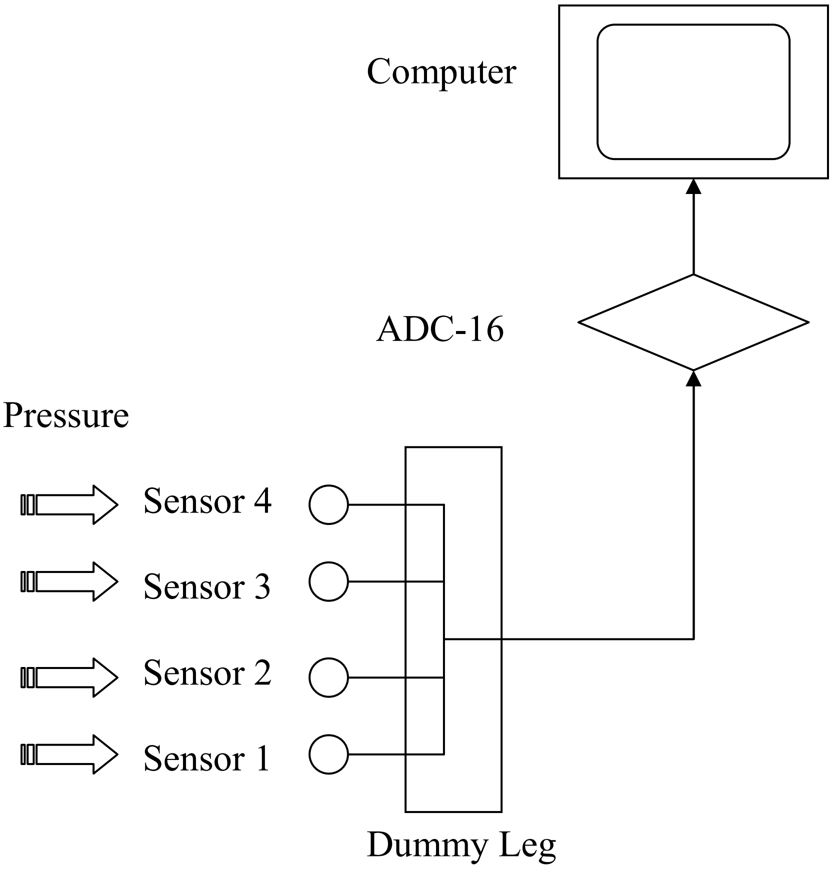


Figure 6.1 Diagram of compression bandage pressure measurement system

Figure 6.2 photo of the compression bandage pressure measurement system

6.2 .Evaluation of trail results:

6.2.1 Methods

Two groups of volunteers, non-experienced and experienced people at applying bandage, took part in the test.

First, ten volunteers without any bandaging experience applied bandage on the dummy leg. Before they applied bandage, a guide of how to do bandage and how to manage keeping tension of the bandage stable was shown to them.

Then a few professional clinic staff, trained in applying bandages performed the same task.

6.2.2 Results

6.2.2.1 No-experienced subjects

10 people without any experience in bandaging were invited to apply the compression bandage on the dummy leg. Before hand, a simple introduction and demonstration performance were given. They were told to keep the bandage tension as stable as they could, but no particular pressures were demanded. They were then allowed to start. The collection of data was as below.

Numbers	1	2	3	4	5	6	7	8	9	10
sensor1	12	18	19	16	13	14	17	12	5	9
sensor2	14	16	13	16	12	14	14	13	7	12
sensor3	17	21	19	14	16	17	14	19	7	13
sensor4	14	18	17	11	15	20	15	14	5	13
Mean	14.25	18.25	17	14.25	14	16.25	15	14.5	6	11.75
s.d.	2.061553	2.061553	2.828427	2.362908	1.825742	2.872281	1.414214	3.109126	1.154701	1.892969
%s.d. error	14.46704	11.29618	16.63781	16.58181	13.04101	17.67558	9.42809	21.44225	19.24501	16.11038

Table 6.1 Pressures applied by not-experienced subjects
(Units are voltages displayed on computer)

From the results of table 7.1, figure 7.1 was drawn.

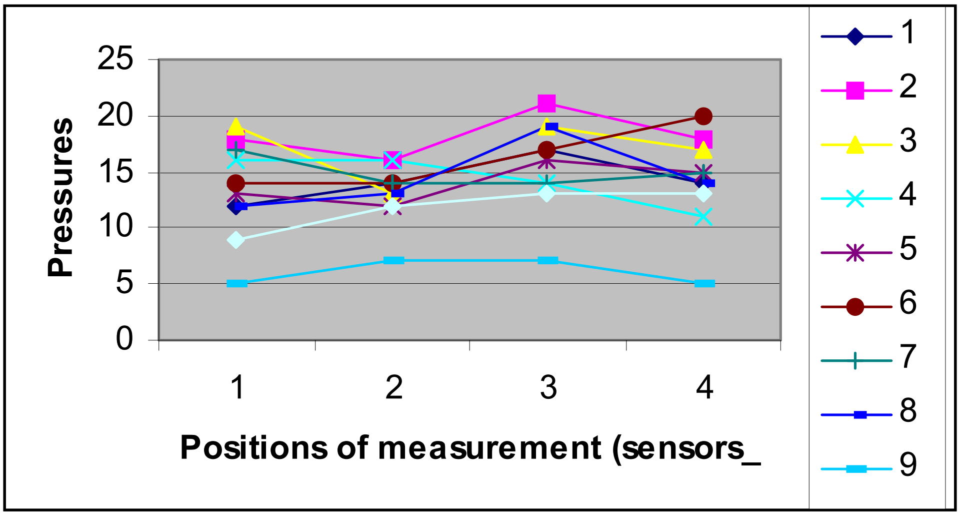


Figure 6.3 Pressures applied by not-experienced subjects

In the figure 6.3, the pressures are various at points of sensor 1, sensor 2, sensor 3 and sensor 4 when people without any experienced bandaging skill applied the compression bandage and the results, in the main, demonstrate this fact (bandage not applied with a constant tension). The %s.d. error is between 9.4 and 19.2.

6.2.2.2 Experienced subjects

Numbers	1	2	3	4	5
sensor1	19	21	13	17	5
sensor2	16	21	13	17	5
sensor3	19	23	13	17	5
sensor4	17	23	13	16	5
Mean	17.75	22	13	16.75	5
s.d.	1.5	1.154701	0	0.5	0
%s.d. error	8.450704	5.248639	0	2.985075	0

Table 6.2 Pressures applied by experienced subjects
(Units are voltages displayed on computer)

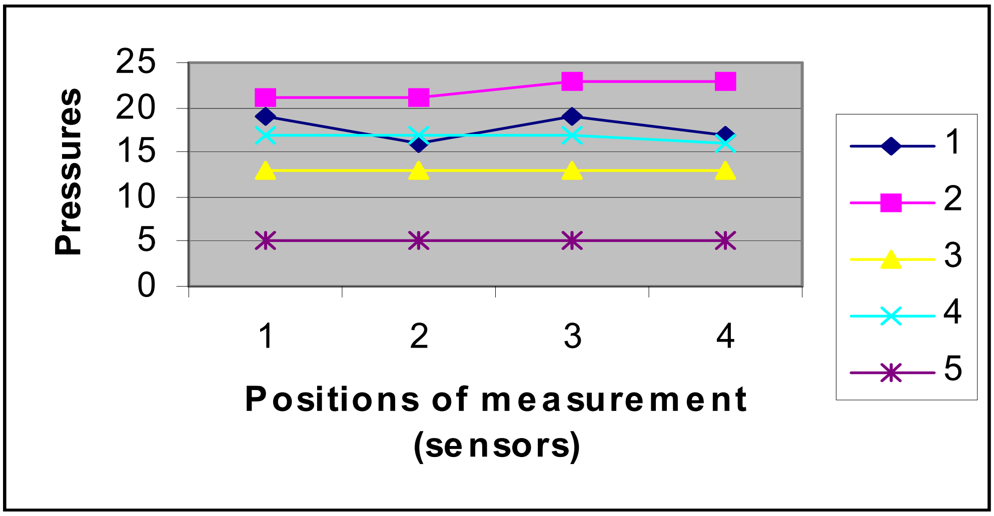


Figure 6.4 Pressures applied by experienced subjects

From the above, it is seen that the experienced subjects could keep the applied pressure constant with the %s.d. error in the range of 0 to 8.5.

The above table shows almost stable pressures from the foot to the knee when the applied bandage tension was kept the same. According to the Laplace's Law and what has been studied before, the pressures were supposed to be graduated - decreasing form the foot up to the knee. So the result contradicts the clinic prediction. The test was repeated many times and the results remained the same. Why? What is the problem? To answer this, a review of what has been done is needed.

6.2.2.3 Non-experienced subjects after training

After a short time training, three of people who had applied the bandage (Table 6.1, Figure 6.3) took a second try. This time when they were applying the bandage they were able keep the square widths on bandage equal quite well. Figure 6.4 shows that the pressures obtained were almost the same. This implied that their skill of applying the bandage had been improved, which was the objective of the training aid. (From table 6.1 the %s.d error for inexperienced subjects with no training is in the range 9.4 to 19.2. The %s.d. error range for inexperienced subjects after training is 2.8 to 8.1. See table 6.3)

Numbers	1	2	3
Sensor 1	18	14	23
Sensor 2	18	14	23
Sensor 3	17	13	20
Sensor 4	18	14	20
Mean	17.75	13.75	21.5
s.d.	0.5	0.5	1.732051
%s.d. error	2.816901	3.636364	8.05605

Table 6.3 Pressures applied by not-experience subjects after training
(Units are voltages displayed on computer)

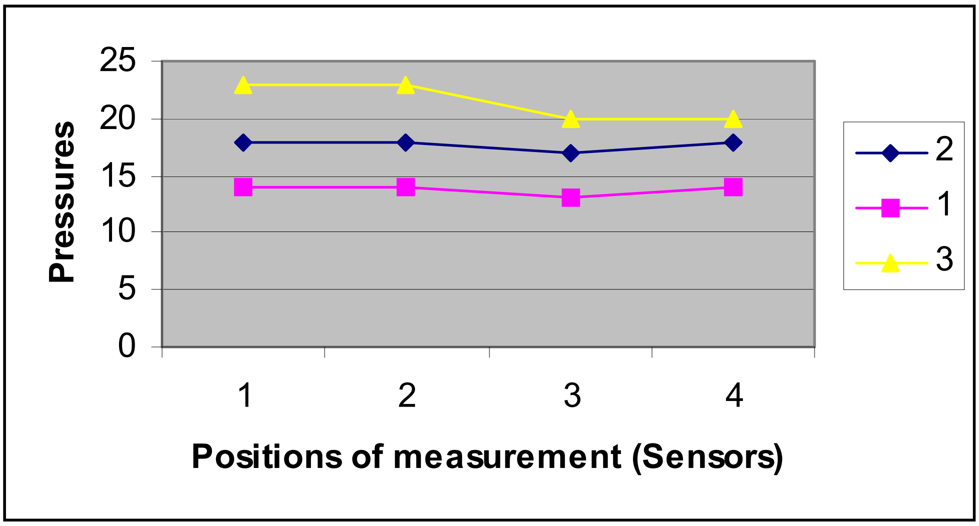


Figure 6.5 Pressures applied by not-experience subjects after training

Chapter 7

7. Review

7.1 The Laplace's Law

So far, many books show it to be a universally accepted truth that Laplace's Law is widely used and correct to be applied in compression bandaging. In clinical practise the Law is main principle to guide clinical staff to apply bandages on human legs. To keep compression bandages tension stable is almost gold standard to achieve the ideal gradual pressures of legs. "At the dawn of the 19th century, M. Laplace presented his theory of capillary attraction to the institute of France." (David. Kass. MD). In origin, the law describes that "the larger the vessel radius, the larger the wall tension required to withstand a given internal fluid pressure." (http://hyperphysics.astr.gsu.edu). From this definition, it is seen that the pressures are due to the wall tension in blood vessels, and the vessels consist of both solid and fluid components. Then, in laboratory, the material of the dummy leg is only solid plastic, the pressure (P) to the model's surface is obtained from:

$$P=\frac{F}{A} \quad \text{(Equation 5)}$$

P ---- the pressure (kg/m^2)

F --- the force applied to the dummy leg (Kg)

A --- the area of the sensor surface (m^2)

Because the tension of the compression bandage is constant, the Force (F) the bandage produces will be same. Meanwhile, the areas of the sensors are same, so the results of the pressures (P) should be same.

However, in this project, no matter whether the Laplace' Law is still suitable to the dummy leg, the key point of applying bandage was to keep same tension. It was already known that if T (tension of compression bandage) is kept stable, an ideal leg pressures on patients will be obtained no matter how other elements of the law change. Thus, in this project, as long as the method could help nurses to practise keeping the tension of the compression bandage unchanged, the aim of the project would have been achieved.

7.2 The effect of radius to the applied pressures

The effect of the leg radius to the applied compression bandage pressures was tested by using a fixed plastic column with different radii. To check the relationship between the radius and applied compression bandage pressure, another tool, a metal column whose radius and curve could be changed, was made (Figure 7.1). Using this tool the radius could be varied and the compression bandage pressure check against varying bandage tension.

Figure 7.1 metal column

7.2.1 Methods

The metal column is fitted with a Force Sensor. The sensor protruded from surface of the column. The test was carried out with the compression bandage applied to the bare sensor (diameter 6.5mm) and then to the sensor with a disk attached (diameter 18mm). This was to determine if surface area of the sensing surface affected the measurements. Each surface was tested with the adjustable column set to three different diameters and 3 bandage tensions. The force sensor output was measured by the computer.

To achieve the same bandage tension, a compression bandage with regular squares was used. The principle was that if the tension of the bandage could be kept same when it was applied, the widths of the squares would be same.

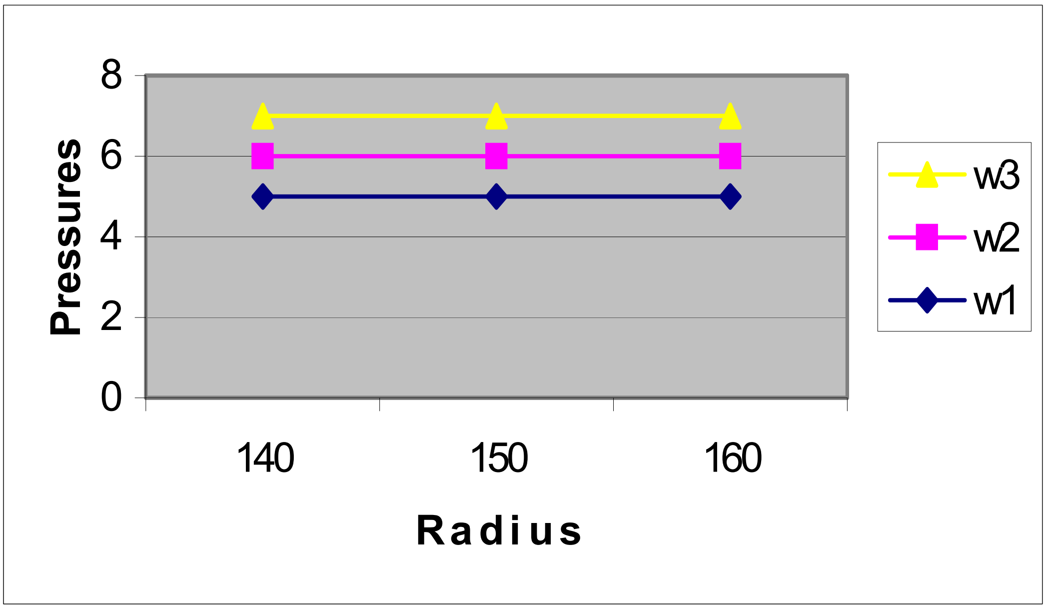
7.2.2 Results

Result 1: Bare Sensor

This result was obtained with a smaller surface of the Force Sensor that is 6.5mm diameter.

Width of square of bandage (mm)	Diameter of column (mm)	Pressures
13.50	140	5
	150	5
	160	5
17.25	140	6
	150	6
	160	6
19.00	140	7
	150	7
	160	7

Table 7.1 pressures on column with different radius
(Units are voltages displayed on computer)



w1=13.50mmm w2=17.25mm w3=19.00mm

Figure 7.2 pressures on columns with different radius

Figure 7.2 shows that if the width of the squares were same (tension is fixed), the pressures of the bandage to the surface of the column with different radius are same. In addition, as the width (tension) increases, the pressure increases. This means the radius of the column does not affect the pressure if the tension does remains constant.

Result 2: Sensor with disk attached.

To avoid the deviation, a big curve surface (18mm diameter) was fixed on the sensor’s surface, so that when the bandage was applied, the force produced could be applied completely on the sensor’s surface, not just a single point. The result was the same as table 7.1. Therefore the area of the sensors does not make any difference to the pressure.

Result 3:

To observe the pressure change form the computer when the bandage is applied twice. On the basis of the result 2, keeping the bandage tension same (the width of square is 13.50mm and 17.25mmm respectively), the results obtained were as below:

width of bandage (mm)	Layers of bandage	Pressures of the point
13.50	1	5
	2	10
017.25	1	6
	2	12

Table 7.2 pressures with double wrapped
(Units are voltages displayed on computer)

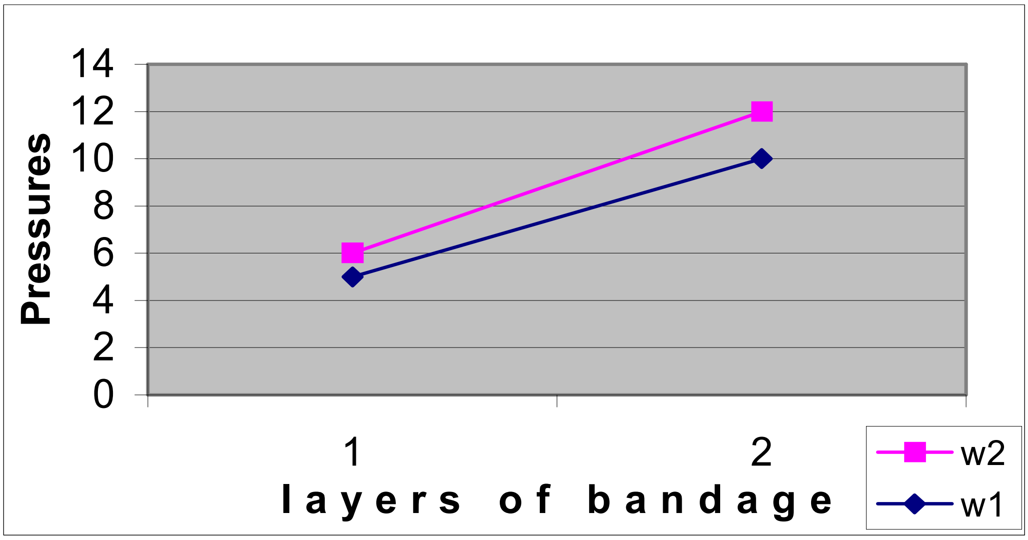


Figure 7.3 pressures with double wrapped

In the figure 7.3, the graphic shows when the bandage was applied two turns at a constant tension, the pressures will be twice the pressures of a single turn.

7.3 Applying compression bandages on the dummy leg

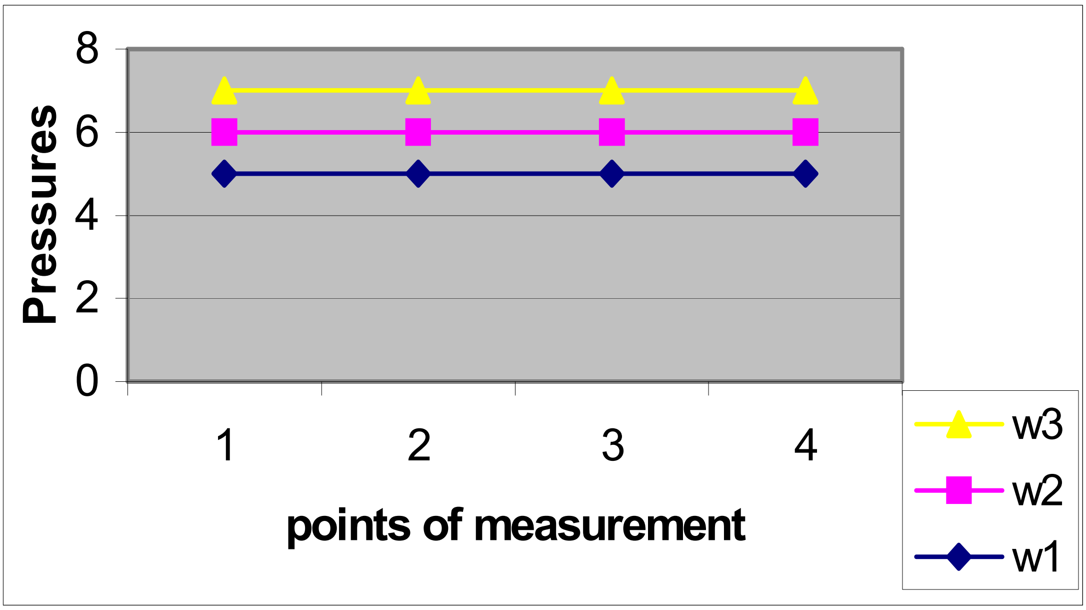
7.3.1 Methods

Using the same dummy leg (Figure 4.10), a compression bandage was applied. From the foot to the knee, the bandage was applied with stable tension. It is known that the tension is fixed if the widths of square on the bandage are same, the bandage tension does not change. A ruler with electric monitor was used to check the square widths.

7.3.2 Results

Width of bandage (mm)	Sensors	Pressures
13.50	1	5
	2	5
	3	5
	4	5
17.25	1	6
	2	6
	3	6
	4	6
19.00	1	7
	2	7
	3	7
	4	7

Table 7.3 Pressures on the dummy leg when keeping stable tension
(Units are voltages displayed on computer)



w1=13.50mm w2=17.25mm w3=19.00mm

Figure 7.4 pressures on the dummy leg when keeping stable tension

This shows that the pressure produced by the compression bandage on the dummy leg did not change when the bandage tension was kept stable. This means that the pressures on the four points of measurement were the same.

7.4 Analysis

Now it is obvious that the results are different between the clinic and the lab as the Laplace's Law is used. There are two major differences that result in this.
The first is that the materials are different. In the clinic the compression bandages are applied on real legs, which have both solid and liquid materials, but in the lab the dummy leg was made of a hard solid plastic. The shape of human leg may be changed when it is wrapped by the compression bandage, while the shape of the plastic leg could not be changed at all when the bandage was used.

The other difference is that, to a real leg, the pressures obtained from the compression bandage are considered to apply on the vessels of the leg. The leg's vessels lie in different depth in the leg and normally the vein vessels lie deeper from the foot to the knee as the leg is becomes thicker. The wall of the vessels will compress to push blood from the high pressure to low pressure when the bandages are applied on the human leg. In contrast, the pressures obtained with the dummy leg just show the force to the leg surface.

Chapter 8

8.Conclusion:

At present, the difference in situation between the clinic and the laboratory has been clarified. Meanwhile, one thing has to be emphasised many times is that the constant compression tension is key point in both clinic and laboratory, although constant tension will results in same pressures on the dummy leg and gradient pressures on human leg respectively.

As a consequence, some changes in this software have to be made. One is that it is not necessary to show the trend of the pressure. Another one is that transferring the digit number from the Pico to an understandable pressure figures is a very complex task, which includes the relationship of shape of leg and depth of vein vessel. This will take time to achieve, so this project will show, on the computer, whether the compression bandage tension is constant. The last result of the software is also shown in the CD.

Chapter 9

9.Recommendation for further work:

To train clinic staff more effectively and actively. Comments about the training system and also related problems about leg ulcers and bandaging should be added to the software.

The relationship between the leg pressure gradient and the depth of the leg's vein vessels should be studied to reveal the difference of leg pressures between real legs and dummy legs when bandages are applied on them.

It is still viable that the program can be used in real leg if suitable sensors could be found to replace the force sensors.

Lastly, investigate the possibility that leg ulcers may be caused by lack of adequate blood flow in the skin due to imbalance of the calf pump and foot pump pressures (see para 1.5).

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Appendix A

A Drawing of the plastic column

(See next page.)

Appendix B

Guide for software installation

Before starting this project with the computer, it must have the following software:

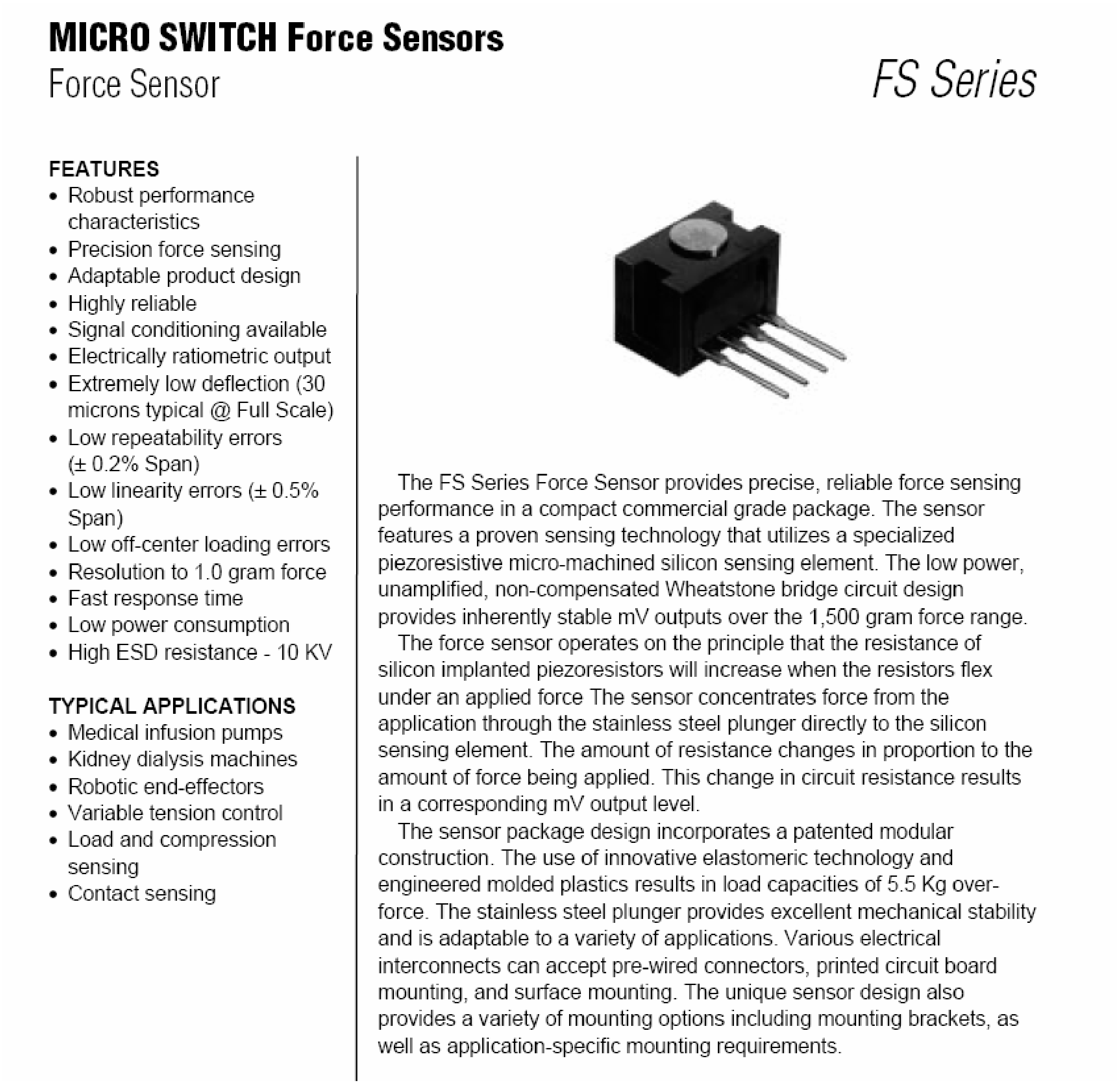
1. Pico technology.
2. Visual Basic 6.0

Appendix C

The codes of compression bandage pressure measurement is attached hereby CD.

Appendix D

Abstract from Honeywell FS Series Data Sheet



MICRO SWITCH Force Sensors

Force Sensor

FS Series

FEATURES

- Robust performance characteristics
- Precision force sensing
- Adaptable product design
- Highly reliable
- Signal conditioning available
- Electrically ratiometric output
- Extremely low deflection (30 microns typical @ Full Scale)
- Low repeatability errors (± 0.2% Span)
- Low linearity errors (± 0.5% Span)
- Low off-center loading errors
- Resolution to 1.0 gram force
- Fast response time
- Low power consumption
- High ESD resistance - 10 KV

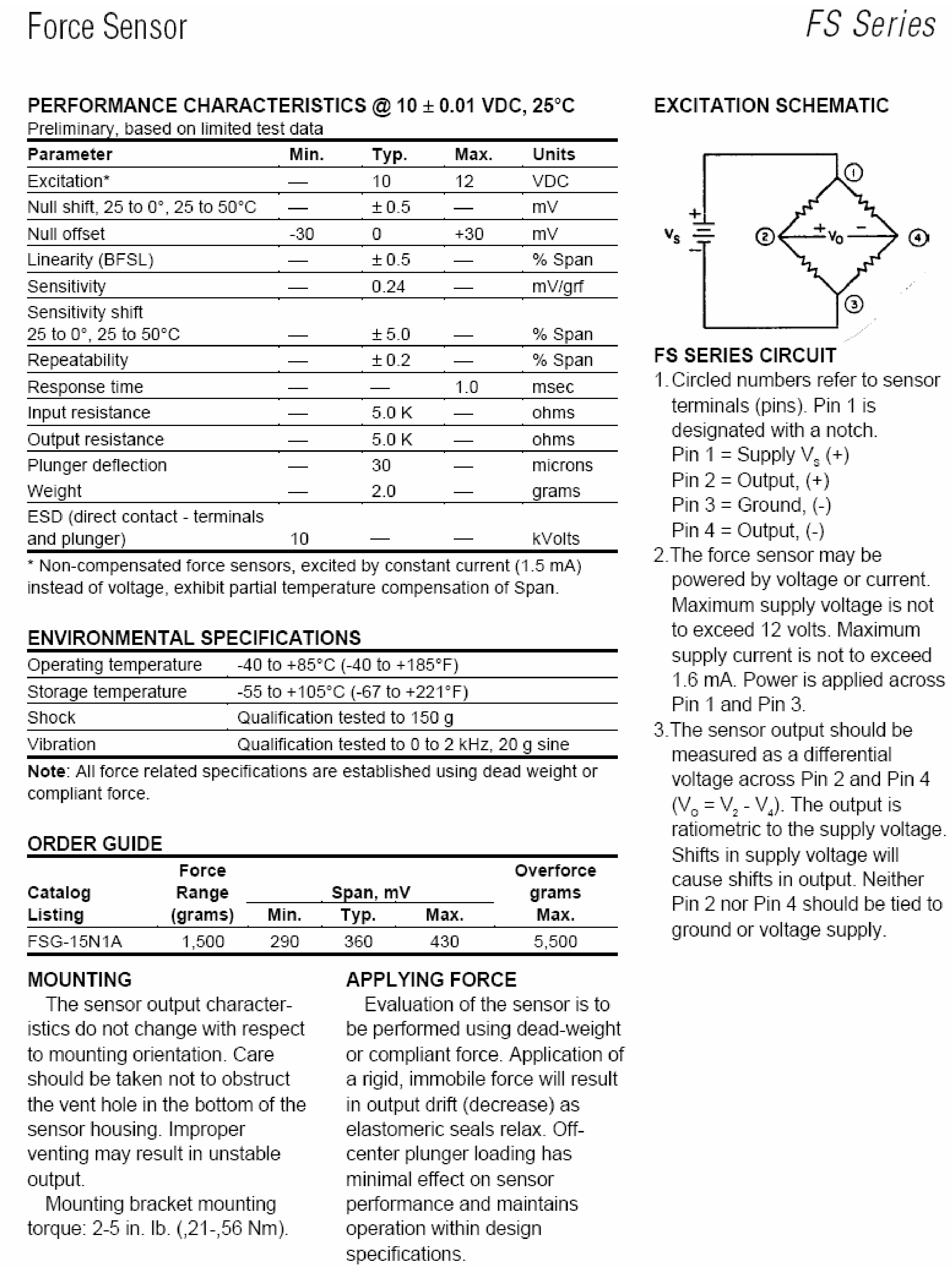
TYPICAL APPLICATIONS

- Medical infusion pumps
- Kidney dialysis machines
- Robotic end-effectors
- Variable tension control
- Load and compression sensing
- Contact sensing

The FS Series Force Sensor provides precise, reliable force sensing performance in a compact commercial grade package. The sensor features a proven sensing technology that utilizes a specialized piezoresistive micro-machined silicon sensing element. The low power, unamplified, non-compensated Wheatstone bridge circuit design provides inherently stable mV outputs over the 1,500 gram force range.

The force sensor operates on the principle that the resistance of silicon implanted piezoresistors will increase when the resistors flex under an applied force The sensor concentrates force from the application through the stainless steel plunger directly to the silicon sensing element. The amount of resistance changes in proportion to the amount of force being applied. This change in circuit resistance results in a corresponding mV output level.

The sensor package design incorporates a patented modular construction. The use of innovative elastomeric technology and engineered molded plastics results in load capacities of 5.5 Kg over-force. The stainless steel plunger provides excellent mechanical stability and is adaptable to a variety of applications. Various electrical interconnects can accept pre-wired connectors, printed circuit board mounting, and surface mounting. The unique sensor design also provides a variety of mounting options including mounting brackets, as well as application-specific mounting requirements.



Force Sensor

FS Series

PERFORMANCE CHARACTERISTICS @ 10 ± 0.01 VDC, 25°C

Preliminary, based on limited test data

Parameter	Min.	Typ.	Max.	Units
Excitation*	—	10	12	VDC
Null shift, 25 to 0°, 25 to 50°C	—	±0.5	—	mV
Null offset	-30	0	+30	mV
Linearity (BFSL)	—	±0.5	—	% Span
Sensitivity	—	0.24	—	mV/grf
Sensitivity shift 25 to 0°, 25 to 50°C	—	±5.0	—	% Span
Repeatability	—	±0.2	—	% Span
Response time	—	—	1.0	msec
Input resistance	—	5.0 K	—	ohms
Output resistance	—	5.0 K	—	ohms
Plunger deflection	—	30	—	microns
Weight	—	2.0	—	grams
ESD (direct contact - terminals and plunger)	10	—	—	kVolts

* Non-compensated force sensors, excited by constant current (1.5 mA) instead of voltage, exhibit partial temperature compensation of Span.

ENVIRONMENTAL SPECIFICATIONS

Operating temperature	-40 to +85°C (-40 to +185°F)
Storage temperature	-55 to +105°C (-67 to +221°F)
Shock	Qualification tested to 150 g
Vibration	Qualification tested to 0 to 2 kHz, 20 g sine

Note: All force related specifications are established using dead weight or compliant force.

ORDER GUIDE

Catalog Listing	Force Range (grams)	Span, mV Min.	Span, mV Typ.	Span, mV Max.	Overforce grams Max.
FSG-15N1A	1,500	290	360	430	5,500

MOUNTING

The sensor output characteristics do not change with respect to mounting orientation. Care should be taken not to obstruct the vent hole in the bottom of the sensor housing. Improper venting may result in unstable output.

Mounting bracket mounting torque: 2-5 in. lb. (,21-,56 Nm).

APPLYING FORCE

Evaluation of the sensor is to be performed using dead-weight or compliant force. Application of a rigid, immobile force will result in output drift (decrease) as elastomeric seals relax. Off-center plunger loading has minimal effect on sensor performance and maintains operation within design specifications.

EXCITATION SCHEMATIC

FS SERIES CIRCUIT

1. Circled numbers refer to sensor terminals (pins). Pin 1 is designated with a notch.
   Pin 1 = Supply V_s (+)
   Pin 2 = Output, (+)
   Pin 3 = Ground, (-)
   Pin 4 = Output, (-)
2. The force sensor may be powered by voltage or current. Maximum supply voltage is not to exceed 12 volts. Maximum supply current is not to exceed 1.6 mA. Power is applied across Pin 1 and Pin 3.
3. The sensor output should be measured as a differential voltage across Pin 2 and Pin 4 ($V_o = V_2 - V_4$). The output is ratiometric to the supply voltage. Shifts in supply voltage will cause shifts in output. Neither Pin 2 nor Pin 4 should be tied to ground or voltage supply.

Appendix E

ADC-16 High resolution data logger

Features

- **High resolution**
- **No power supply required**
- **Compact design**
- **Data Logging software included**

The ADC-16 data logger offers high resolution (16 bits + sign) and is capable of detecting signal changes as small as 40µV. It provides a PC with 8 highly accurate input channels. Pairs of channels can be used differentially to reject noise. Reference outputs can be used to directly power sensors.

An optional terminal board provides screw terminals to simplify connection to the D type connectors.

The ADC-16 can be used with our **signal conditioning** range to enable connection of a wide range of sensors and transducers.

For higher speed, high resolution data loggers see also the **ADC-212 and ADC-216**.

Specification	
No of channels	8
Resolution	16 bit + sign
Input range	±2.5V
Overload protection	±30V
Sampling rate	1.5Hz
Accuracy	0.2%
Input impedance	1M□
Input connector	D25 female
Output connector	D9 male to PC serial port
Outputs	2 (fixed ±5V references)
Supplied software	PicoLog for Windows (3.x, 95/98, NT/2000) Drivers & examples C, Pascal, Delphi, Visual Basic, HP VEE and LabVIEW. A macro is also provided to collect data directly into an Excel spreadsheet

http://www.picotech.com/high-resolution.html