A STUDY ON 3D SPACER FABRIC APPLICATION ON HIP PROTECTORS

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

Hip protectors, act as cushions to shunt the force and energy of the impact away, have been developed for the special needs of elderly. Previous researches on hip protectors focus on its functionality. Various materials, such as foam pads, plastic shields, or a combination of materials, are used to enhance its protective properties. Nevertheless, limited attention is paid on the comfort level and convenience, which are the major concerns of the wearers. This contributes to low acceptance of hip protectors. This consequently shows a need for developing hip protectors those fulfilling needs or wearers from fitting, comfort and aesthetics. To addressing the challenges, this study aims to study hip protectors with a design approach to halve existing problems of current hip protectors.

After investigating several types of protective materials based on their performance and comfort level, 3D spacer fabrics are utilized for developing hip protectors due to its relatively superior physical properties. Then, various apparel technologies, including cutting, edge finishing and sewing, are adopted to optimize the comfort and the appearance of the hip protectors. Both subjective and objective testing is carried out to evaluate the new developed hip protectors. Eventually, a collection of hip protectors is designed with a well balance on its functionality and comfort level.

It is expected that the development of this hip protectors will bring countless benefits to people who are at high risk of falls. In addition, the design approach used can be extended to other potential protective apparel applications, and it also may arouse researchers' or product developers' awareness towards the aesthetics needs. This

hence helps to accelerate the merging of functional technology application with fashion design.

PUBLICATIONS

Conference Paper:

1. W. Y. YIU, L. LI, C. K. CHAN, H. HU, Effect of Top Stitching on 3D Spacer Fabric. 8th International Shibori Symposium.
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2. W. Y. YIU, L. LI, C. K. CHAN, H. HU, Pressure Readings under Hip Protectors.
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CHAPTER 1 INTRODUCTION

1.1. Research background

Elderly are easy to fall and falls are also one of the most common causes of traumatic brain injuries (Sleet, et al., 2008). The risk of having severe injuries after a fall increases with age and most injury-related deaths in are related to falls for cases of elderly. The rates of fall injuries for people aged or aged above 85 years old are four to five times in excess of the rates for people aged between 65 and 74 years old and about 85% of deaths following a fall happen among people aged above 75 years old (Sleet, et al., 2008). Hip fracture following a fall has been a pronounced health concern among the elderly around the world. Falls and hip fractures have led to a significant amount of medical cost in the society and the quality of life of elderly has been reduced after injuries.

In order to reduce the number of injuries and injury-related deaths, external hip protectors have been developed in the market (Kannus & Parkkari, 2007) to shunt the force and energy of the impact away and protect the wearers from injuries. The materials applied on the hip protectors offered in the market are generally foam pads, plastic shields, and a combination of both materials, which are not very comfortable to wear and this problem is getting more serious when the wearers need to wear it for a long period of time for a better protection effect. Also, these materials, including foam pads and plastic shields, are having problems of shape distortion and yellowing after washing, making them not very easy to take care of. Also, the current design of hip protectors is based on the figures of Caucasians. The design of the hip protectors is usually very conservative and may not meet the requirements of local market.

Although hip protectors have been developed, elderly are not willing to wear the hip protectors. The reasons of low acceptance of current hip protectors may involve comfort, convenience and aesthetics of current hip protectors. Therefore, there is a demand of new hip protector design in the market to fill the gap mentioned.

This study is concerned with the development of hip protectors with a design approach and hip protectors with improved comfort, convenience and aesthetics have been produced in this study. Shock absorbing materials have been sourced from the market, and the problems in production regarding cutting, edge finishing and sewing have been investigated. The prototype has been assessed with both objective and subjective testing. The pressure distribution and shock absorbing performance of the hip protectors have been measured. A wear trial and case study of prototype have been carried out and the relationships between different factors of prototype have been evaluated.

1.2. Aims and objectives

The main aim of this study is to develop a collection of hip protectors with a design approach and the principal objectives are

1) To examine the application and performance of different shock absorbing materials in the market.

2) To source and examine the shock absorbing materials in the market.

3) To optimize the applications of 3D spacer fabrics on hip protectors using apparel technologies in terms of cutting, edge finishing and sewing.

4) To evaluate numerous apparel technologies applied on 3D spacer fabrics, including cutting, edge finishing and sewing methods, for improved comfort, convenience and aesthetics for the development of hip protectors.

5) To develop prototype of hip protectors for both men and women with variations in design.

6) To evaluate the performance of prototype using objective and subjective testing.

1.3. Methodology

This study focus on the development of a collection of hip protectors, and this study has been carried out with a design approach to improve their comfort, convenience and aesthetics. First of all, different shock absorbing materials and protective clothing design have been explored. The needs of elderly and the problems with current products have been investigated. Then, different shock absorbing materials have been sourced from the market and their physical properties have been evaluated. The applications of 3D spacer fabrics on hip protectors have been optimized using apparel technologies in terms of cutting, edge finishing and sewing, to improve their performance in terms of comfort, convenience and aesthetics. The prototype has been developed using desired apparel technologies and their performance have been assessed using both objective and subjective testing. The four phases of this study are shown in Figure 1-1. The four phases in this project are listed below outlining methodology of this study.

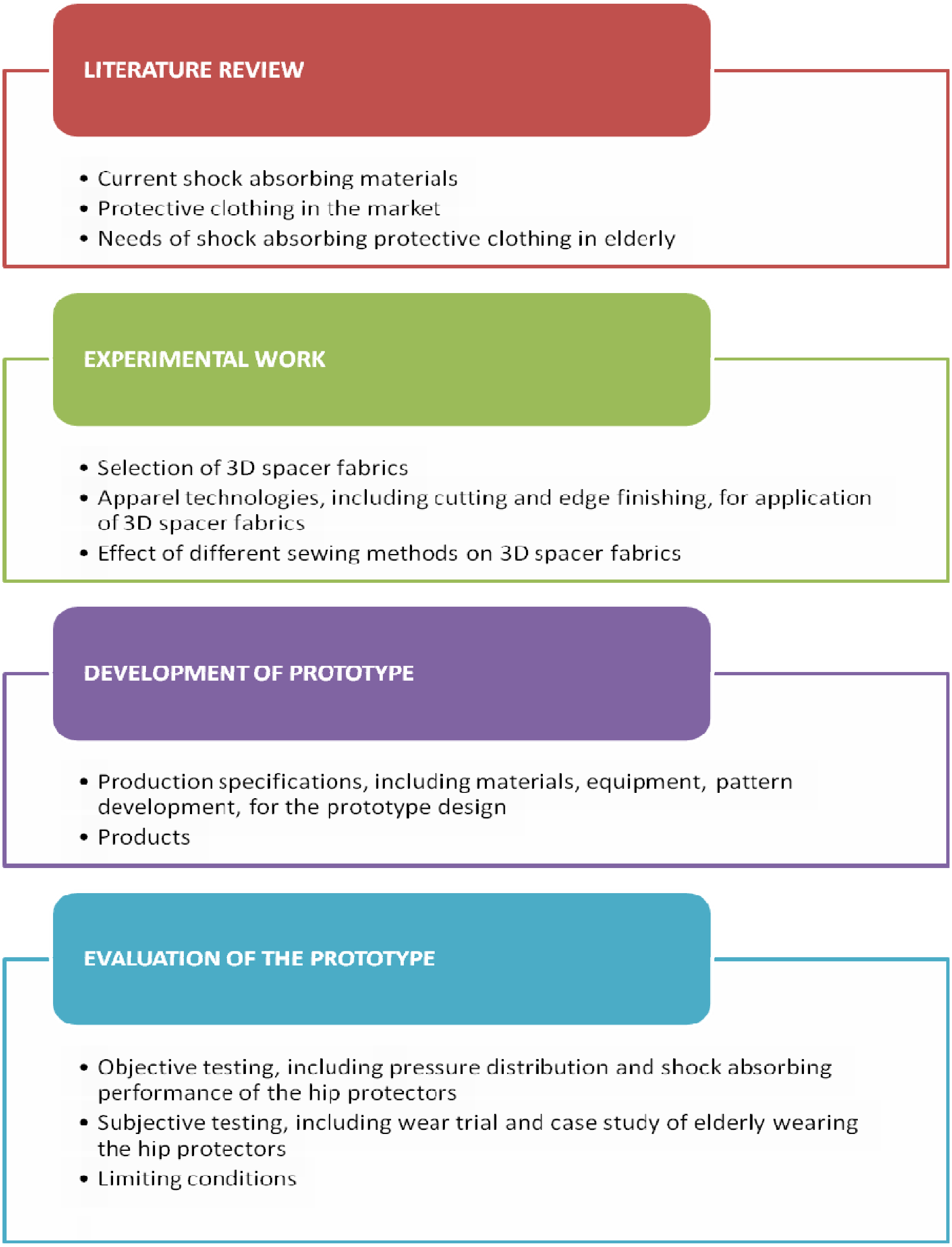


Figure 1-1 Methodology of the study

The shock absorbing materials offered in the market have been explored in the literature review. Assorted protective clothing design in the market and the needs of shock absorbing protective clothing in elderly have been investigated.

Experiments related to the selection of 3D spacer fabrics have been carried out. Numerous apparel technologies, including cutting and edge finishing, for application of 3D spacer fabrics have been evaluated, and the effect of numerous sewing methods on 3D spacer fabrics have been investigated.

From the preliminary study of 3D spacer fabrics and apparel technologies, the development of prototype of hip protectors using 3D spacer fabrics has emerged.

The prototype has been evaluated using both objective and subjective testing. Objective testing, including pressure distribution and shock absorbing performance of the hip protectors has been investigated; and subjective testing, including wear trial and case study of elderly wearing the hip protectors has been explored.

The context of this study includes:

- Literature review of current shock absorbing materials and protective clothing in the market, and the needs of shock absorbing protective clothing in elderly

- Identification and selection of 3D spacer fabrics by physical characterizations.

- Evaluation of apparel technologies for the production of hip protectors with knowledge acquisition for 3D spacer fabrics and design approach.

- Development of prototype of a collection of hip protectors with design approach.

- Evaluation of the prototype by objective testing, including pressure distribution and shock absorbing performance of the hip protectors, and subjective testing, including wear trial and case study of elderly wearing the hip protectors.

1.3.1. Vertical segmentation

This study covers the following vertical segmentations:

- Characterizations of current shock absorbing materials
- Design of protective clothing in the market
- Needs of shock absorbing protective clothing in elderly
- Selection of 3D spacer fabrics
- Development of prototype
- Pressure distribution under hip protectors developed
- Shock absorbing performance of the hip protectors developed
- Wear trial of the hip protectors developed
- Case study of elderly wearing the hip protectors

1.3.2. Horizontal segmentation

This study covers the following horizontal segmentations:

- 3D spacer fabrics production
- Apparel technologies for 3D spacer fabrics applications
- Shock absorbing protective clothing design
- Healthcare for elderly

1.3.3. Primary research

The sources of the primary research of this study have been collected from journals, books and websites. Primary research has been carried out for current shock absorbing materials and protective clothing in the market, and the needs of shock absorbing protective clothing in elderly.

- Literature review on current shock absorbing materials: different materials applied on protective clothing in the market have been summarized and compared in this study.
- Literature review on protective clothing in the market: shock absorbing protective clothing from different brands and price ranges, with different functions and applications have been summarized and compared in this study.
- Literature review on the needs of shock absorbing protective clothing in elderly: the medical issues related to elderly have been investigated and the measures to protect them from injuries have been summarized with their needs of shock absorbing protective clothing.

1.3.4. Secondary research

Secondary research has been carried out based on the information summarized in primary research to further study the production of hip protections using 3D spacer fabrics.

- Characterization and selection of 3D spacer fabrics: twelve samples of 3D spacer fabrics with different structures have been compared for their physical properties. Experiments have been conducted to measure their thicknesses, areal densities, bulk densities and stiches densities for the selection of the 3D spacer fabrics for the development of hip protectors.

- Applications of 3D spacer fabrics on protective clothing: experiments have been carried out to evaluate the performance of apparel technologies on 3D spacer fabrics. Numerous cutting, edge finishing and sewing methods have also been investigated. Cutting and edge finishing method to be applied in the development of hip protectors have been selected based on the subjective assessment by textile students, despite the fact the subjective assessment has been carried out in the form of survey and the feedback has been given based on the subjective assessment of different samples with numerous cutting and edge finishing method applied.

- Development of hip protectors: prototype of assorted styles of hip protectors has been designed different design detail. The properties of prototype of assorted styles of hip protectors have been evaluated by both objective testing and subjective testing in this chapter.

1.3.5. Standard

- Standard Test Method for Thickness of Textile Materials ASTM D1777
- Standard Test Methods for Rubber Properties in Compression ASTM D575
- Motorcyclists' protective clothing against mechanical impact. Requirements and test methods for impact protectors BS EN 1621–1:1998

1.4. Significance of the study

This study can be responsible for knowledge for further development of hip protectors with a design approach. Knowledge related to 3D spacer fabrics application can also be provided for further study on pioneering textile materials. Upon success, hip protectors which are the most comfortable and convenience to wear and with best aesthetics will be produced for the first time in the local market. The medical cost can then be reduced in the society, and the elderly can also have an improved quality of life, confidence, independency and capability to take care of themselves.

1.5. Outline of the study

In chapter 1, background and an overview of this study has been given with detail in aims and objectives, methodology and significance of this study.

In chapter 2, literature review from absorbing materials to protective clothing design, and related medical issues have been summarized in this chapter. Assorted protective clothing design and applications of 3D spacer fabrics have also been reviewed. And the limitations in the application of 3D spacer fabrics have been explained to give a better understanding.

In chapter 3, experiments related to the physical properties of 3D spacer fabrics, numerous cutting, edge finishing and sewing methods have also been explained. 3D spacer fabrics to be used in this study have been selected based on their physical properties. Cutting and edge finishing method has been selected based on the subjective assessment by textile student, despite the fact the subjective assessment has been carried out in the form of survey and the feedback has been given based on the subjective assessment of different samples with numerous cutting and edge finishing method applied.

In chapter 4, the prototype of assorted styles of hip protectors has been designed with their design detail deliberated in this chapter. And products of assorted styles have been produced with reference to the production specifications given, and the material, cutting, edge finishing and sewing method selected in chapter 3.

In chapter 5, the properties of prototype of assorted styles of hip protectors have been evaluated by both objective testing, wear trial and case study and subjective testing in this chapter. The detail of objective testing: pressure distribution of the hip protectors and shock absorbing performance of the hip protectors; and subjective testing: wear trial and case study have also been explained and the results verified that this study has made an improvement on aesthetics, comfort and function performance of hip protectors.

CHAPTER 2 LITERATURE REVIEW

2.1. Introduction

In this chapter, literature review on different shock absorbing materials, mechanical issues and medical issues related to shock have been summarized. Different protective wear design and applications of 3D spacer fabrics have also been reviewed. And the limitations in the application of 3D spacer fabrics have been explained to give a clear concept. Apparel technologies and notions have been added to the design of the hip protectors for the production and their information has been studied.

2.2 Shock absorbing materials

In recent years, different types of shock absorbing materials have been developed to smooth out the shock impulse and to dissipate the kinetic energy. Typical cushioning materials include polymeric foams, polymeric solid elastomers, rubberized fibre cushion, air cushion and corrugated fibreboard. Different types of protective materials have been applied mainly on sports protective gears in the market and it has been found that both cushioning and support are needed for protection from impact injuries for sports activities.

Shock absorbing materials	Application	Benefit
Armour	• Motorcycle • Sportswear • Head gear	• High protection performance • Able to resist friction

Foamed rubber	• Sportswear • Protective pad	• Comfortable • Lightweight • High protection performance • Durable • True compression • Prevent skin irritation, chafing, and abrasions
Polyurethane	• Motorcycle • Sportswear • Footwear • Electronics	• High performance shock absorption • Trusted protection • Maximum flexibility • Extremely comfortable • Tested to highest standards
Silicone	• Motorcycle • Sportswear • Footwear • Electronics	• High performance shock absorption • Trusted protection • Maximum flexibility • Extremely comfortable • Tested to highest

		standards
3D Spacer fabrics	• Sportswear • Shoes • Luggage • Electronics	• High protection while remaining comfortable • Good fit with freedom of movement • Durable • Washable • Excellent breathability • Water resistant • Keep working across temperature extremes without becoming rigid

Table 2-1 Comparison of different shock absorbing materials

From Table 2-1, it can be found that the shock absorbing materials commonly used in sports protective gears are armour, foamed rubber, polyurethane and silicone.

Apart from sports, these shock absorbing materials have also been applied on functional garments for people with special needs, for example the elderly. Hip protectors have been used to reduce the risk of hip fractures in the elderly (M. J. Parker, Gillespie, & Gillespie, 2003).

2.2.1. Polymers

Polymeric foams are the most commonly used cushioning materials for human body impact protection. Several kinds of polymers have been applied for producing foams, such as polyurethane (PU), polystyrene (PS), polyethylene (PE), polypropylene (PP), Acrylonitrile-Butadiene-Styrene (ABS), phenolic, and olefinic. Although they have good cushioning properties, they cannot meet the comfort requirement of most protective clothing due to the low air permeability and moisture transmission capability of foams.

2.2.2. Rubber

Rubber consists of suitable polymers of the organic compound isoprene, with minor impurities of other organic compounds plus water. Forms of polyisoprene that are useful as natural rubbers are classified as elastomers. Currently, rubber is harvested mainly in the form of the latex from certain trees. The latex is a sticky, milky colloid drawn off by making incisions into the bark and collecting the fluid in vessels. The latex then is refined into rubber ready for commercial processing. Natural rubber is used extensively in many applications and products, either alone or in combination with other materials.

Rubber exhibits unique physical and chemical properties. Rubber's stress-strain behavior exhibits the Mullins effect and the Payne effect, and is often modeled as hyperelastic. Rubber strain crystallizes. In most of its useful forms, it has a large stretch ratio, high resilience, and is extremely waterproof. Owing to the presence of a double bond in each repeat unit, natural rubber is susceptible to vulcanisation and sensitive to ozone cracking.

2.2.3. Silicone

Silicones are polymers that include silicon together with carbon, hydrogen, oxygen, and sometimes other elements. Some common forms include silicone oil, silicone grease, silicone rubber, silicone resin, and silicone caulk.

Silicones exhibit many useful properties, including: low thermal conductivity, low chemical reactivity, and low toxicity. They show a constancy of properties over a wide temperature range of −100 to 250°C. They have the ability to repel water and form watertight seals, although silicones are not hydrophobes. They do not support microbiological growth. They have a high resistance to oxygen, ozone, and ultraviolet (UV) light.

2.2.4. 3D spacer fabrics

There are different kinds of 3D spacer fabrics available in the market and they can be produced base on customer's requirements. 3D spacer fabrics have a structure consisting of two separate outer fabric layers joined together but kept apart by spacer yarns. This kind of fabric can be manufactured by warp knitting, weft knitting, weaving and nonwoven technologies, while warp knitting technology is the most commonly used technology for 3D spacer fabric production because of the lower cost, higher productivity and wide structure variations compared to the 3D spacer fabrics produced by other technologies as shown in Table 2-2.

Technology	Thickness (mm)	Productivity	Surface pattern variation	Spacer structure variation	Compression resistance
Warp knitting	1 - 65	1000rpm	Large	Large	Designable
Flat weft knitting	3 - 12	1.2m/sec	Small	Medium	Designable
Circular weft knitting	1.5 - 5.5	30rpm	Large	Small	Low
Woven	1 - 1000	400rpm	Small	Small	Low
Nonwoven	3 - 60	3 - 10m/min	No	Large	Very low

Table 2-2 Comparison of different types of spacer fabric production

It has been shown that warp-knitted spacer fabrics have the best performance in all the aspects, the unique feature of warp-knitted spacer fabrics makes them a better alternative for cushioning materials than the other types of spacer fabrics. In general warp-knitted spacer fabrics are having width ranges from 160 to 240cm. Their weights are from 280g to 1200g/m^2 and their thicknesses are from 5mm to 40mm. Most of the 3D spacer fabrics are made of 100% polyester. The critical characteristic distinguishing warp-knitted spacer fabrics from other kinds of 3D spacer fabrics is that their three basic structural elements, which are top layer, bottom layer and spacer layer, are knitted together in the same knitting cycle.

Warp-knitted spacer fabrics are produced on double-needle bar Raschel machines. Raschel machines produce both outer layers simultaneously on two needle bars with their own sets of needles. Thus, it is possible for the front needle bar and back needle bar to knit different yarns and form different structures. By using different threading on and different lapping movements of each guide bar, different outer layer structures with different patterns can be obtained.

Raschel machines also have the greatest production capabilities, with a higher production speed and the ability to adjust knockover comb bar distance giving greater opportunity for spacer thickness. While spacer yarns are chosen mainly from monofilament yarns, multifilament yarns are always used to knit outer layers. The properties of spacer yarns can also affect the properties of the final products.

Over the past few decades, there have been many Raschel machines available in the market for the production of warp-knitted spacer fabrics, such as DG 506 from LIBA, MDK80 from Jakob Muller AG, and a series of machines including RD 6 (DPLM), RD 7 (DPLM), and HighDistance® from Karl Mayer. HighDistance® has been equipped with six electronically controlled guide bars achieves swing distances of up to 65 mm which allow it to produce a great variety of spacer fabrics with thicknesses from 20mm to 65mm.

3D spacer fabric have special properties compared to conventional textiles due to their unique 3D structures, and their special properties allow them to have a great variety of application fields. And because of their special warp knitting structures, they have a number of characteristics. First of all, they have a high breathability as there are pores on the fabrics. Secondly, they have a good cushioning effect and excellent recovery property since there are spacer yarns supporting the fabrics. Also, they are very light in weight. And 3D spacer fabrics are washable, recyclable and environmental friendly because of the composition of 100% polyester. Besides, there are hundreds of mesh design for the 3D spacer fabrics and they give different forming property and contour flow. These characteristics of 3D spacer fabrics also made them a potential shock absorbing materials to be applied on protective clothing.

2.3. Shock

Shock is a sudden acceleration or deceleration caused, for example, by impact or fall. Shock is term for extreme forces subject to matter, often quantified by acceleration per unit time. A shock interaction can be characterized by the peak acceleration, the duration, and the shape of the shock pulse.

2.3.1. Fall

Falls and fall injuries are very common, and the frequency of falls is even higher than having strokes among the elderly. Nevertheless, the consequence of having a fall can be very serious. However, the social and economic problem of falls and fall-related injuries will keep increasing if no effective preventive measures are executed, as the number of aged people is still growing. Therefore, developing fall prevention measures to lower the number of fall and fall injuries has became an important issue in the world (Bleijlevens et al., 2010).

From 1994 to 2003, the death rates after having a fall have been increased significantly for both men and women; in 2003, the death rate for men was even 49% higher than women in the United States. Nearly a half of the elderly living in the community, including both fallers and non-fallers have a fear of falling. And this can lead to a number of problems, they are loss of confidence, loss of independence, social withdrawal, physical frailty, new falls, restriction of physical activities, functional decline and a reduced quality of life (Zijlstra et al., 2007).

However, there are differences between the prevalence of fractures and the cause of the fall between the injurious fall types. Previous research suggested that special attention should be given to outdoor fallers and indoor fallers during lavatory visits, and causes of the fall (Bleijlevens, et al., 2010) in order to prevent serious fall injuries.

Since effective preventive measures are still in the developing process, this study focuses on how to reduce the severity of fall injuries instead, and a collection of hip protectors has been developed in this study.

2.3.2. Injury

Injuries mean damages to biological organisms which can be divided into different types, based on their causes, locations or activities. Injuries following falls generally lead to problems, including long-term pain, functional impairment, disability and death in elderly. Nearly a quarter of patients suffered from injuries, such as bruising, hip fractures and head traumas, after a fall, and these injuries can bring negative influences to their independent living and increase the risk of death. Falls are also one of the most common causes of traumatic brain injuries (Sleet, et al., 2008).

The risk of having serious injuries after a fall increases with age and most injury-related deaths in are related to falls for cases of elderly. The rates of fall injuries for people aged or aged above 85 years old are four to five times more than the rates for people aged between 65 and 74 years old and about 85% of deaths following a fall happen among people aged above 75 years old (Sleet, et al., 2008). In 2005, about 1.8 million elderly received treatment in hospital emergency departments in the United States because of fall-related injuries, nearly 500000 of them were hospitalized and 15000 of them died.

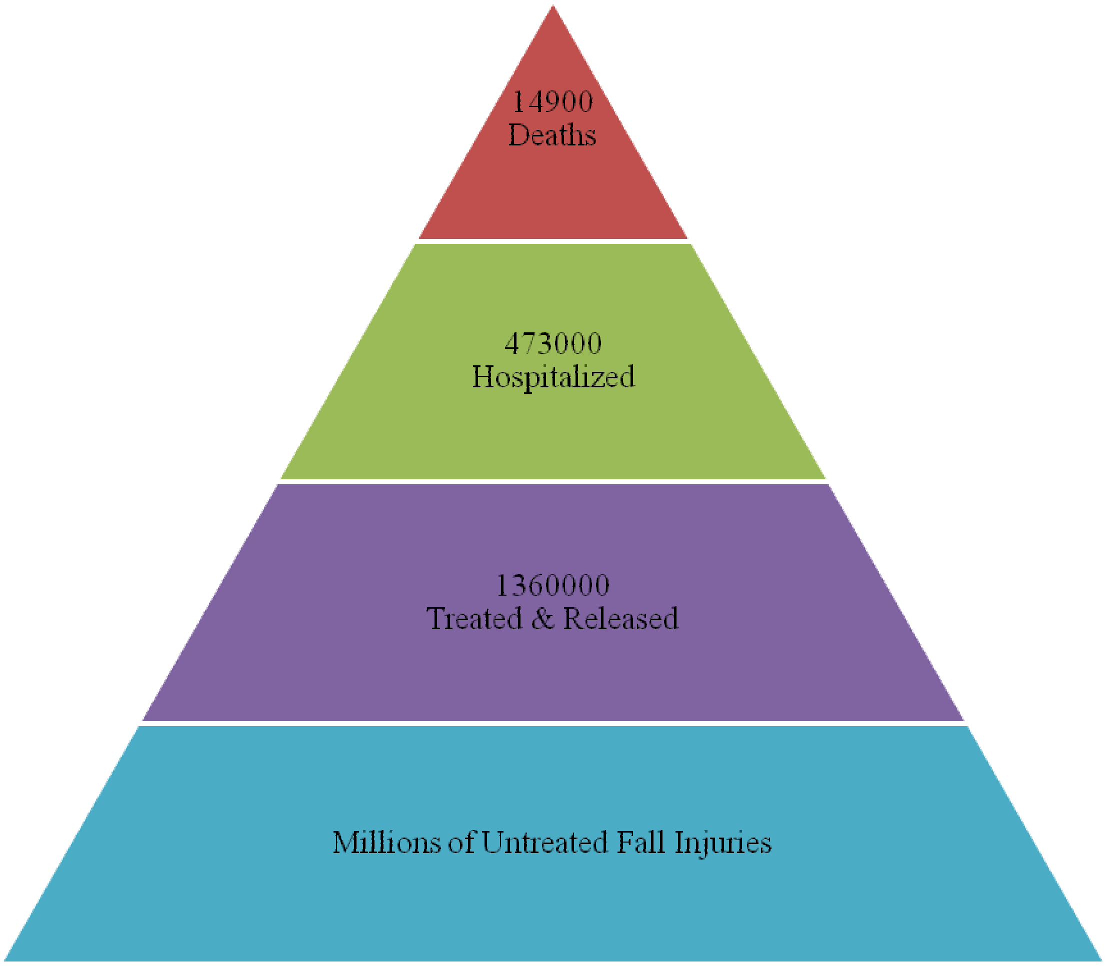


Figure 2-1 Falls in the United States in 2005 (Sleet, et al., 2008)

Women have a higher frequency of having a non-fatal injury than men, while men have a higher death rate following a fall than women, but, the underlying causes are still not known (Sleet, et al., 2008).

2.3.3. *Bone fracture*

Bone fractures are a medical term to describe a break in the continuity of the bone. Bone fractures are sometimes abbreviated as FRX, Fx, F_x or #. Bone fractures following a high force impact of stress with bones weakened under certain medical conditions can be termed pathologic fractures, while the medical conditions can be osteoporosis, bone cancer, or osteogenesis imperfecta.

People are frequently suffering unexpected mechanical shock impulses in daily life. Mechanical shocks are force actions on human body and may bring similar harmful effects, such as tissue destruction and bone fractures.

Hip fracture is used to describe the different fracture patterns, and hip fracture is often due to osteoporosis. Most of the hip fractures are fragility fractures following a fall or a minor trauma in patients with weakened osteoporotic bone. The risk of a fall and therefore of a fracture increases with age, and the average age of patients with hip fractures is over 80. The majority of hip fracture patients have one or more simultaneous chronic medical conditions.

Hip fractures therefore particularly affect residents with a previous invalidity, and so a fracture often has serious consequences. If falls can be prevented from resulting in fractures, the risk of both invalidity and mortality can presumably be significantly reduced, and at the same time it will be possible to reduce the number of casualty ward contacts, bed days on admission and rehabilitation courses. However, for people with normal bone, hip fractures are generally due to a high-energy trauma, for example a car accident.

Among different fracture patterns, femoral neck fractures have proven to be one of the most serious injuries associated with high mortality and morbidity (Schmidt & Swiontkowski, 2002) (Raaymakers, 2006). This incidence has increased since the 1960s. And it has a tendency to increase in the future, as life expectancies increases (Macaulay, Yoon, Parsley, Nellans, & Teeny, 2007).

Garden classification system is used to describe fractures base on the distortions of the principal compressive trabeculae before reduction, which the distortions can be seen on anteroposterior radiographs. Fractures can be classified base on radiographic appearances, while the most popular classification system for avascular necrosis staging of the femoral head is explained by Ficat and Arlet (Greenspan, 2000).

Stage	Radiograph	Description
0	/	• No radiographic findings • Diagnosed by means of magnetic resonance imaging or bone scanning
1		• Slight osteoporosis on plain images • Clinical symptoms may be present • Sclerosis does not present

2		• Diffuse osteoporosis and sclerosis at the region of the infarction • Infarcted area is well delineated due to a reactive shell of bone • Spherical shape of the femoral head is maintained
3		• Crescent sign or radiolucency under the subchondral bone represents a fracture • Contour of the femoral head is abnormal • Joint space is preserved
4		• Characterized by femoral head collapse • Joint-space narrowing • Subchondral sclerosis

Table 2-3 Avascular necrosis staging (Greenspan, 2000)

Falls are related to most types of bone fractures, and the majority of hip fractures for people aged above 70 years old are resulted from falls, while only half of them can recover their pre-fracture mobility status after having bone fractures. Falls are also responsible for about a quarter of vertebral fractures with clinical attention drawn. For the hip fractures in elderly, most of them happened following a lateral fall onto the hip. There are about 300000 elderly having a fall and hip fracture in each year. Most of them are hospitalized for a week in approximation, while a quarter of them who used to live independently will stay in a nursing home for at least a year after the injury. Among the patients, 15% of them die in the hospital and a third of them die within a year (McClure et al., 2005).

In the United States, falls are the most significant causes of both fatal and non-fatal injuries in patients aged or aged over 65 years old. About a third of the people over 65 years old living in the community fall once or more than once a year; half of them even fall repetitively. Half of the patients aged over 80 years old fall once or more than once a year. In 2005, two-third of the non-fatal injury in elderly is related to falls (Sleet, Moffett, & Stevens, 2008).

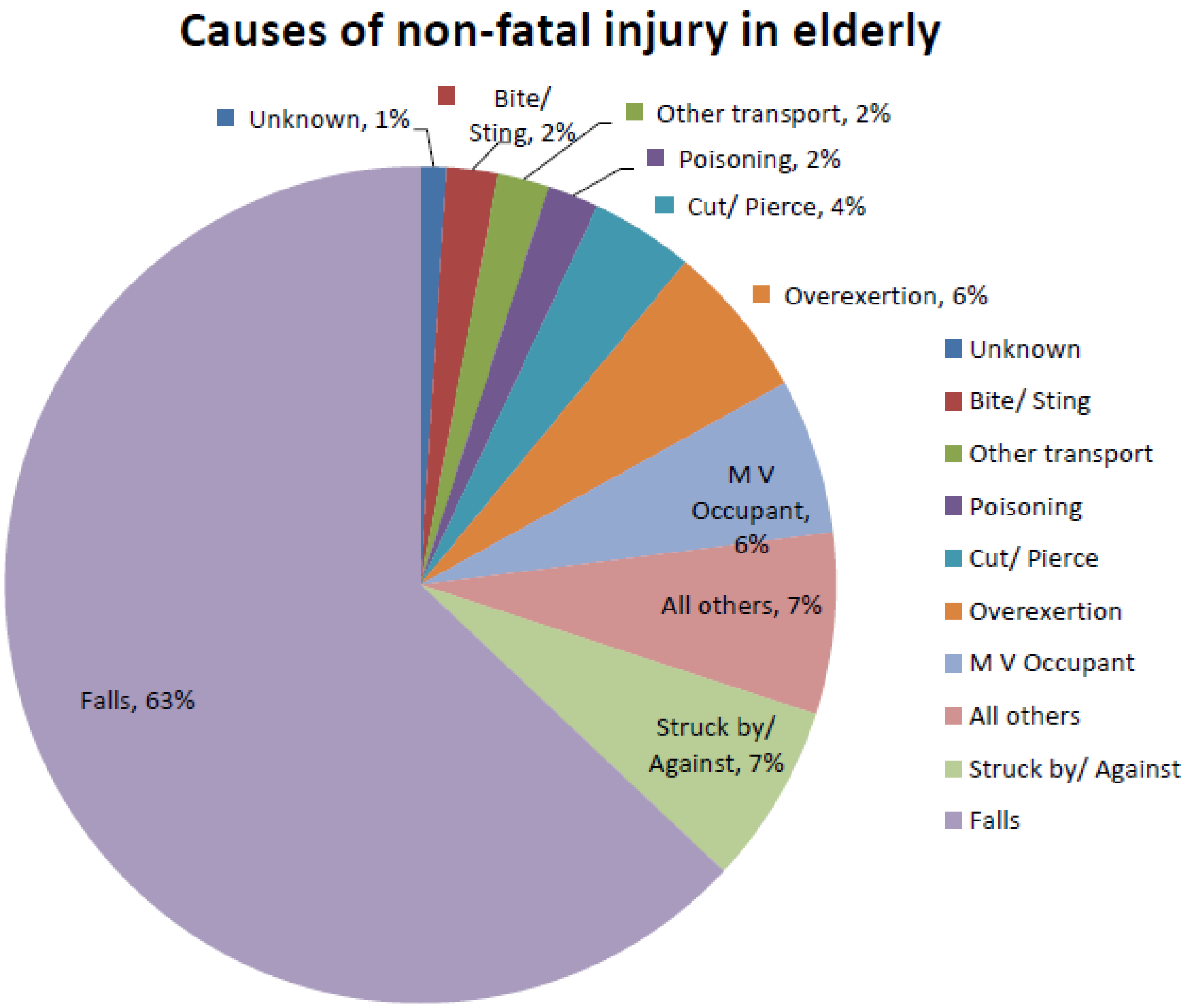


Figure 2-2 Causes of older adult non-fatal injury (Sleet, et al., 2008)

In the United States, hip fracture is a result of fall for nearly all of the hip fracture patients. Most of the patients said that they have fallen to the side directly. 56% of the patients have a fresh subcutaneous hematoma appeared on the greater trochanter of the proximal femur. It has been explained that a typical hip fracture follows a fall and a subsequent impact on the greater trochanter of the proximal femur. It also implied that hip fractures can be reduced by lowering the number and severity of falls of the elderly, while the severity of falls can be reduced using external hip protector (J. Parkkari et al., 1999).

According to 2011 NEISS Data Highlights from National Electronic Injury Surveillance System (NEISS), there are also a significant number of sport-related injuries in the United States and the numbers of cases in 2011 has been shown in Figure 2-3. The sports leading to most of the sport-related injuries are basketball, bicycles and accessories, and football while the numbers of cases are 16554, 15809 and 14660 respectively.

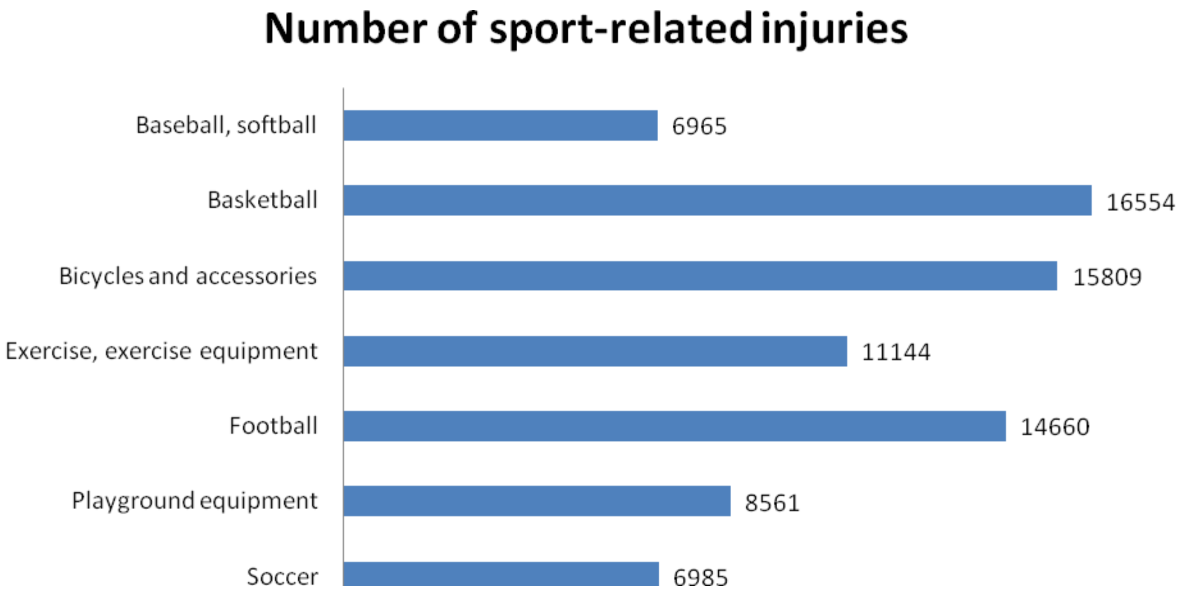


Figure 2-3 Number of sport-related injuries in the United States (NEISS, 2013)

2.3.4. Prevention

Cushioning can be applied to manage the magnitude of shock, so the subject will have a lower chance of getting hurt. Protectors are normally manufactured to include energy absorbing materials in the form of pads. They are integrated or inserted to protective clothing or equipment specially designed for protecting the human body from impact, blows or falls.

The principle of a cushioning material is to reduce the force created when one surface comes abruptly into contact with another, by compressing or deforming so as to produce a gradual, rather than instantaneous, change in velocity. This can reduces potentially high decelerations to more moderate values and thereby minimizes damaging impact forces. Cushioning materials generally absorb kinetic energy under compression at a relatively constant stress over a large range of displacement to achieve cushioning.

In this study, 3D spacer fabrics have been used to give the cushioning effect of hip protectors to lower the shocks transmitted to the hip following a fall and reduce the chance of having hip fractures and injuries after a fall for elderly. 3D spacer fabrics can absorb the energy generated during impact and transmit a reduced force when compressed throughout its thickness.

2.4. Protective wear design

A range of protective wear has been developed to protect human body from injuries under various exposure conditions. Most of them are designed for sports uses to reduce the risk of injury to wearers.

Nowadays, different brands have started to incorporate soft hip protective pads made from compressed foam pads into pants to produce hip protective pants for elderly. The hip protective pants were used to lower the impact force on the trochanter during a fall by providing a cushioning effect. Both hard hip protective pads and soft hip protective pads have been used in hip protective pants and are now commercially available in the market. They are available in a range of styles and colours of pants, with different styles for different genders (Hayes, 2004).

In recent years, the variety of hip protective pads and protectors in the market has been increased significantly. The rise can be explained by the economic analysis of the cost-effectiveness of the use of hip protector established in the previous study (Cathleen S. Colón-Emeric, Datta, & Matchar, 2003).

Also, different kinds of impact protectors for different parts of body under various conditions are now available in the market to meet the needs of different customers and sportswear with different protection functions have been very popular for athletes.

2.4.1. Sports

Product	**Type**	**Brand**	**Protection**	**Price**
	Short	Adidas	Hip	USD 24.99
	Short	Diadora	Hip	USD 36 - USD 41.95
	Longshort	Uhlsport	Hip, knee, leg	USD 49.99

	Short	McDavid	Hip	USD 44.95
	Short	Puma	Hip	USD 29.99

Table 4-4 Football/soccer shorts in the market

According to Table 4-4, the price range for football/soccer shorts is around USD 25 - USD 50, with mean price at around USD 40. The major protection areas are hip for shorts, and hip, knee and leg for long shorts. The major material used is foamed rubber.

Product	**Type**	**Brand**	**Protection**	**Price**
	Short	Andiamo	Women specific	USD 23.25
	Short	Canari	Crotch	USD 25.99 - USD 30

	Short	Fox	Hip	USD 47.95
	Short	SixSixOne	Hip	USD 49.95
	Short	Adidas	Hip, leg	USD 59.99
	Short	McDavid	Hip, leg	USD 79.95 - USD 89.95

Table 4-5 Cycling shorts in the market

According to Table 4-5, the price range for cycling shorts is around USD 24 - USD 60, with mean price at around USD 50. The major protection areas are crotch, hip and leg. The major materials used are foamed rubber.

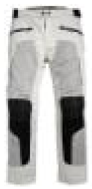
Product	Type	Brand	Protection	Price
	Trousers	Alpinesters	Hip, shin, knee	USD 392
	Trousers	REV'IT!	Hip, knee	USD 259.99
	Trousers	Scorpion	Hip	USD 159.95
	Trousers	Xelement	Shin, knee	USD 189.95
	Trousers	Icon	Hip, knee	USD 251.99

Table 4-6 Motorcycling pants in the market

According to Table 4-8, the price range for motorcycling pants is around USD 160 - USD 400, with mean price at around USD 250. The major protection areas are hip, knee and shin. The major materials used are armour and foamed rubber.

These protective clothing are mainly developed by international brands, including Adidas, Diadora, McDavid, Puma and Reebok, and the prices are between USD 23.25 and USD 392. If the application of 3D spacer fabrics has been investigated, there is an opportunity for 3D spacer fabrics to enter the industry of protective clothing and lower the price of protective clothing.

2.4.2. Elderly

Hip protectors have been developed to protect the elderly from injuries and bone fractures after a fall. Hip protectors are a kind of protective garments, which are protective clothing designed to protect people from injury for safety reasons and health purposes. The terms protective clothing and protective gear are usually interchangeable, whereas protective clothing is a specific term used to describe traditional types of clothing, and gear is a more general term used to describe uniquely protective categories, including pads, guards, shields and masks.

With rapid progress in science and engineering research, the gap between design and technology is getting smaller. Smart clothing is predicted to keep expending in the foreseeable future and growth is expected to occur in two different directions, they are performance-driven smart clothing and fashion-driven smart clothing, while there are still challenges to be encountered (Tang & Stylios, 2006).

In the field of clothing, rapid development in high performance materials has attracted great interest from the sports and protective clothing industry. And the limitations of textiles have been stretched even further. The outcomes from technical textiles research over years have been put together with founding from other fields of study, such as engineering, science and design. This has led to a new breed of smart technologies. Although this is not the first time for the clothing industry to share the benefits of these technologies, this give a potential to revolutionize with the commercialization of the latest smart textiles research (Tang & Stylios, 2006).

Wearable hip protectors represent a promising strategy for preventing hip fractures. Nowadays, different kinds of hip protectors are available in the market and most of them are in specialized form of pants or underwear with padding along the side seam of each hip or leg. Hip protectors are designed to prevent hip fractures following a fall and they are commonly used by elderly, who have a higher risk of falls and underlying osteoporosis (G. Holzer & Holzer, 2007).

Hip protectors are divided into two types; they are crash helmet type and energy absorbing type. The working principle of crash helmet type protectors is to distribute impacts onto the surrounding soft tissue, while the working principle of energy absorbing type is to diminish the force of impact. Both types of hip protectors aim at controlling the focused force under an estimated threshold for fracture (G. Holzer & Holzer, 2007).

There are different brands of hip protector in the market, including Safehip from Tytex A/S, AHIP Protector from Astrotech, and KPH hip protector from HRA

Pharma (G. Holzer & Holzer, 2007). And Safehip has been used in most clinical trials (Julie T. Lin & Lane, 2008).

Figure 2-4 Safehip hip protector shield

Safehip hip protector shields are made of a breathable textile material, which can disperse the energy of the fall away from the hip area. There are different styles and sizes for different genders.

Model	**Product**	**Gender**	**Feature**
SAFEHIP® AirX		Male	• For hospitals, nursing homes or at home • For people requiring intensive nursing care • Sewn in shields for excellent protection • Removable shields for flexibility and freedom to choose • Can be used with sanitary pads for light incontinence

- Can be worn over user's underwear
- Discreet and comfortable to wear
- Available in sizes XS to XXL

Female

		Unisex	
SAFEHIP® AirX Open		Unisex	• For hospitals, nursing homes or at home • Can be worn over user's underwear • Ideal for medium to heavy incontinence • Ideal for individuals suffering from dizziness or reduced physical strength • Excellent for night time use • Sewn-in shields for optimal protection • Available in sizes XS to XXL
SAFEHIP® Active		Unisex	• For use in rehabilitation and training centres or at home • Designed for active elderly people • Easy to put on and take off for user and care givers • Can be used when needed

			• To be used over normal clothing • AirX™ - a breathable fabric for excellent comfort • Available in black and apricot • Sizes S to XXL
SAFEHIP® Dorso	 	Unisex	• Combined back support and hip protector • Designed to give pain relief and hip protection in one product • Easy to put on and take off for both user and care givers • Can be used when needed • Can be customised by orthopaedic technician • Available in black and apricot • Sizes S to XXL

Table 2-7 Safehip hip protectors

Although there are many different hip protectors available in the market, their acceptance and compliance still remain in a low level (Martyn J. Parker, Gillespie,

& Gillespie, 2006). In a previous clinical trial, soft hip protectors and hard protectors have been distributed to patients in different nursing homes and it has found that the probability of continued use among patients using soft hip protector was a little higher and there were much more 24-hour users among patients using the soft protector (H. Bentzen, Forsén, Becker, & Bergland, 2008). It has also been explained that hip protectors provide some benefit in reducing hip fractures in patients living in residential facilities (Leytin & Beaudoin, 2011) and the use of hip protectors does not bring any important adverse effects (Martyn J. Parker, et al., 2006). Bayesian meta-analysis also showed a reduced risk of hip fractures in elderly living in nursing home (Anna M. Sawka et al., 2007).

2.5. Applications of 3D spacer fabrics

At this moment, applications of warp-knitted spacer fabrics are generally based on their compression resistance and some effort has already been made to experimentally study the properties of 3D spacer fabric for exploring new application.

2.5.1. Current applications

3D spacer fabrics have been applied in many different areas, including automotive, medical, industrial, sports and safety and the current applications of 3D spacer fabrics have been shown in Table 2-8.

Areas	Examples
Automotive	Car seat cover, door panelling, care roof lining, car window shelf, care head liner, car rear seat pockets, car seat heating, dash board cover, car boot liners, truck rain water mist protector.

Medical	Bandage, knee braces, decubitus mats, absorbent fleece, neck supports, wheelchair cushions, sensor fabrics for patient monitoring, operating table mats, thermal mats.
Industrial	Water purification, concrete, sound absorption, textile antenna, composite reinforcement, electronic cases, solar thermal collectors.
Sports and Leisure	Sports protectors, sportswear, sports shoe, mattress, pillows.
Safety and protection	Hip protector, cycle helmets, body armour.

Table 2-8 Applications of warp-knitted spacer fabrics

High breathability and excellent recovery property of 3D spacer fabrics also made them a potential shock absorbing materials to be applied on protective clothing.

2.5.2. Features

According to the special warp knitting structures of 3D spacer fabrics, they have a number of characteristics, including high breathability, good cushioning effect and excellent recovery property. The 3D spacer fabrics made of 100% polyester are very light in weight and they are washable, recyclable and environmental friendly. The mesh structures on the surface of 3D spacer fabrics have also given them different forming property and contour flow.

2.5.3. Limitations

The physical properties of 3D spacer fabrics have made them a potential shock absorbing materials to be applied on protective clothing. However, the fraying edges of 3D spacer fabrics have a very uncomfortable handle, and cause a lot of abrasion on skin. And the thicknesses of 3D spacer fabrics have also made them different to be finished and sewn using conventional sewing machines. This limited the application of 3D spacer fabrics on clothing. Therefore, experiments related to the physical properties of 3D spacer fabrics, different edge finishing methods and sewing methods have been carried out in the study to optimize the applications of 3D spacer fabrics on hip protectors with suitable apparel technologies.

2.6. Apparel technologies

With knowledge about different shock absorbing materials currently available in the market, different apparel technologies have also been studied for the production of hip protectors using 3D spacer fabrics.

2.6.1. Sewing

Sewing is the apparel technology applied to attach objects using stitches with a needle and thread. Sewing is a kind of earliest textile arts, arising in the Palaeolithic era (Kooler, 2009). Sewing was applied to stitch animal skins together for clothing and for shelter and archaeologists assumed that Stone Age people across Europe and Asia sewed fur and skin clothing by means of bone, horn or ivory needles and thread made of various animal body parts including tendon, cord, and veins.

For thousands of years, all sewing was finished by hand. During the Middle Ages, Europeans who could pay for it used to employ seamstresses and tailors, and most sewing was finished by hand before the 19th century. Therefore, clothing was a luxurious investment for most people at that time.

The world's first sewing machine was patented in 1790 by Thomas Saint. By the early 1840s, other early sewing machines began to appear. Barthélemy Thimonnier announced a modest sewing machine in 1841 to produce military uniforms for France's army; in a while afterward, a crowd of tailors broke into Thimonnier's shop and threw the machines out of the windows, believing the machines would put them out of work (Carlson, 2003). By the 1850s, Isaac Singer developed the first sewing machines that could function quickly and precisely and surpass the efficiency of a seamstress or tailor sewing by hand. The development of the sewing machine in the 19^{th} century and the widespread of automation in the later 20^{th} century directed to mass production of sewn items.

2.6.2. Stitch

Sewers practice a modest design needs only a small number of sewing tools, including measuring tape, needle, thread, cloth, and sewing scissors. More complicated designs done on a sewing machine may only need a few more simple tools to get the job done, but there are an increasing variety of supportive sewing aids available.

Construction stitches consist of the edge stitching, under stitching, stay stitching and topstitching; seam types consist of the plain seam, zigzag seam, flat fell seam, French seam, etc. Supporting materials, for instance interfacing, interlining or lining, or fusing, may be used as well, to give the fabric a more stiff or durable shape.

2.6.3. Seam

Seam is the connection where two or more layers of fabric or other materials are held together with stitches. In advance of the development of the sewing machine, all sewing was finished by hand. Seams in current mass produced domestic textiles, sporting goods, and prêt-à-porter items are sewn by computerized machines, while crafts, haute couture and tailored items may use a combination of hand and machine sewing.

In clothing production, seams are categorized by their type, including plain, lapped, abutted, and French seams; and position in the finished garment, for example centre back seam, inseam and side seam. A seam finish is a treatment that locks up and neatens the raw edges of a plain seam to prevent ravelling, by sewing over the raw edges or hem in them using binding.

For mass produced clothing, the seam allowances of plain seams are usually cut and stitched together with an overlock stitch using a serger. Plain seams may also be pressed open, with each seam allowance separately secured with an overlock stitch. Traditional home sewing techniques for plain seams finishing include trimming with pinking shears, oversewing with a zig-zag stitch, and hand or machine overcasting.

A bound seam has each of the raw edges of its seam allowances hemmed in a strip of fabric, lace or net binding that has been folded in half along the length. A case in point of binding is double folded bias tape. The binding's fold is bound around the raw edge of the seam allowance and is stitched, through all thicknesses, holding underside of binding in stitching. Bound seams are every so often used on lightweight fabrics, including silk and chiffon, and on unlined garments to give a neat finish.

A Hong Kong seam or Hong Kong finish is a home sewing term for a type of bound seam in which each raw edge of the seam allowance is individually enclosed in a fabric binding. For couture sewing or tailoring, the binding is usually a bias cut strip of a lightweight lining fabric; for home sewing, commercial bias tape is frequently used.

In a Hong Kong seam, a bias strip of fabric is cut to the width of the seam allowance and 1/4" more. The bias strip is placed on top of the seam allowance, right sides together, and stitched 1/8" from the raw edges. The bias strip is then folded over the raw edge and around to the underside and stitched in position.

2.7. Notions

3D spacer fabrics have been used in this study for the production of hip protectors using appropriate apparel technologies and notions have been added to the design of the hip protectors for fastening and finishing.

2.7.1. Bias tapes

Bias tape or bias binding is a thin strip of fabric, cut on the bias. The strip's fibres aligned 45◦to the length of the strip, making it more stretchable and drapeable when compared with a strip that is cut on the grain. Many strips can be patched together into a long tape while the width of the tape varies from about 1/2" to about 3" depending on the uses. Bias tape is used in making piping, binding seams, finishing raw edges, etc.

Different types of bias tapes are available in the market and the most common types are simple bias tape, single-fold bias tape, and double-fold bias tape. Extra wide double fold bias tapes are used to sewn as a binding on a thicker fabrics.

2.7.2. Velcro

Velcro is a hook and loop fastener invented in 1948 and Velcro was patented in 1955, successively refining and developing its practical production until its commercial introduction in the late 1950s (Stephens, 2007).

Hook and loop fasteners are typically made up of two components: two lineal fabric strips which are attached to the opposing surfaces to be fastened. The first component consists of tiny hooks; the second consists of even smaller loops with a hairy appearance. When the two components are pressed together, the hooks catch in the loops and the two pieces become attached for the time being, until they are pulled apart. The hooks are flexible to some degree, so when the surfaces are pulled apart, the hooks straighten and slide out of the loops without any destruction. The hooks return to their ordinary shape when the straightening force is released, so the Velcro can be used again.

2.7.3. Zippers

Zipper, zip, or zip fastener is a device commonly used for binding the edges of an opening of fabric or other flexible material. It is used in different items, including jackets, jeans, bags, sporting goods, tents, sleeping bags, and other items. Zipper consists of two rows of protruding teeth which may be made to interdigitate, linking the two rows, carrying from tens to hundreds of specially shaped metal or plastic teeth. These teeth can be either separate or shaped from a continuous coil, and are also referred to as elements. The slider operated by hand, moves along the rows of teeth. Inside the slider is a Y-shaped channel that interlocks together or splits the two rows of teeth, depending on the movement direction of the slider (Friedel, 1994).

Some zippers include a designed anti-slide zipper locks to hold in a secure open or closed position, resisting forces that would attempt to move the slider and open the zipper all of a sudden.

The zipper handle can have a short protruding pin carved into it, which inserts between the zipper teeth through a hole on the slider, when the handle is folded down flat against the zipper teeth, and the handle is pressed down by the tension caused by the slider and the fabric fold over the fly.

The slider can also have a two-piece hinge assembly attaching the handle to the slider, with the base of the hinge under spring tension and with protruding pins on the bottom that insert between the zipper teeth. To move the zipper, the handle is pulled outward against spring tension, lifting the pins out from the teeth as the slider moves. When the handle is released, the pins automatically engage between the zipper teeth again.

A three-piece version of the above uses a small turning arm held under tension inside the hinge. Pulling on the handle from any direction can lift the turning arm's pins out of the zipper teeth so that the sliders can move.

2.8. Summary

Literature review on different shock absorbing materials, mechanical issues and medical issues related to shock have been summarized in this chapter. Different protective wear design and applications of 3D spacer fabrics have also been studied and the limitations in the application of 3D spacer fabrics have been explained. Apparel technologies and notions have also been added to the design of the hip protectors for the production and their information has been studied.

CHAPTER 3 EXPERIMENTAL WORK

3.1. Introduction

In this chapter, experiments related to (1) physical properties of 3D spacer fabrics, (2) the technology on the applications of 3D spacer fabrics to protective clothing, in terms of (I) numerous cutting and edge finishing methods, (II) the comparison of various sewing methods, and (III) a number of alignments of 3D spacer fabrics and their assessments. Twelve samples of 3D spacer fabrics with different structures have been developed by research team with the support from Wuyang Warp Knitting Machine Ltd., and their physical properties have been measured in keeping with international standards, and their compression properties at 20J impact have been tested on an INSTRON 5566 device according to Standard Test Methods for Rubber Properties in Compression ASTM D575. Numerous cutting and edge finishing methods including conventional cutting, laser cutting, overlocking, binding, interlining, heating and silicon application, have been applied on the twelve samples and their performances have been evaluated by subjective assessment. Various types of top stitching, including different distance between lines of top stitching, different angle of lines of top stitching, different number of set of top stitching, and different direction of top stitching on the twelve samples to investigate the relationship between the compression properties and top stitching applied as well as the relationship between the distortion of fabric and the density, direction and pattern of the top stitching applied.

3.2. Systematic study on selection of 3D spacer fabrics

3D spacer fabrics are having a desired physical performance for their application in hip protectors and other protective clothing. They are durable, washable, breathable and flexible. They can be made of different materials and structures, therefore, the 3D spacer fabrics applied in this study have also been explained in detail for a better understanding.

3.2.1. Materials and structures of 3D spacer fabrics

The 3D spacer fabrics used in the study were produced by warp knitting using a GE296 high speed double needle bar Raschel machine of six yarn guide bars, supported by Wuyang Warp Knitting Machine Ltd. The machine gauge for the warp knitting machine is E18, and 300D/96F polyester multifilament was used to create the binding of the structure in the knitting process and polyester monofilament of 0.2mm in diameter was used as spacer yarns to connect the two outer layers together. There are four different structures, including locknit, chain plus inlay, rhombic mesh, and hexagonal mesh for the outer layers and three different lapping for spacer yarns as shown in Table 3-1.

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and hexagonal mesh for the outer layers and three different lapping for spacer yarns as shown in Table 3-1.

Figure 3-1 High speed double needle bar Raschel machine

Figure 3-2 Polyester yarn

Lapping	GB3	GB4	Threading
I	1-0 2-1/ 2-1 1-0//	2-1 1-0/ 1-0 2-1//	1 full 1 empty
II	1-0 3-2/ 3-2 1-0//	3-2 1-0/ 1-0 3-2//	1 full 1 empty
III	1-0 4-3/ 4-3 1-0//	4-3 1-0/ 1-0 4-3//	1 full 1 empty

Table 3-1 Lapping in spacer fabrics

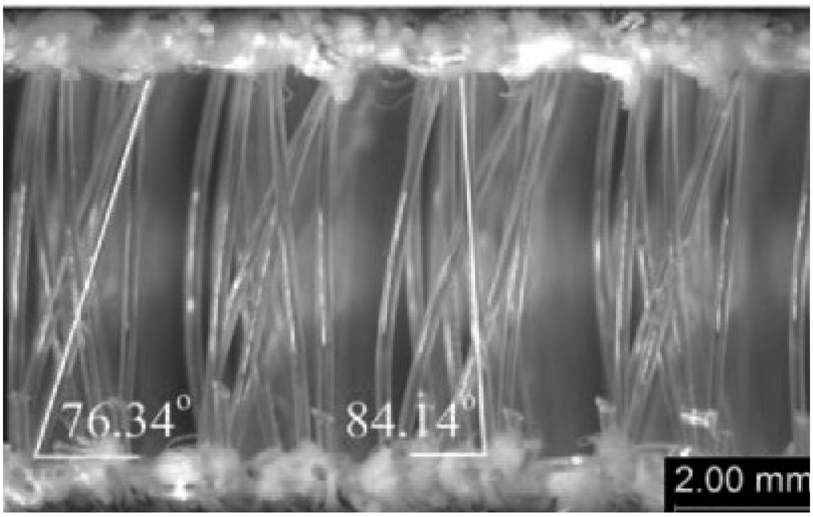


Figure 3-3 Cross-sectional microscopic pictures of spacer fabric with lapping I

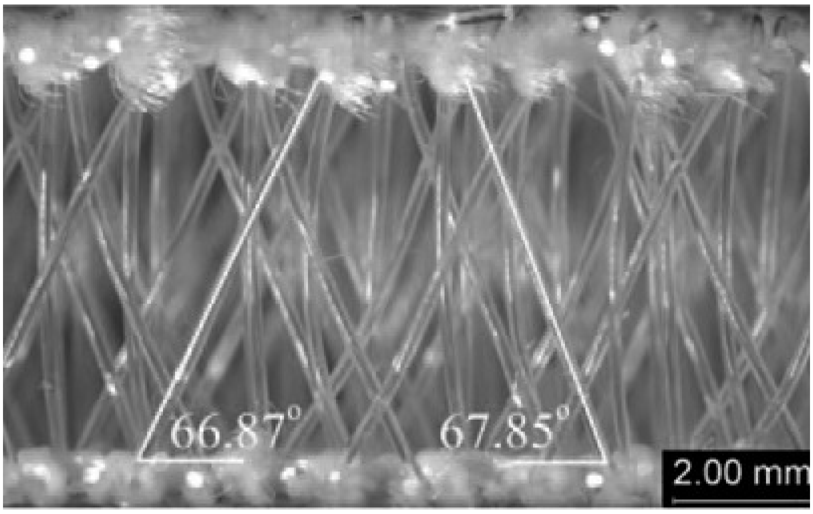


Figure 3-4 Cross-sectional microscopic pictures of spacer fabric with lapping II

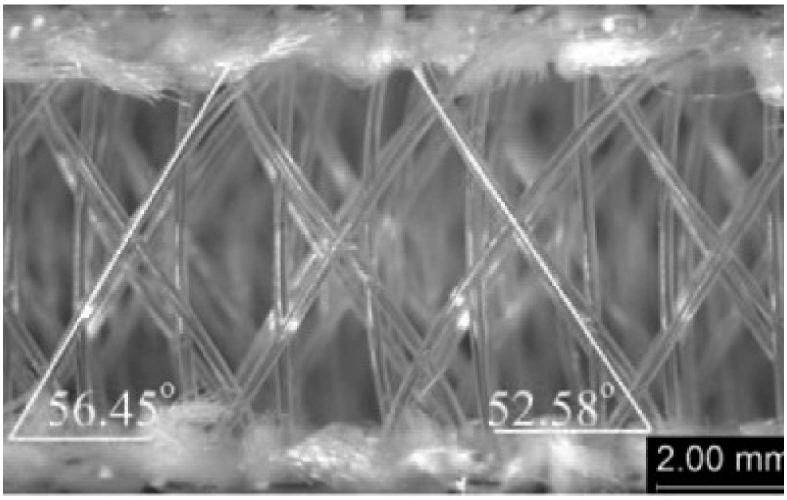


Figure 3-5 Cross-sectional microscopic pictures of spacer fabric with lapping III

3.2.2. Experimental procedures

There are twelve samples of 3D spacer fabrics with different structures and their physical properties have been measured and listed in Table 4-2, they have thickness ranges from 5.64 ± 0.03mm to 10.62 ± 0.10mm; areal density ranges from 724.82 ± 8.34g/m2 to 1022.08 ± 13.38g/m2; bulk density ranges from 95.14 ± 0.83kg/m3 to 140.08 ± 2.57kg/m3; and stitches per cm2 ranges from 34.98 to 51.10.

3.2.2.1. Testing equipment

The thicknesses of the samples have been measured by a thickness gauge following Standard Test Method for Thickness of Textile Materials ASTM D1777 and the samples of the 3D spacer fabrics were tested on an INSTRON 5566 device set up with two compression circular platens of 150mm in diameter according to Standard Test Methods for Rubber Properties in Compression ASTM D575 to investigate their compression properties. The sizes of all the specimens were 100mm × 100mm and placed on the fixed platen. The compression tests were conducted at a speed of 12 mm/min up to a deformation 80% of the initial thickness of each fabric under the standard condition of 20°C and 65% relative humidity. Five tests were carried out for each sample under the standard testing condition and the transmitted force at 20J impact presented below is an average of the five experimental results.

Figure 3-6 Thickness gauge

Figure 3-7 INSTRON 5566 device

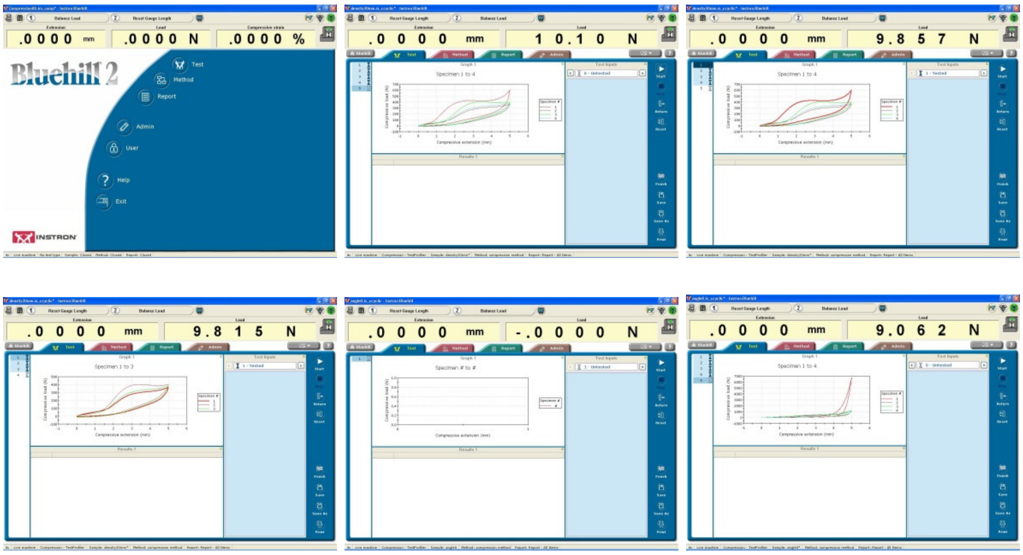


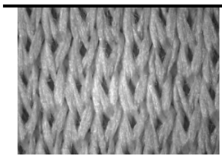
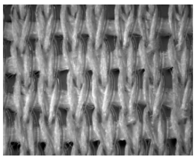
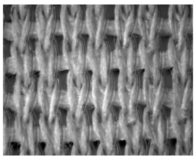
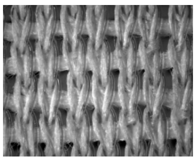
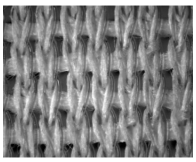
Figure 3-8 INSTRON software processing

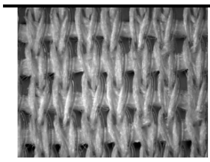
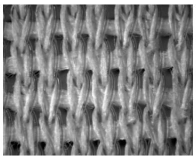
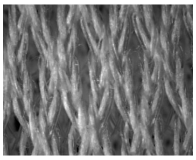
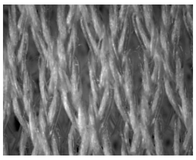
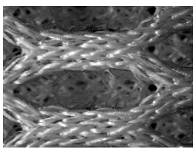
3.2.2.2. Sample preparation

36 specimens of the twelve samples have been prepared and placed under the standard condition of 20°C and 65% relative humidity for 24 hours before measuring their physical properties. The specimens have been cut into the same size (100mm × 100mm) and the physical testing has been carried out according to different standards.

3.2.2.3. Results and discussion

Sample	**Lapping**	**Thickness (mm)**	**Areal density (g/m^2)**	**Bulk density (kg/m^3)**	**Stitches/ cm^2**	**Transmitted force at 20J impact (on a flat surface)/ kN**
S1	II	7.52 ± 0.06	1008.29 ± 10.68	134.08 ± 1.42	41.15	5.59793

						
S2	I	7.57 ± 0.08	900.11 ± 9.01	118.87 ± 1.19	37.95	7.51172
						
S3	II	7.59 ± 0.10	901.75 ± 14.58	118.84 ± 1.92	37.26	4.52668
						
S4	III	7.40 ± 0.06	923.20 ± 8.44	124.76 ± 1.14	37.95	6.42523
						
S5	II	5.64 ± 0.03	790.63 ± 14.51	140.08 ± 2.57	34.98	6.69722
						
S6	II	8.45 ±	1022.08	120.96	43.50	6.0877

		0.09	± 13.38	± 1.58		
S7 	II	10.62 ± 0.10	1010.42 ± 8.83	95.14 ± 0.83	37.95	6.40683
S8 	II	7.20 ± 0.05	830.05 ± 11.53	115.22 ± 1.60	39.33	4.98817
S9 	II	7.76 ± 0.06	907.24 ± 17.07	116.91 ± 2.20	51.10	2.41592
S10 	II	7.56 ± 0.08	812.70 ± 6.61	107.50 ± 0.87	37.95	6.30229
S11	II	7.62 ±	724.82	95.17 ±	38.86	9.85575

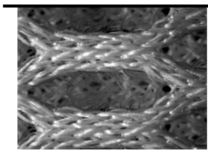
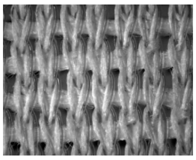
		0.06	± 8.23	1.10		
S12 	III	7.06 ± 0.09	746.53 ± 6.81	105.68 ± 0.96	39.44	5.56503

Table 3-2 Physical properties of different spacer fabric samples

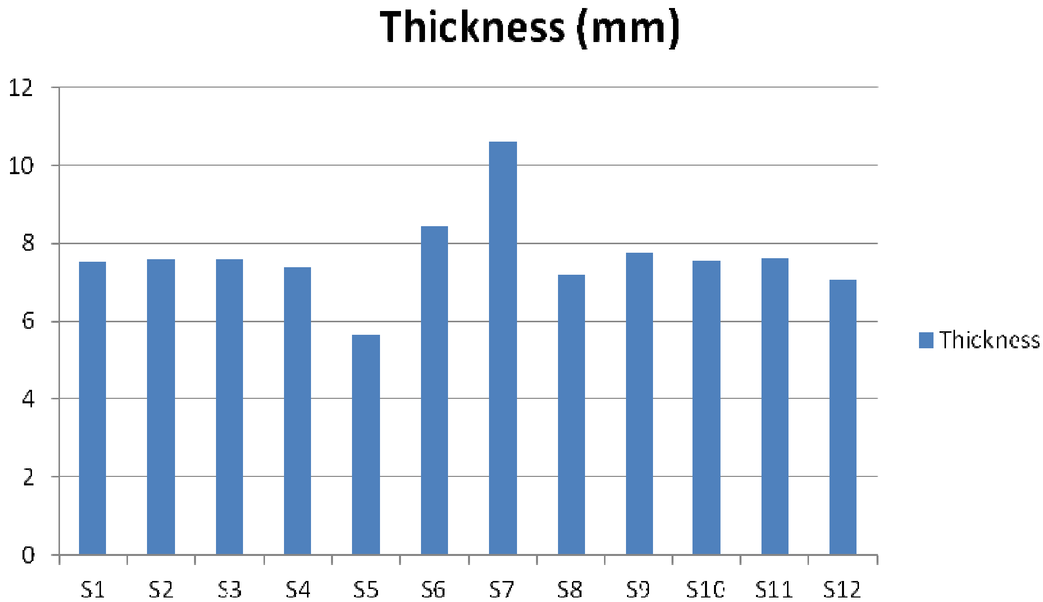


Figure 3-9 Thicknesses of spacer fabric samples

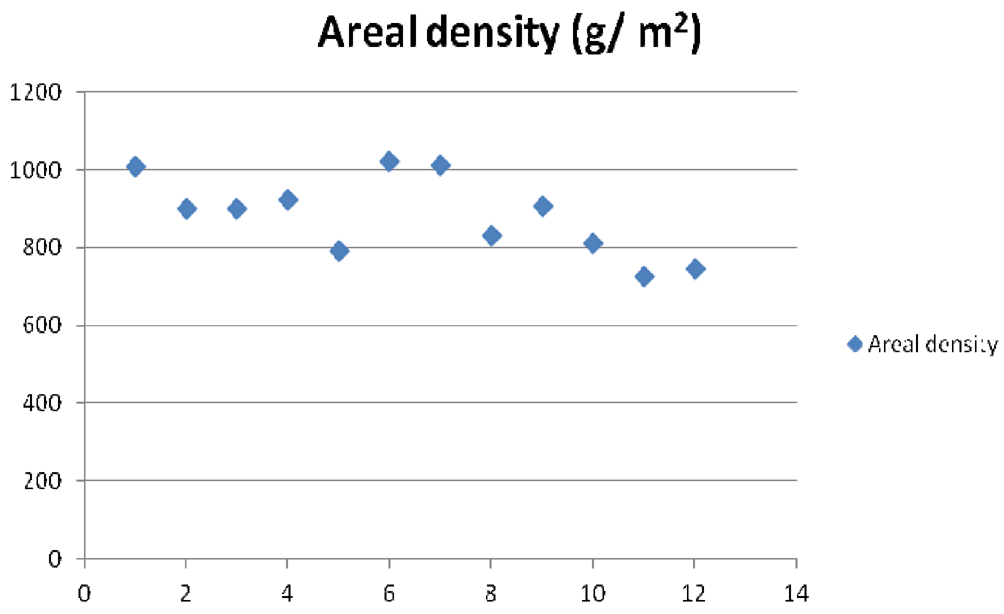


Figure 3-10 Areal density of spacer fabric samples

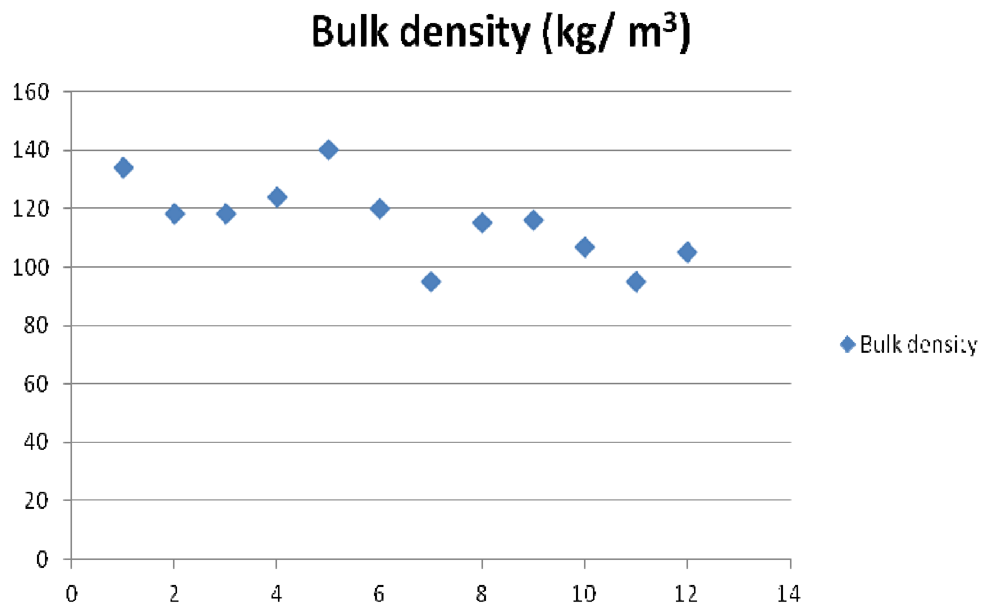


Figure 3-11 Bulk density of spacer fabric samples

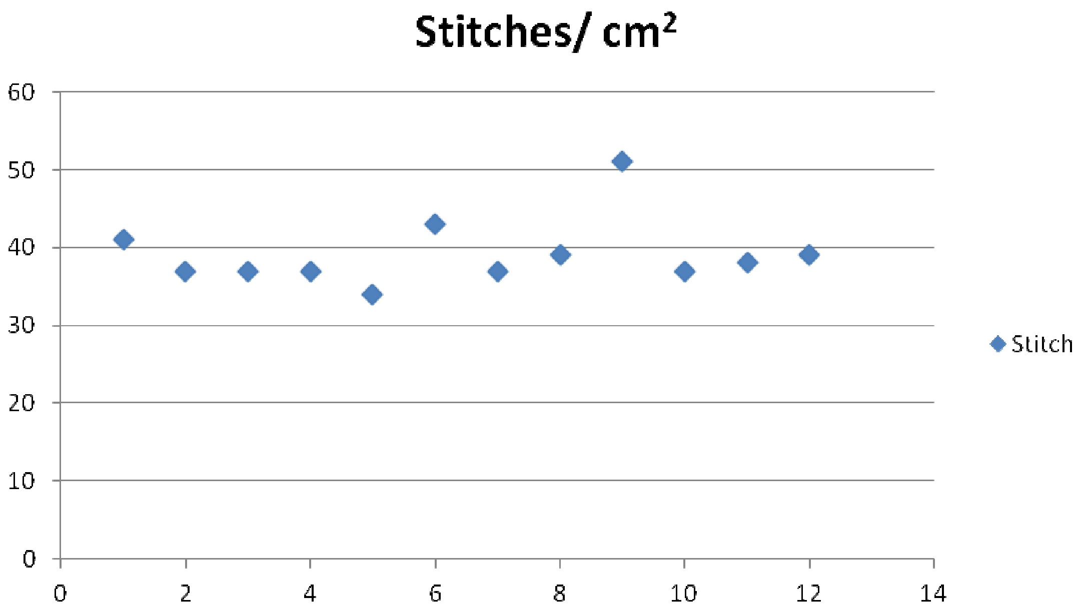


Figure 3-12 Stitch density of spacer fabric samples

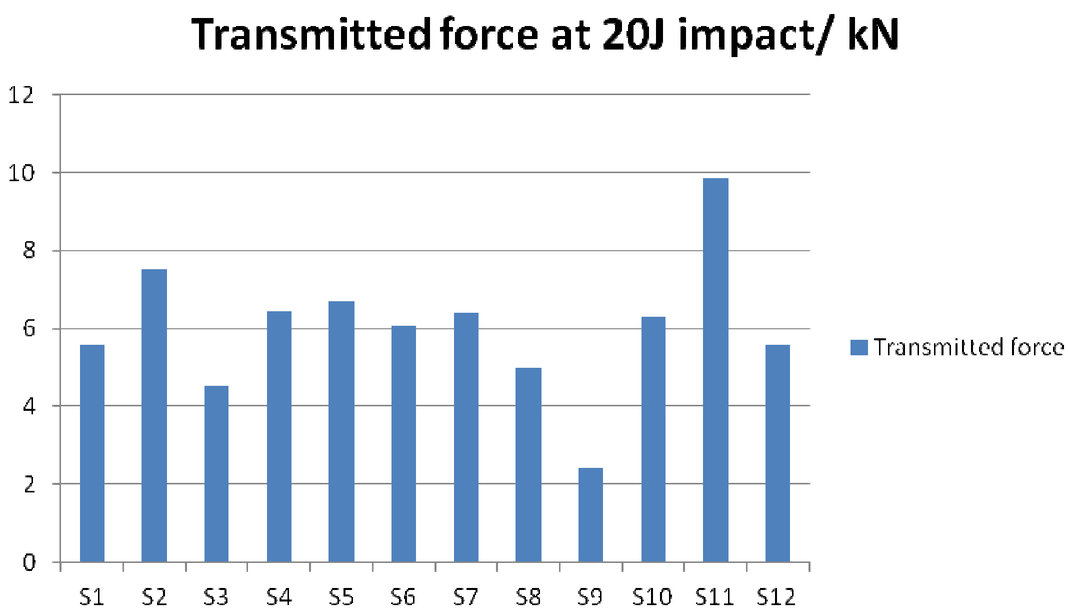


Figure 3-13 Transmitted force at 20J impact of spacer fabric samples

The selection of 3D spacer fabrics has been recommended to be based on the performance of different fabrics and the 3D spacer fabric with best shock absorbency should has the lowest value of transmitted force with an impact on a flat surface. S9 has the lowest value of transmitted force. However, S9 is too thick for the production of hip protector as it cannot be processed with cutting and sewing machines easily. Therefore, the 3D spacer fabric with the second lowest value of transmitted force and a reduced thickness, which is S3, has been selected for the production of hip protectors in this study.

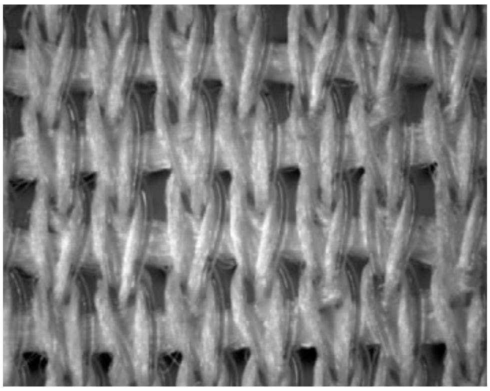


Figure 3-14 S3 sample

3.3. Apparel technologies for the application of 3D spacer fabrics

A combination of outstanding compressibility, high moisture conductivity, and good thermoregulation capability makes 3D spacer fabrics a suitable alternative cushioning materials for human body protection. However, the thicknesses of 3D spacer fabrics have made them difficult to be applied on protective clothing and experiments have been designed to evaluate numerous apparel technologies applied on 3D spacer fabrics.

3.3.1 Cutting methods for 3D spacer fabrics

3D spacer fabrics have having a special structures and the fraying edges of 3D spacer fabrics with polyester filaments protruding out after cutting give a very uncomfortable handle, and cause a lot of abrasion on skin. And experiments have been designed to evaluate the two cutting methods for 3D spacer fabrics.

3.3.1.1. Conventional cutting

There is fraying for edges of the 3D spacer fabric processed with conventional cutting method, despite the fact the edge in the wale direction gives a straighter appearance than the edge in the course direction after cutting, which is due to the warp knitting structure of the 3D spacer fabric.

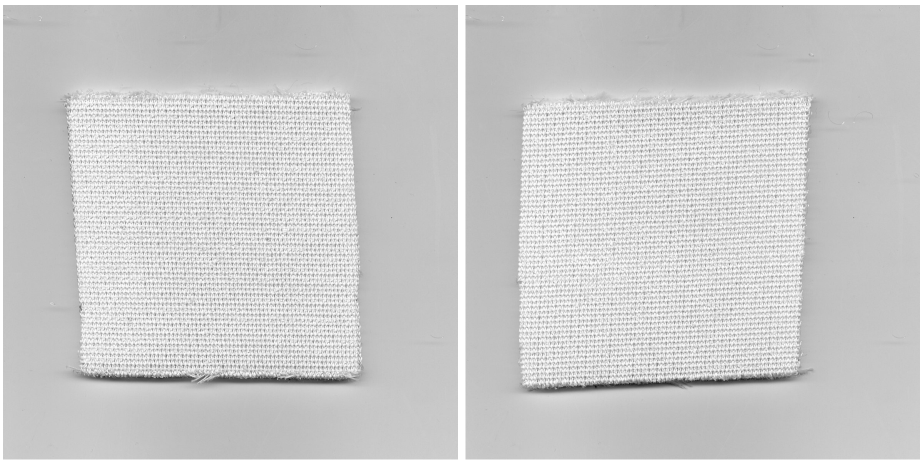


Figure 3-15 Front and back view of specimen for conventional cutting

Performance	**Rating**
Comfort of the edge	***
Neatness of the edge	*
Appearance of the edge	**
Efficiency in processing	*****
Effectiveness in edge finishing	*
Durability in edge finishing	*****
Change in thickness of the edge	*
Easiness to sew on shell fabric	*

Table 3-3 Performance and rating of conventional cutting

*Remarks: * is the least satisfied and ***** is the most satisfied.*

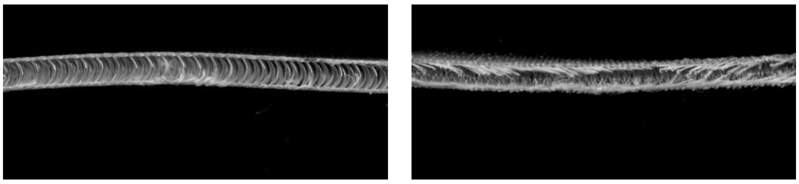


Figure 3-16 Side views from wale and course direction for conventional cutting

3.3.1.2. Laser cutting

There is no fraying for edges of the 3D spacer fabric processed with laser cutting method, and the edges give a neat appearance for both wale and course directions. However, the edge is hardened after being cut as the polyester filament is melt by the laser beams. And yellowing of the fabric comes about on the area around the edges.

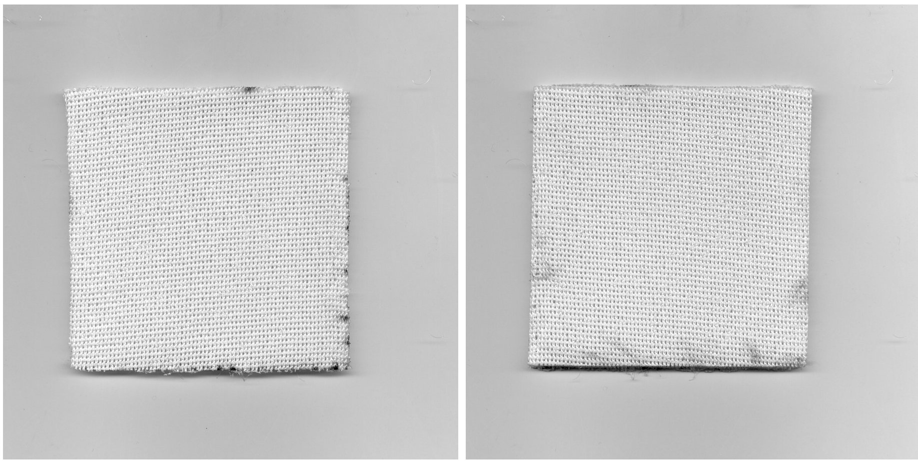


Figure 3-17 Front and back view of specimen for laser cutting

Performance	Rating
Comfort of the edge	*
Neatness of the edge	*****
Appearance of the edge	*****
Efficiency in processing	*****
Effectiveness in edge finishing	***
Durability in edge finishing	*****
Change in thickness of the edge	*
Easiness to sew on shell fabric	*

Table 3-4 Performance and rating of laser cutting

*Remarks: * is the least satisfied and ***** is the most satisfied.*

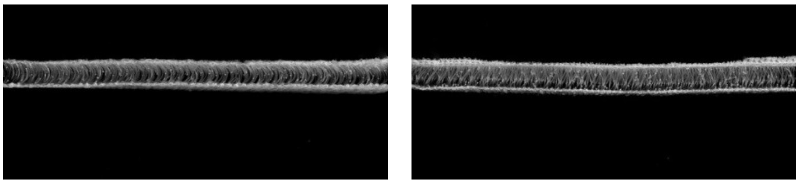


Figure 3-18 Side views from wale and course direction for laser cutting

3.3.2 Edge finishing methods

The thicknesses of 3D spacer fabrics have caused problems on edge finishing using conventional sewing machines and restricted the application of 3D spacer fabrics on protective clothing. Therefore, numerous edge finishing methods have been applied on the samples and their performances have been evaluated by subjective assessment.

3.3.2.1. Overlocking

There is no fraying for edges of the 3D spacer fabric processed with overlocking method, and the edges did not give a very neat appearance for both wale and course directions as some of the filaments are protruding out. Also, the edges give an abrasive handle as the fabric is compressed during the sewing process and the broken filaments are forced to move outward. And the sewing thread did not cover the edge very well, so many filaments are coming out and lead to poor handle.

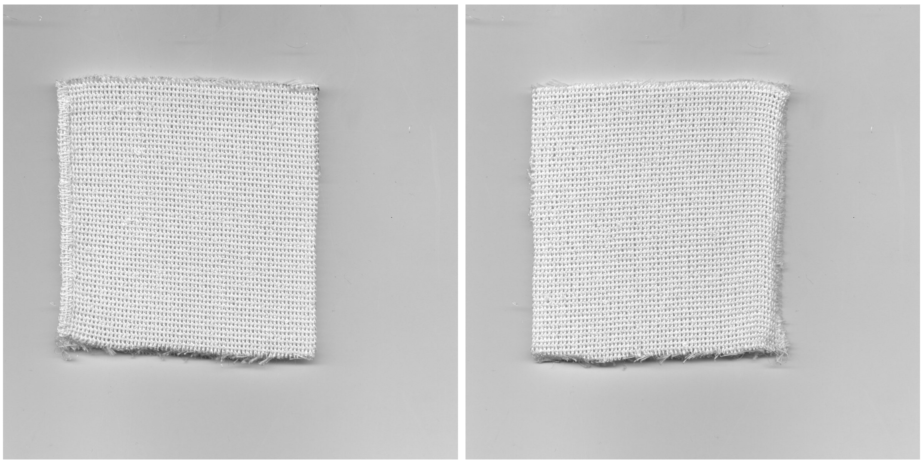


Figure 3-19 Front and back view of specimen for overlocking

Performance	Rating
Comfort of the edge	*
Neatness of the edge	*
Appearance of the edge	**
Efficiency in processing	*****
Effectiveness in edge finishing	*
Durability in edge finishing	*****

Change in thickness of the edge	****
Easiness to sew on shell fabric	**

Table 3-5 Performance and rating of overlocking

*Remarks: * is the least satisfied and ***** is the most satisfied.*

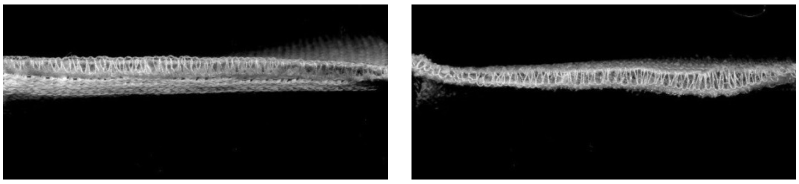


Figure 3-20 Side views from wale and course direction for overlocking

3.3.2.2. Binding

There is no fraying for edges of the 3D spacer fabric processed with binding method, and the edges by and large give a neat appearance for both wale and course directions, with the exception of when the binding tape was not yet fully cover the edge at the beginning of sewing. Nevertheless, the edges finished with binding give a good handle, the area around the edges give an abrasive handle as the 3D spacer fabric is packed down during the sewing process and the broken filaments are forced to move outward, so many filaments are coming out and lead to poor handle.

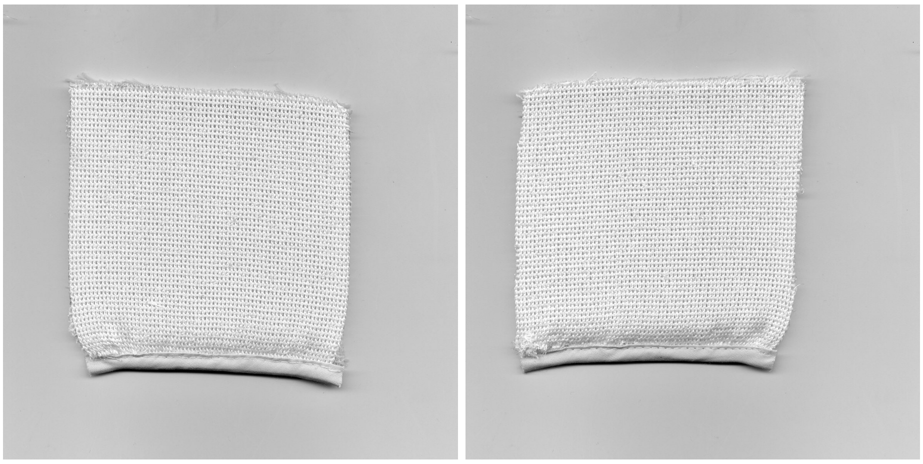


Figure 3-21 Front and back view of specimen for binding

Performance	Rating
Comfort of the edge	*****
Neatness of the edge	****
Appearance of the edge	****
Efficiency in processing	***
Effectiveness in edge finishing	****
Durability in edge finishing	*****

Change in thickness of the edge	*****
Easiness to sew on shell fabric	***

Table 3-6 Performance and rating of binding

*Remarks: * is the least satisfied and ***** is the most satisfied.*

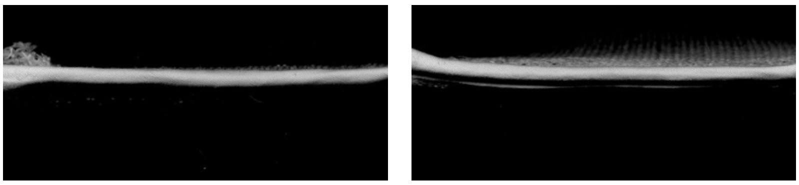


Figure 3-22 Side views from wale and course direction for binding

3.3.2.3. Interlining (one layer)

There is no fraying for edges of the 3D spacer fabric processed with interlining (one layer) method, and the edges give a straight appearance for both wale and course directions. However, the interlining is easy to tear off, hence do not cover the edge very well. And, the edges give an agreeable handle when they are covered by the interlining.

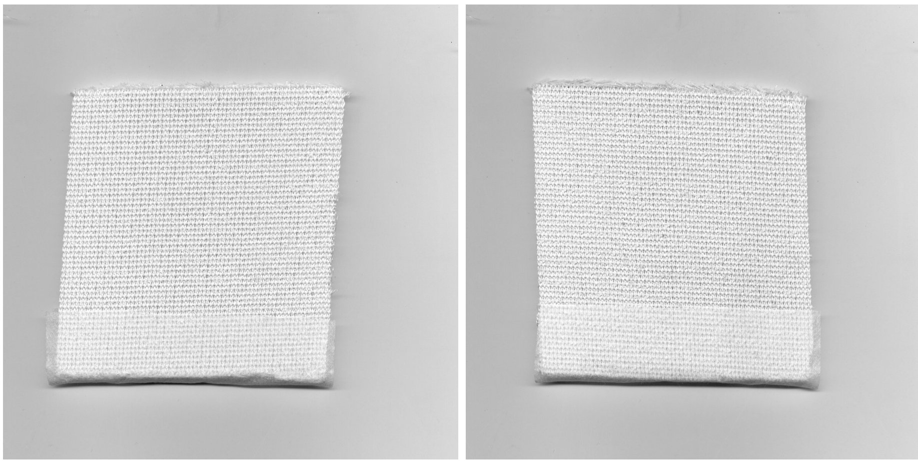


Figure 3-23 Front and back view of specimen for interlining (one layer)

Performance	Rating
Comfort of the edge	*****
Neatness of the edge	*****
Appearance of the edge	*****
Efficiency in processing	*****
Effectiveness in edge finishing	*****
Durability in edge finishing	*

Change in thickness of the edge	*
Easiness to sew on shell fabric	*

Table 3-7 Performance and rating of interlining (one layer)

*Remarks: * is the least satisfied and ***** is the most satisfied.*

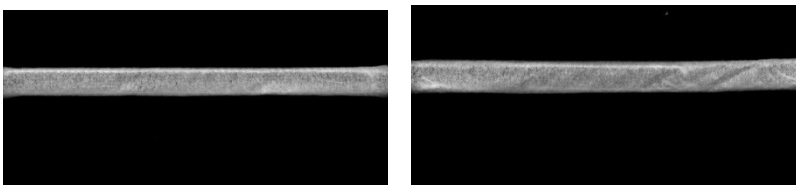


Figure 3-24 Side views from wale and course direction for interlining (one layer)

3.3.2.4. Interlining (two layers)

There is no fraying for edges of the 3D spacer fabric processed with interlining (two layer) method, and the edges give a neat appearance for both wale and course directions. However, the interlining is easy to tear off, hence do not cover the edge very well. And, the edges give a satisfactory handle when they are covered by the interlining.

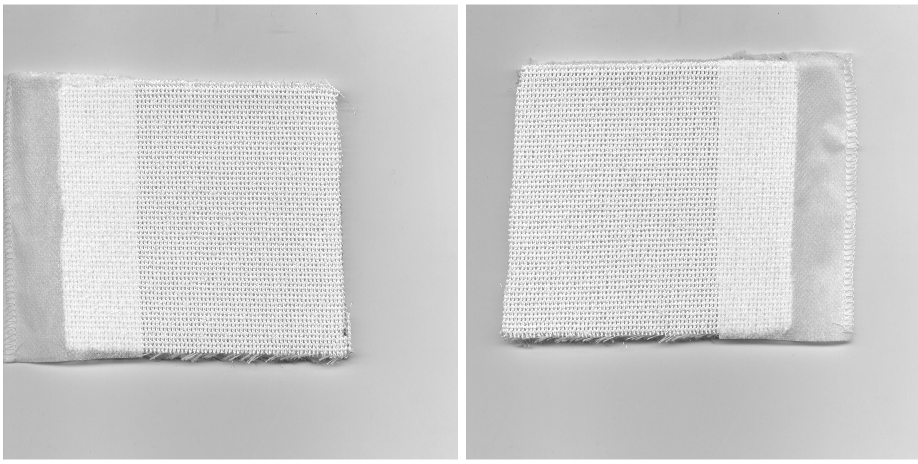


Figure 3-25 Front and back view of specimen for interlining (two layers)

Performance	Rating
Comfort of the edge	*****
Neatness of the edge	*****
Appearance of the edge	*****
Efficiency in processing	*****
Effectiveness in edge finishing	*****
Durability in edge finishing	*

Change in thickness of the edge	*
Easiness to sew on shell fabric	*****

Table 3-8 Performance and rating of interlining (two layers)

*Remarks: * is the least satisfied and ***** is the most satisfied.*

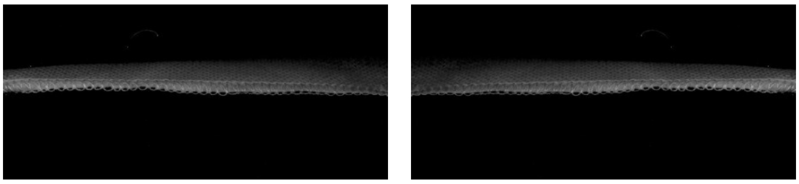


Figure 3-26 Side views from wale and course direction for interlining (two layers)

3.3.2.5. Heating

There is no fraying for edges in the wale direction of the 3D spacer fabric processed with heating method using a 14W ceramic heating element at 450°C ± 5%, despite the fact the two surfaces of the edge are protruding outward in the course direction. The edges give a neat appearance in wale direction and an undesirable appearance in course direction. Also, the edges are very hard that give a very scratchy handle and cause serious abrasion on skin.

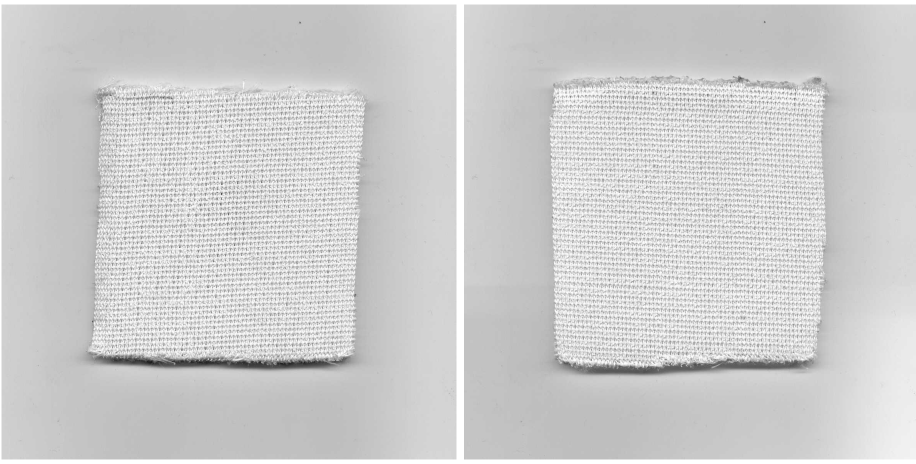


Figure 3-27 Front and back view of specimen for heating

Performance	Rating
Comfort of the edge	*
Neatness of the edge	****
Appearance of the edge	*****
Efficiency in processing	****
Effectiveness in edge finishing	****
Durability in edge finishing	*

Change in thickness of the edge	****
Easiness to sew on shell fabric	*

Table 3-9 Performance and rating of heating

*Remarks: * is the least satisfied and ***** is the most satisfied.*

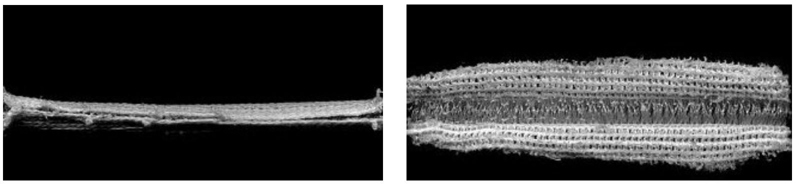


Figure 3-28 Side views from wale and course direction for heating

3.3.2.6. Silicon application

There is no fraying for edges of the 3D spacer fabric processed with silicon application method, and the edges did not give a very neat appearance for both wale and course directions as some of the filaments are protruding out with silicon surrounding them. However, the edges did not give an abrasive handle as the silicon give a softer and evener finish to the edges. However, the application of silicon take a long processing time as the silicon used need to take 10 days to be completely dry in standard condition.

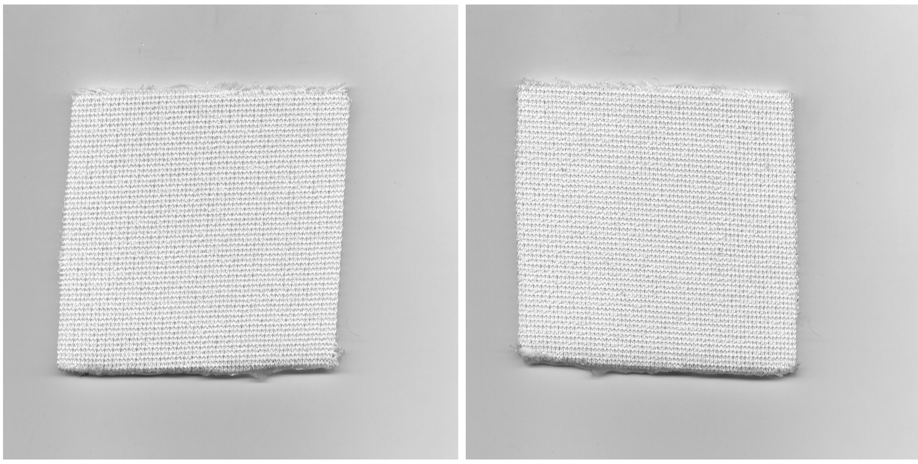


Figure 3-29 Front and back view of specimen for silicon application

Performance	Rating
Comfort of the edge	****
Neatness of the edge	***
Appearance of the edge	***
Efficiency in processing	*
Effectiveness in edge finishing	**
Durability in edge finishing	*****

Change in thickness of the edge	*
Easiness to sew on shell fabric	*

Table 3-10 Performance and rating of silicon application

*Remarks: * is the least satisfied and ***** is the most satisfied.*

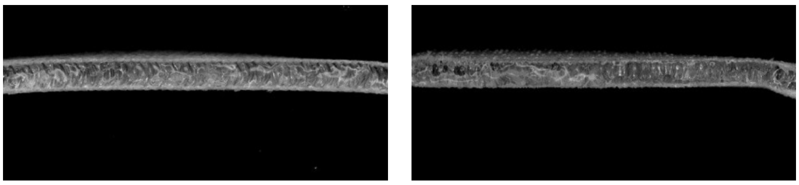


Figure 3-30 Side views from wale and course direction for silicon application

3.3.3. Survey results and discussion

The selection of cutting and edge finishing method has been recommended to be based on the result of subjective assessment. Therefore subjective assessment has been carried out in the way of conducting a survey among 100 textiles students. In the survey, interviewees have been given a set of 16 samples with numerous cutting and edge finishing methods in either wale or course direction of the 3D spacer fabrics and a copy of questionnaire asking for their attitudes towards the properties of spacer fabric specimen treated with numerous cutting and edge finishing methods: conventional cutting, laser cutting, silicon application, overlocking, binding, interlining (one layer), interlining (two layers) and heating, and their ratings on different specimens have been referred in the selection process.

Sample	**Description**	**Direction**
1a	Conventional cutting	Wale
1b	Conventional cutting	Course
2a	Laser cutting	Wale
2b	Laser cutting	Course
3a	Overlocking	Wale
3b	Overlocking	Course
4a	Binding	Wale
4b	Binding	Course
5a	Interlining (one layer)	Wale

5b	Interlining (one layer)	Course
6a	Interlining (two layers)	Wale
6b	Interlining (two layers)	Course
7a	Heating	Wale
7b	Heating	Course
8a	Silicon application	Wale
8b	Silicon application	Course

Table 3-11 Sample detail in survey

Previous study has explained that the subjective assessment result can be influenced by many factors, such as the personality and state of mind or health of the interviewees and internal assessment scaling. Therefore, it becomes very important to avoid analysis techniques which are invalid, and the quality of the assessors, the assessment procedure, assessment scaling and analysis methods have to be well considered before carrying out the assessment so as to improve the reliability of the results of the subjective assessment (Fan, Yu, & Hunter, 2004).

It has been found that the validity of the average rating increases when the number of assessors increases as any individual differences in health, state of mind, etc. can be cancelled out. However, it has been explained that the reliability of assessment cannot be increased by further increasing the number of assessors beyond a certain level (Fan, et al., 2004). Therefore, the number of interviewees has been control to a level around 100 for a better balance between the reliability of assessment and the consumption of time.

Besides, it has been explained that assessors may try to give appropriate results in their mind which may lead to certain level of bias in the experimental results (Fan, et al., 2004). Therefore, the assessors have not been told about the aims of the assessment so they may not know what effect a response will have on the investigation.

The assessment scale and rating technique should also be devised carefully for a more reliable assessment results. The intervals between the grades should be equal to each other in ideal case (Fan, et al., 2004). However, it is almost impossible to classify the performances of the 3D spacer fabrics processed with numerous cutting and edge finishing methods into rating with equal intervals and it is hard to manage if all the assessors follow the same scaling when answering the questions in survey, so a points system has been applied for a more comparable result, despite the fact 5 represents the highest rating, followed by 4, 3, 2 and 1 represents the lowest rating.

	Appearance		Comfort		Durability		Effectiveness		Neatness			
Sample	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Total Mean	Total S.D.
1	1.79	0.80	1.86	0.77	1.86	1.17	1.43	0.51	2.14	1.17	1.81	0.92
2	2.29	1.59	1.43	0.76	2.93	1.64	2.14	1.41	2.29	1.27	2.21	1.41
3	1.93	0.92	2.21	0.89	3.21	1.31	2.79	1.05	2.71	1.07	2.57	1.12
4	4.29	0.73	4.00	0.78	4.29	0.83	4.07	1.00	4.21	0.89	4.17	0.83
5	4.43	0.51	4.07	0.83	3.36	1.15	4.21	0.80	4.29	0.61	4.07	0.87
6	3.14	1.03	3.50	1.09	2.93	1.44	3.36	1.15	3.57	1.28	3.30	1.20
7	1.50	0.94	1.21	0.58	2.64	1.39	2.07	1.49	1.57	1.09	1.80	1.22
8	2.57	1.09	2.64	1.08	3.36	1.08	2.86	1.17	2.43	1.16	2.77	1.13

Table 3-12 Result of the survey

At the end of the survey, a hundred copies of questionnaires have been collected while two of them have been removed from the database as the interviewees did not answer all the questions in the questionnaires and made the two questionnaires invalid for further analysis.

The result of the survey has been summarized in Table 3-12. It has been shown that sample 4, binding, has the highest overall rating, followed by sample 5 and 6, interlining (1 layer) and interlining (2 layers). Therefore, it has been concluded using binding is the more favoured edge finishing method among eight methods in the experiment. Its ratings among all the five areas of performance are very high. Although sample 5 also has high ratings on areas of appearance, comfort, effectiveness and neatness, its performance on the durability is significantly lower than that of sample 4. It is principally because that the binding is applied onto the 3D spacer fabrics by stitching, despite the fact the interlining is applied onto the 3D spacer fabrics by heating and pressing, and the bonding between the 3D spacer fabric, binding and the line of stitching is much stronger that that between the 3D spacer fabric, interlining and the resin. However, durability is a very important factor of the edge finishing method applied as it is related to the life span of the edge finishing and hence the protective pads made of 3D spacer fabric. Therefore, binding has been selected for the edge finishing of 3D spacer fabrics for the production of protective pads in this study.

3.4. Effect of different sewing methods on 3D spacer fabrics

Sewing of 3D spacer fabrics in clothing area is still a critical problem unsolved due to the special structures and thicknesses of 3D spacer fabrics, which also limited the uses of 3D spacer fabrics in clothing.

In this study, the common sewing problems of 3D spacer fabrics are breaking needles, skipping stitches; sewing machine thread is tangling, bunching, or breaking. The needle breaks when the 3D spacer fabrics are forced through the feed. 3D spacer fabrics are forced as the 3D spacer fabrics are too thick to be pressed under the presser foot of a conventional sewing machine, and the feed dog fails to work in conjunction with the machine's feeding system to improve the flow of the fabric. In this case, the needle bends or even breaks; a bent needle may hit the hook when sewing, which can lead to broken needles and damage to the hook. Although there are different needle sizes for different thicknesses of the material being sewn. Appropriate needles for 3D spacer fabrics are still hard to find and specialty needles for 3D spacer fabrics should be designed. Skipped stitches are also caused by a damaged or bent needle. The needle is damaged by sewing 3D spacer fabric, which is too thick for the needle and caused sewing problems.

Sewing of 3D spacer fabrics may lower their compression properties by altering their thicknesses and physical properties. Therefore, experiments have been carried out to investigate the relationship between the compression properties and top stitching applied as well as the relationship between the distortion of fabric and the density, direction and pattern of the top stitching applied. The compression properties can be evaluated by compressive load-extension curves, cushioning curves, efficiency curves, ideality curves, energy absorption diagrams, Janssen factor and Rusch curves and compressive load-extension curves have been used in this study to show the relationship between compression and extension of 3D spacer fabrics.

The spacer fabric used is produced on a GE296 high speed double-needle bar Raschel machine of six yarn guide bars, supported by Wuyang Warp Knitting Machine Ltd. The machine gauge used is E18 and the material used is 300D/96F polyester multifilament. The structure of the sample is having chain and inlay on both top and bottom outer layer, and one lapping in spacer layer. It has 7.57 ± 0.08mm for thickness; 900/11 ± 9.01g/m^2 for areal density and 37.95 stitches per cm^2.

60 specimens have been produced by applying several types of top stitching, including different distance between lines of top stitching, different angle of lines of top stitching, different number of set of top stitching, and different direction of top stitching, on the spacer fabric 100mm × 100mm in size using Brother S6200-403 UBT Lockstitch machine. The thread used is spun polyester thread (SZFR1851664) from COATS, the sewing speed used is about 500 stitches per minute and the stitch length is 1.5mm.

After the specimen preparation, the specimens of 3D spacer fabrics were tested on an INSTRON 5566 device, set up with two compression circular platens of 150mm in diameter according to the Standard Test Methods for Rubber Properties in Compression ASTM D575 to evaluate their compression properties. The compression tests were conducted at a speed of 12mm/min up to a deformation until the thickness of each specimen have been reduced for 5mm or when the load is greater than 10kN under the standard condition of 20°C and 65% relative humidity.

Five tests were carried out for each sample with five different specimens with same configuration under the standard condition mentioned. Each compressive extension-compressive load curve presented is an average of three experimental results with the most deviated result being removed since there is always deviation among the specimens prepared for each sample, which may be due to the problems related to sewing during specimen preparation.

Also, the specimens have been scanned and the interior angle between the wale and course direction has been measured using computer-aided design software to evaluate the relationship between fabric distortion and several types of top stitching and therefore any distortion resulted from top stitching can be measured and considered. Otherwise, distortion may also be appeared on the hip protectors and other protective clothing made with the 3D spacer fabric.

3.4.1. Different distance between lines of top stitching

Specimen	**Distance between lines of top stitching**
D1	5mm
	• Spun polyester thread (SZFR1851664) from COATS • Sewing speed: 500 stitches per minute • Stitch length is 1.5mm

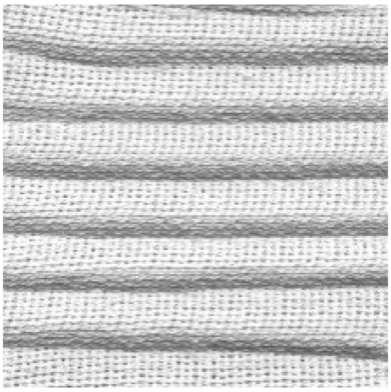
D2	10mm	
	• Spun polyester thread (SZFR1851664) from COATS • Sewing speed: 500 stitches per minute • Stitch length is 1.5mm	
D3	40mm	
	• Spun polyester thread (SZFR1851664) from COATS • Sewing speed: 500 stitches per minute • Stitch length is 1.5mm	

Table 3-13 Specimens produced with different distance between lines of top stitching

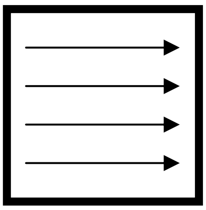
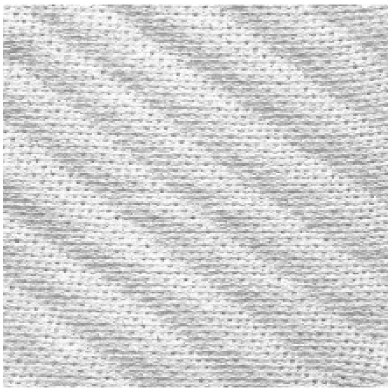
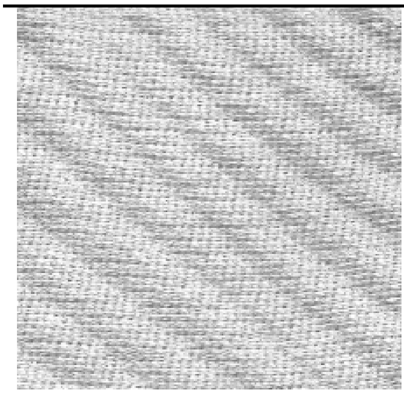


Figure 3-31 Direction of sewing on specimen D1, D2 and D3

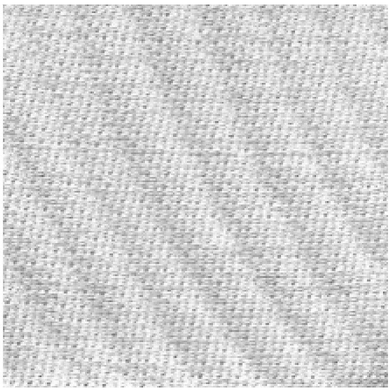
3.4.2. Different angle of lines of top stitching

Specimen	**Angle of lines of top stitching (to the wale direction)**
A1 	0° • Spun polyester thread (SZFR1851664) from COATS • Sewing speed: 500 stitches per minute • Stitch length is 1.5mm
A2 	30° • Spun polyester thread (SZFR1851664) from COATS • Sewing speed: 500 stitches per minute • Stitch length is 1.5mm
A3	45° • Spun polyester thread (SZFR1851664) from COATS • Sewing speed: 500 stitches per minute



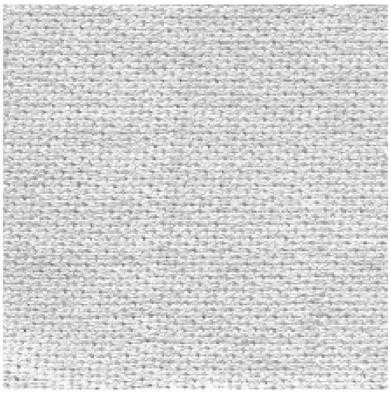
- Stitch length is 1.5mm

A4 60°



- Spun polyester thread (SZFR1851664) from COATS
- Sewing speed: 500 stitches per minute
- Stitch length is 1.5mm

A5 90°



- Spun polyester thread (SZFR1851664) from COATS
- Sewing speed: 500 stitches per minute
- Stitch length is 1.5mm

Table 3-14 Specimens produced with different angle of lines of top stitching

Remark: The distance between adjacent lines of top stitching is 10mm for all the above specimens.

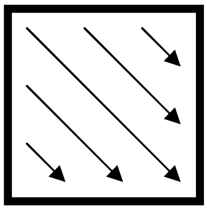
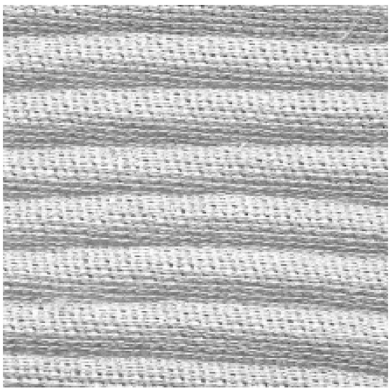


Figure 3-32 Direction of sewing on specimen A1, A2, A3, A4 and A5

3.4.3. Different number of set of top stitching

Specimen	**Number of set of top stitching**
N1 	1 • Spun polyester thread (SZFR1851664) from COATS • Sewing speed: 500 stitches per minute • Stitch length is 1.5mm
N2	2 • Spun polyester thread (SZFR1851664) from COATS • Sewing speed: 500 stitches per minute

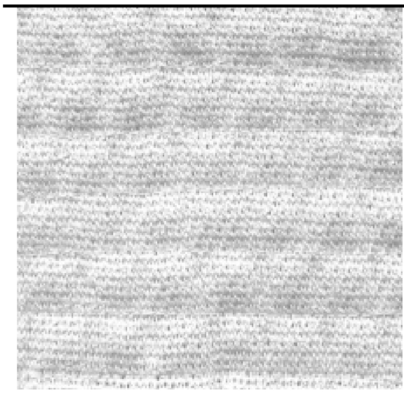
	• Stitch length is 1.5mm

Table 3-15 Specimens produced with different number of set of top stitching

Remark: The distance between adjacent lines of top stitching is 10mm for all the above specimens.

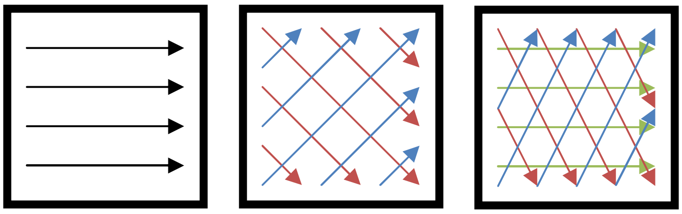


Figure 3-33 Direction of sewing for different set of top stitching on specimen N1, N2 and N3

Remarks: The distance between adjacent lines of top stitching in each set is 10mm for all the above specimens. In addition, serious sewing problems have occurred when preparing the specimen N3, so it has been removed from the study.

3.4.4. Different direction of top stitching

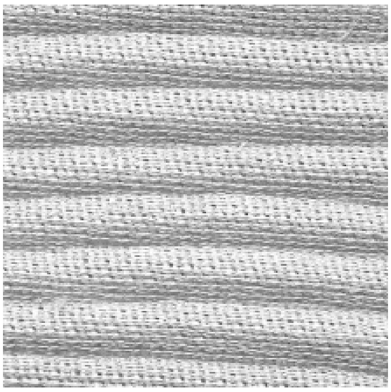
Specimen	Direction of top stitching
W1 	Forward • Spun polyester thread (SZFR1851664) from COATS • Sewing speed: 500 stitches per minute • Stitch length is 1.5mm
W2 	Forward and backward (alternatively) • Spun polyester thread (SZFR1851664) from COATS • Sewing speed: 500 stitches per minute • Stitch length is 1.5mm

Table 3-16 Specimens produced with different direction of top stitching

Remark: The distance between adjacent lines of top stitching is 10mm for all the above specimens.

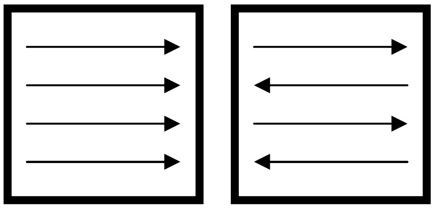


Figure 3-34 Direction of sewing on specimen W1 and W2

3.4.5. Experimental results and discussion

The compressive load-extension curves for the specimens produced with different distance between lines of top stitching are shown in Figure 3-35. The raw spacer fabric exhibits a rapid increase of the compression load when the compressive extension is lower than 2mm. Subsequently, a long plateau with relatively constant load was observed. It can also be found that the compressive resistance of the fabric decreases significantly after adding top stitching. This can be explained that the stitches added during the sewing process change the geometrical configuration of the spacer yarns in the fabric. Both the top and bottom layers were sewn together thereby the spacer yarns close to the top stitching tilted along the walewise direction. It can also be found from the previous studies that the compressive load of the spacer yarn depends on the initial geometrical shape (Yanping Liu & Hu, 2011) and the binging condition (Y. Liu, Hu, Long, & Zhao, 2012). Higher compressive load can be obtained when the spacer yarn are oriented to the direction of compression. Therefore, the compressive performance of the fabric is greatly reduced after the sewing process. It is obvious that the load level decreases when the distance between lines of top stitching decreases. It is because that the specimens with less distance between lines of top stitching have a higher density of stitches. For the fabric with the highest density of stitches, its plateau stage disappeared and it enters the densification stage directly because the sewing process can decrease the thickness of the 3D spacer fabrics while the space between the two outer layers decreases. Therefore, the fabric with less distance between lines of top stitching is easier to enter densification stage.

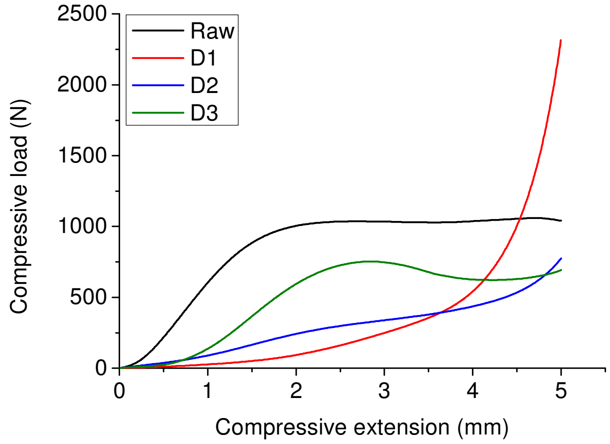


Figure 3-35 Compressive load-compressive extension curves for specimen D1, D2, and D3 compared with untreated 3D spacer fabric

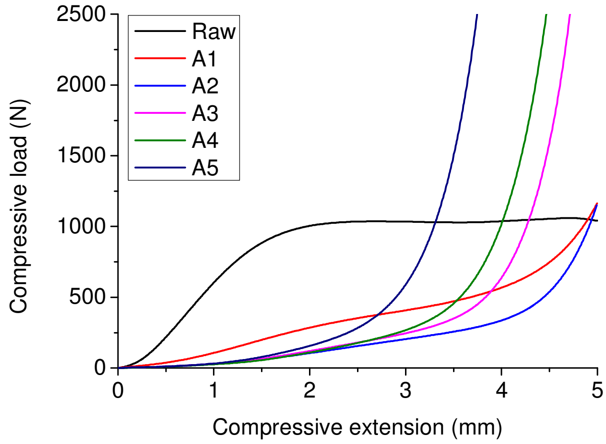


Figure 3-36 Compressive load-compressive extension graph for specimen A1, A2, A3, A4 and A5 compared with untreated 3D spacer fabric

The compressive load-extension curves for the specimens sewn with different angles of lines of top stitching are shown in Figure 3-36. It is similar to the result of the fabrics with different distance between lines of top stitching. The compressive resistances of the specimens reduced significantly. It shows that the larger the angles of lines of top stitching, the lower the compressive resistances. The top stitching with an angle to the walewise direction makes the spacer yarns tilting to both walewise and coursewise directions. This kind of tilting makes the spacer yarns easier to shear and thereby lowered the compressive resistance of the specimens.

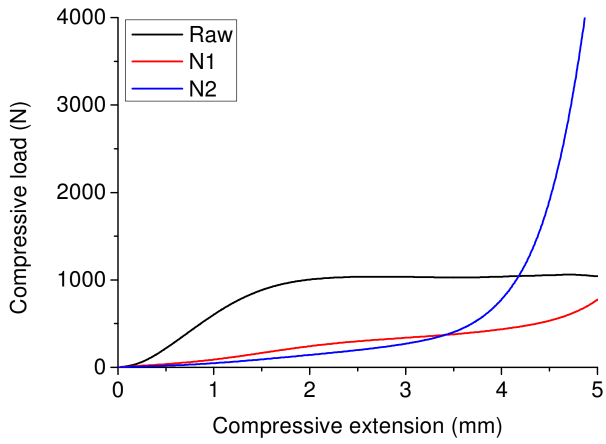


Figure 3-37 Compressive load-compressive extension graph for specimen N1 and N2 compared with untreated 3D spacer fabric

The compressive load-extension curves for the specimens sewn with different sets of top stitching are shown in Figure 3-37. The results are as expected that the specimens sewn with two sets of top stitching have a lower compressive resistance. The reason is as same as the effect of the different angles of lines of top stitching that two sets of stitch can make the spacer yarns tilting to both walewise and coursewise directions. The tilted spacer yarns are easier to shear under compression, and therefore reduce the compressive resistance.

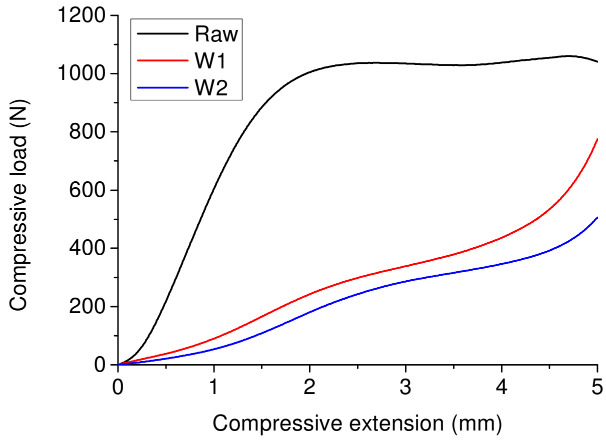


Figure 3-38 Compressive load-compressive extension graph for specimen W1 and W2 compared with untreated 3D spacer fabric

The compressive load-extension curves for the specimens sewn with one-way and two-way top stitching are shown in Figure 3-38. The specimens sewn with two-way top stitching possesses lower compressive resistance when compared with those sewn with one-way top stitching. Two-way stitching disturbed the distribution of the spacer yarns. In this way, the spacer yarns are getting less oriented to the compressive directions.

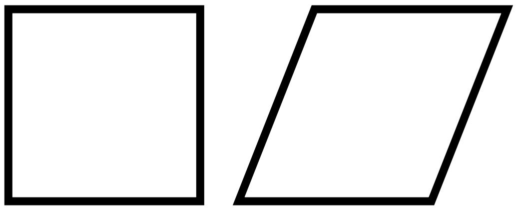


Figure 3-39 Dimensional differences of 3D spacer fabric before and after applying top stitching

The specimens tend to distort after having top stitching on it. For specimens with different distance between lines of top stitching, the interior angle between the wale and course directions range from 72.56° to 86.43°. It is found that the interior angle is sharper when the distance between lines of top stitching is closer.

For specimens with different angle of lines of top stitching, the interior angle between wale and course directions range from 77.52° to 81.82°. It is found that there is no significant relationship between the angle of lines of top stitching and the interior angle measured between the wale and course directions on the distorted specimens.

Specimen	**Interior angle between wale and course directions**
D1	72.56°
D2	76.62°
D3	83.88°
D4	86.43°

Table 3-17 Interior angles between wale and course directions
for specimen with different distance between lines of top stitching

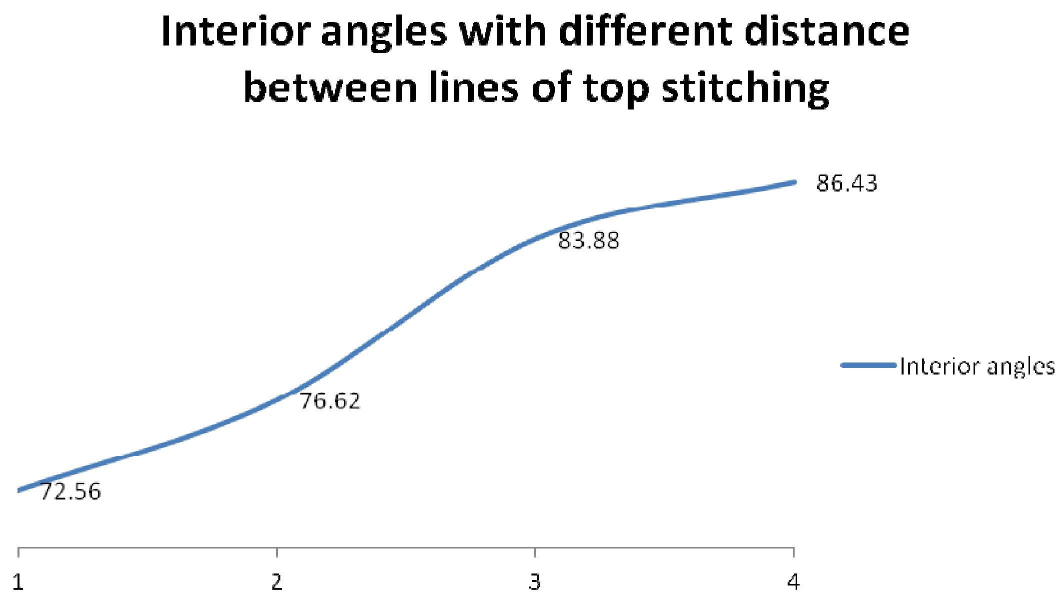


Figure 3-40 Interior angles with different distance between lines of top stitching for specimen D1, D2, D3 and D4

Specimen	**Interior angle between wale and course directions**
A1	79.68°
A2	78.09°
A3	81.50°
A4	77.52°
A5	81.82°

Table 3-18 Interior angles between wale and course directions

for specimen with different angle of lines of top stitching

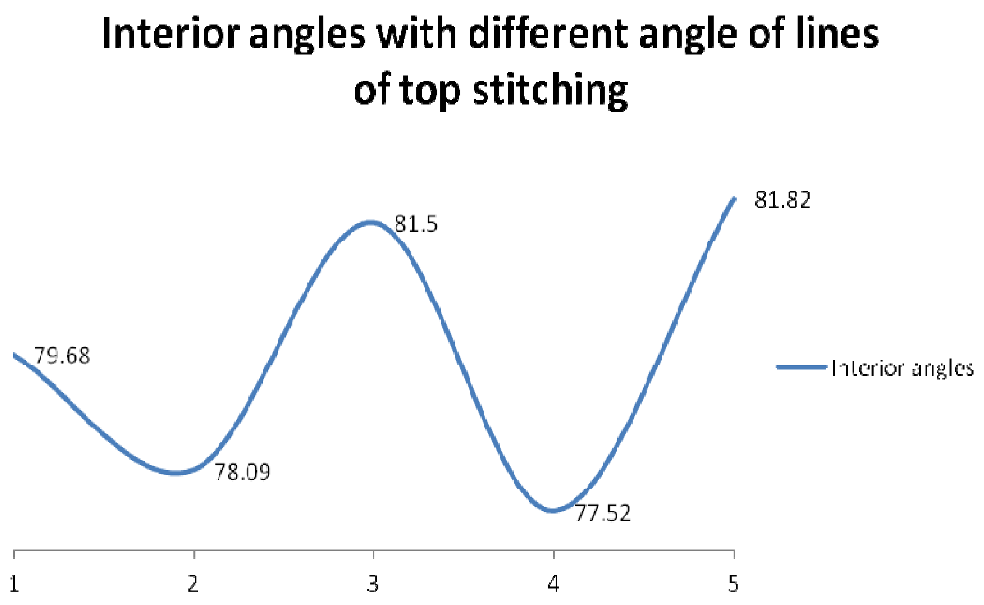


Figure 3-41 Interior angles with different angle of lines of top stitching

for specimen A1, A2, A3, A4, A5

The selection of sewing method has been proposed to be based on the result of objective assessment. Therefore, several types of top stitching have been added on top of the 3D spacer fabrics to investigate the relationship between the compression properties and top stitching applied as well as the relationship between the distortion of fabric and the density, direction and pattern of the top stitching applied. It has been found that the top stitching brings a destructive effect on the compression properties of 3D spacer fabrics and the distortion of fabric increases as the density of top stitching increases. Therefore, sewing has only been done on the edge of the 3D spacer fabrics to avoid lowering the compression properties of 3D spacer fabrics significantly.

3.5. Summary

Experiments related to the physical properties of 3D spacer fabrics, numerous cutting and edge finishing methods and sewing methods have also been explained. 3D spacer fabrics to be used in this study have been selected based on their physical properties. Cutting and edge finishing method has been selected based on the subjective assessment by textile student, despite the fact the subjective assessment has been carried out in the form of survey and the feedback has been given based on the subjective assessment of different samples with numerous cutting and edge finishing method applied. Also, sewing method has been decided based on the objective evaluation of experimental results

CHAPTER 4 DEVELOPMENT OF PROTOTYPE

4.1. Introduction

In this chapter, a collection of hip protectors has been developed by design approach to improve their comfort, convenience and aesthetics, the production of assorted styles of hip protectors has been explained in detail. And the products produced has been presented and investigated.

4.2. Production specifications

Prototype of hip protectors have been designed and produced based on the experimental results from chapter 3. It has been found that both protective function and comfort are the crucial factors in the performance of hip protectors, therefore the design of the hip protectors has been focused on the optimization of the comfort and the appearance of the hip protectors, together with the application of functional technology.

4.2.1. Materials for production of prototype

Nine different styles of hip protectors have been designed in this study and they have been produced using four different knitted fabrics, which are 96% polyester 4% spandex fabric, 96% cotton 4% spandex fabric, 60% bamboo 35% cotton 5% spandex fabric and 55% polyester 40% cotton 5% spandex fabric.

4.2.2. *Equipment for production of prototype*

Brother S6200-403 UBT Lockstitch machine has been used for the production of protective pads in this study. The threading applied is spun polyester thread (SZFR1851664) from COATS with sewing speed around 500 stitches per minute, and the stitch length is 1.5mm.

4.2.3. *Pattern development*

There are different standards for garment fit, including live models and dress forms, and they all have their own advantages and disadvantages (Fan, et al., 2004).

Fitting standard	Advantage	Disadvantage
Live model	Real body shape	Subjective and qualitative
	Real movement	Psychological interruption
Dress form	Static and convenient to use	Subjective and qualitative
	High repeatability	Personal assessment of tension

Table 4-1 Comparison of different fitting standards (Fan, et al., 2004)

Hip protectors were designed to protect the hip from fracture. Since hip fracture is often as a result of osteoporosis and patients of osteoporosis usually have a comparatively small body size, the pattern of the prototype is constructed based on a size 10 dummy by draping for a better fit and precise cutting. And nine different styles of hip protectors have been developed in this chapter.

4.2.4. Design of hip protectors

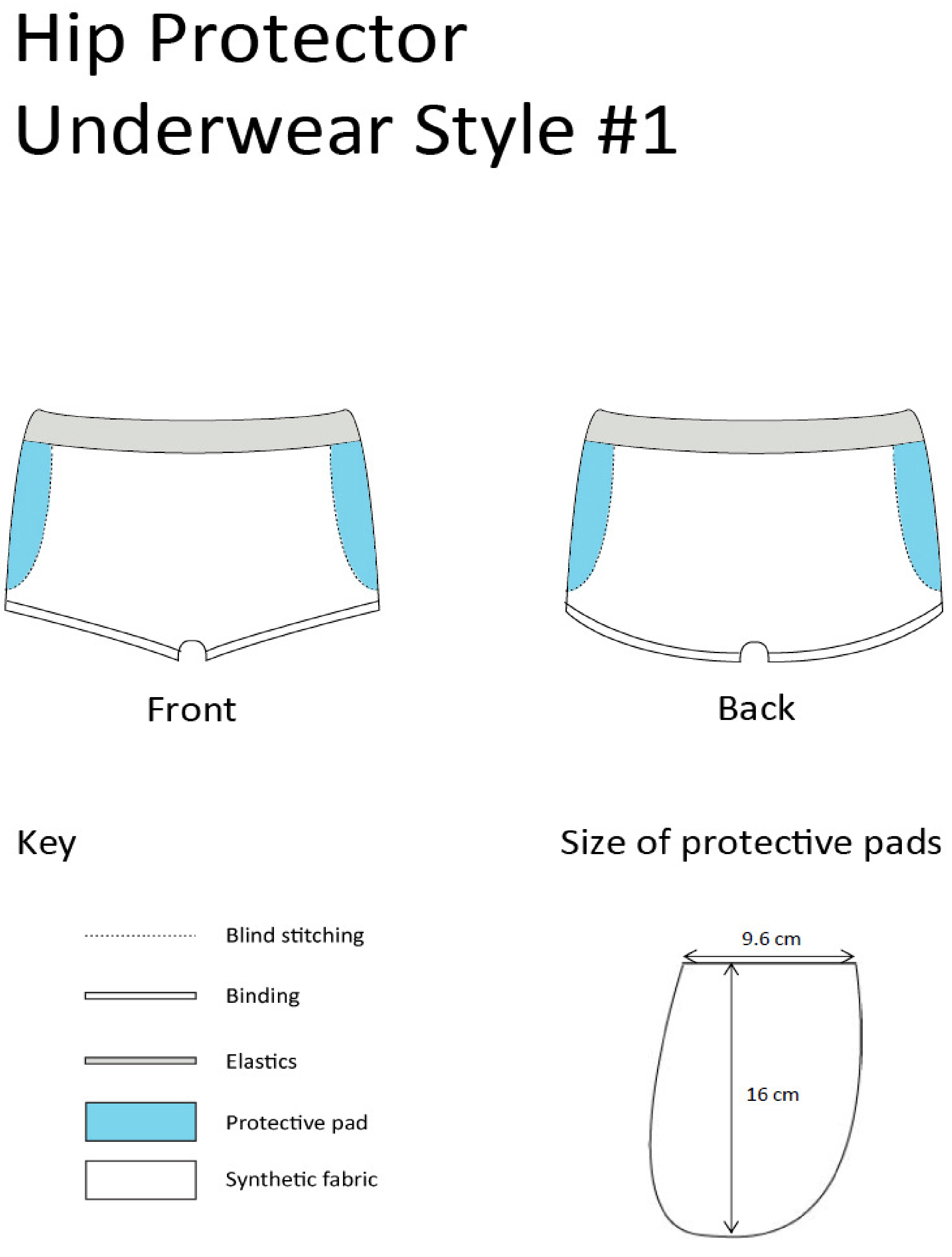


Figure 4-1 Production specification of hip protector style 1

This is a plain design of hip protector with protective pads on two sides of the protector to protect the hips from fracture following a fall. This design has a low waistline. There is an elastic waist band for the protector and binding for the hem finishing.

Features:

1. The fabric used is knitted 96% polyester 4% spandex fabric which is ordinarily used for underclothes. It is generally adopted for making hip protectors in order to achieve a close fit and guarantee that the protective pads are positioned at correct positions over the hip areas in order to accomplish the optimal protection.

2. The protective pads are sewn on the shell fabric of the hip protector for a fixed position and the pads can stay on the right position during movement or a fall to protect the hip areas and provide optimal protection. And the users need not to spend time on placing the pads on the right position after taking it out for laundry.

3. The low waistline allows the user to wear assorted types of pants without showing the hip protectors, so the user can have more versatile choices of clothing. And other people will not know if they are wearing a hip protector, hence the acceptance of this protector can be improved.

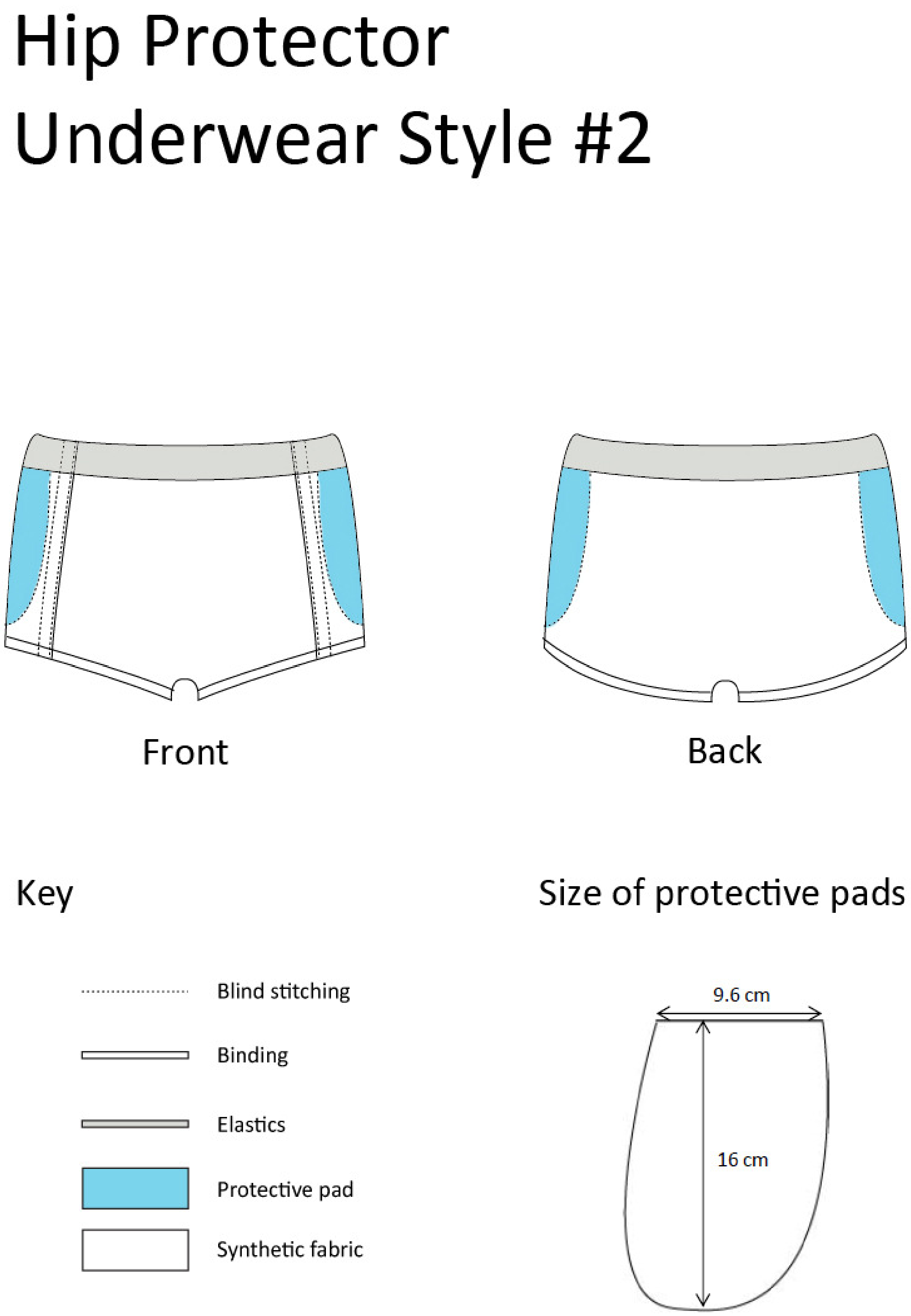


Figure 4-2 Production specification of hip protector style 2

This is a plain design of hip protector similar with the one above. However, it can be unwrapped by releasing the snap fasteners so user can put it on or off easily. There are protective pads on two sides of the protector to protect the hips from fracture following a fall. This design has a low waistline. There is an elastic waist band for the protector and binding for the hem finishing.

Features:

1. The fabric used is knitted 96% polyester 4% spandex fabric which is ordinarily used for underclothes. It is generally adopted for making hip protectors in order to achieve a close fit and ensure that the protective pads are located at correct positions over the hip areas in order to accomplish the optimal protection.

2. The protective pads are sewn on the shell fabric of the hip protector for a fixed position and the pads can stay on the right position during movement or a fall to protect the hip areas and give optimal protection. And the users need not to spend time on placing the pads on the right position after taking it out for laundry.

3. The low waistline allows the user to wear assorted types of pants without showing the hip protectors, so the user can have more versatile choices of clothing. And other people will not know if they are wearing a hip protector, hence the acceptance of this protector can be improved.

4. The fastening at the side seams also assists the user to wear it and put it off more easily, especially when the user need to put it on without others' assistance.

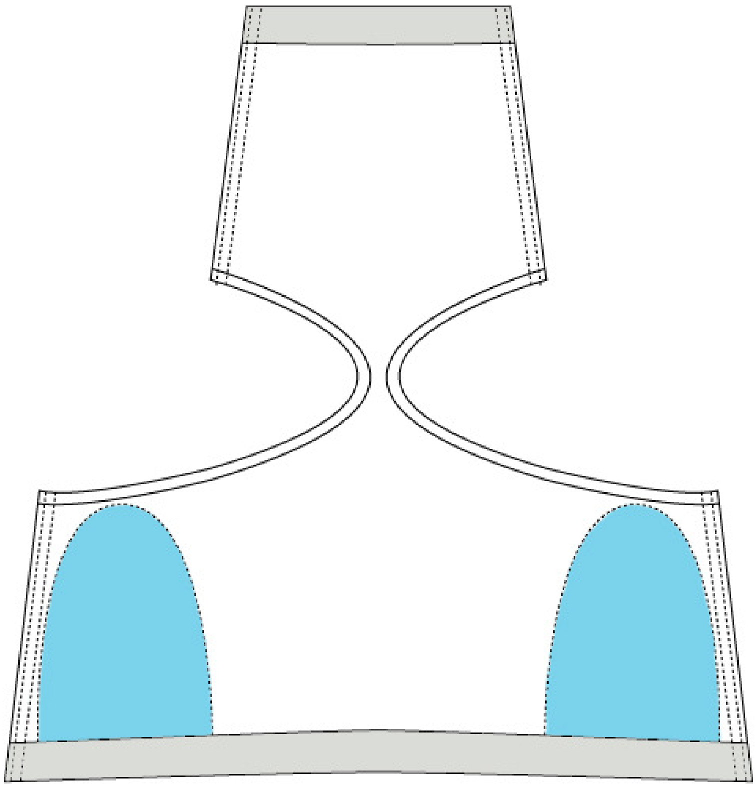
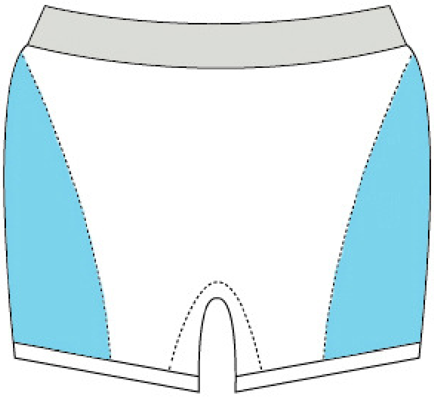


Figure 4-3 Detail of hip protector style 2

Hip Protector Underwear Style #3



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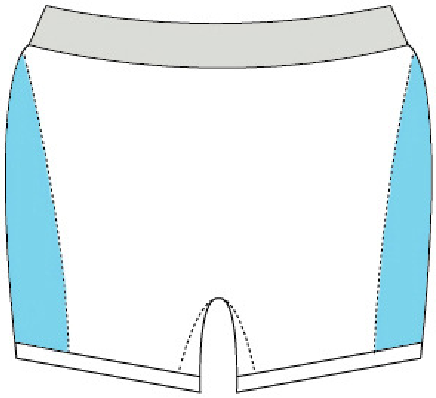

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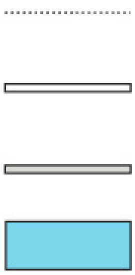


Size of protective pads

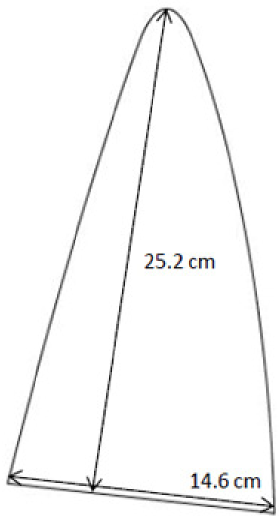


Figure 4-4 Production specification of hip protector style 3

This is one more elementary design of hip protector with larger protective pads on two sides of the protector to protect the hip from fracture following a fall. This design has a regular waistline and has a large area of hips under the protection. There is an elastic waist band for the protector and binding for the hem finishing.

Features:

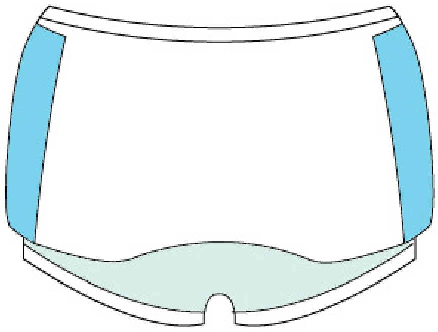
1. The fabric used is knitted 60% bamboo 35% cotton 5% spandex fabric to obtain a close fit and ensure that the protective pads are located at right positions over the hip areas in order to achieve the optimal protection. Knitted fabrics consist of blends of cotton and synthetic fibres that possess recoverable stretch characteristics (Ng, et al., 2011).

2. The protective pads are sewn on the shell fabric of the hip protector for an immovable position and the pads can stay on the right position during movement or a fall to protect the hip areas and give optimal protection. And the users need not to spend time on placing the pads on the right position after taking it out for laundry.

3. The normal waistline of the hip protector gives an appearance approximating to the conventional underclothes for elderly and as a consequence can improve the acceptance of this protector.

4. The sizes of the protective pads are large in size to give more protection around the hip areas, especially in the course of a fall.

Hip Protector
Underwear Style #4



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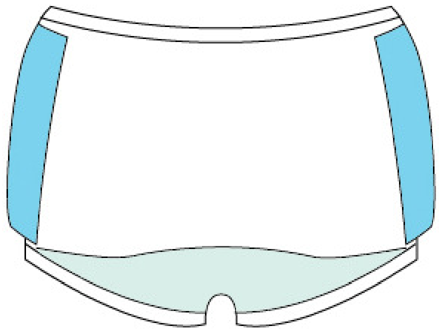

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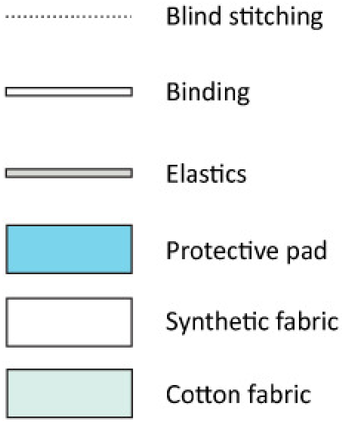


Size of protective pads

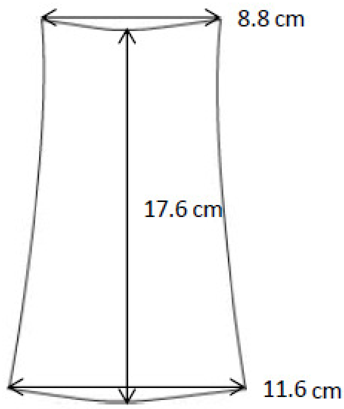


Figure 4-5 Production specification of hip protector style 4

This hip protector design has detachable protective pads on two sides of the protector to protect the hip from fracture following a fall. Two detachable protective pads are being positioned on top of the shell fabric, one on each side and fixed firmly by snap fasteners. This design has a regular waistline and there is an elastic waist band for the protector and binding for the hem finishing. The top part of the protector is made of knitted 55% polyester 40% cotton 5% spandex fabric while the bottom part is made of knitted 96% cotton 4% spandex fabric.

Features:

1. The fabric used for the top part is knitted 55% polyester 40% cotton 5% spandex fabric which can bring a very close fit and make sure that the protective pads are located at right positions over the hip areas in order to achieve the optimal protection as it has good recoverable stretch characteristics. Knitted 96% cotton 4% spandex fabric is used for the bottom part to give a better comfort, breathability and moisture absorbency (Ng, et al., 2011).

2. The protective pads are detachable and placed on top of the shell fabric of the hip protector so it can be detached during laundry for an extended life span of the pads. And the pads are fastened on the shell fabric by Velcro to give a stronger fastening which can hold the pads in position during a fall and Velcro is also easy for elderly to use.

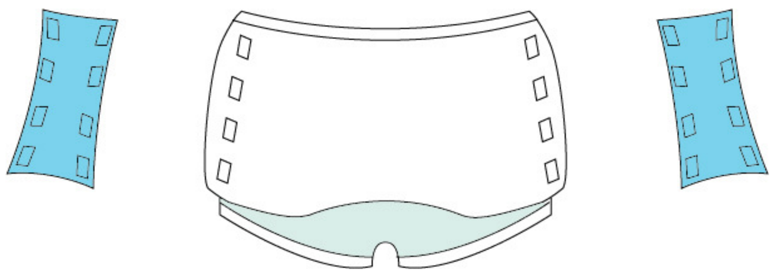


Figure 4-6 Detail of hip protector style 4

3. The normal waistline of the hip protector gives an appearance similar to the conventional underclothes for elderly and as a consequence can improve the acceptance of this protector.

4. The protective pads are placed at position directly above the thigh position so the user can move and walk easily without triggering any uncomfortable feeling.

Hip Protector Underwear Style #5

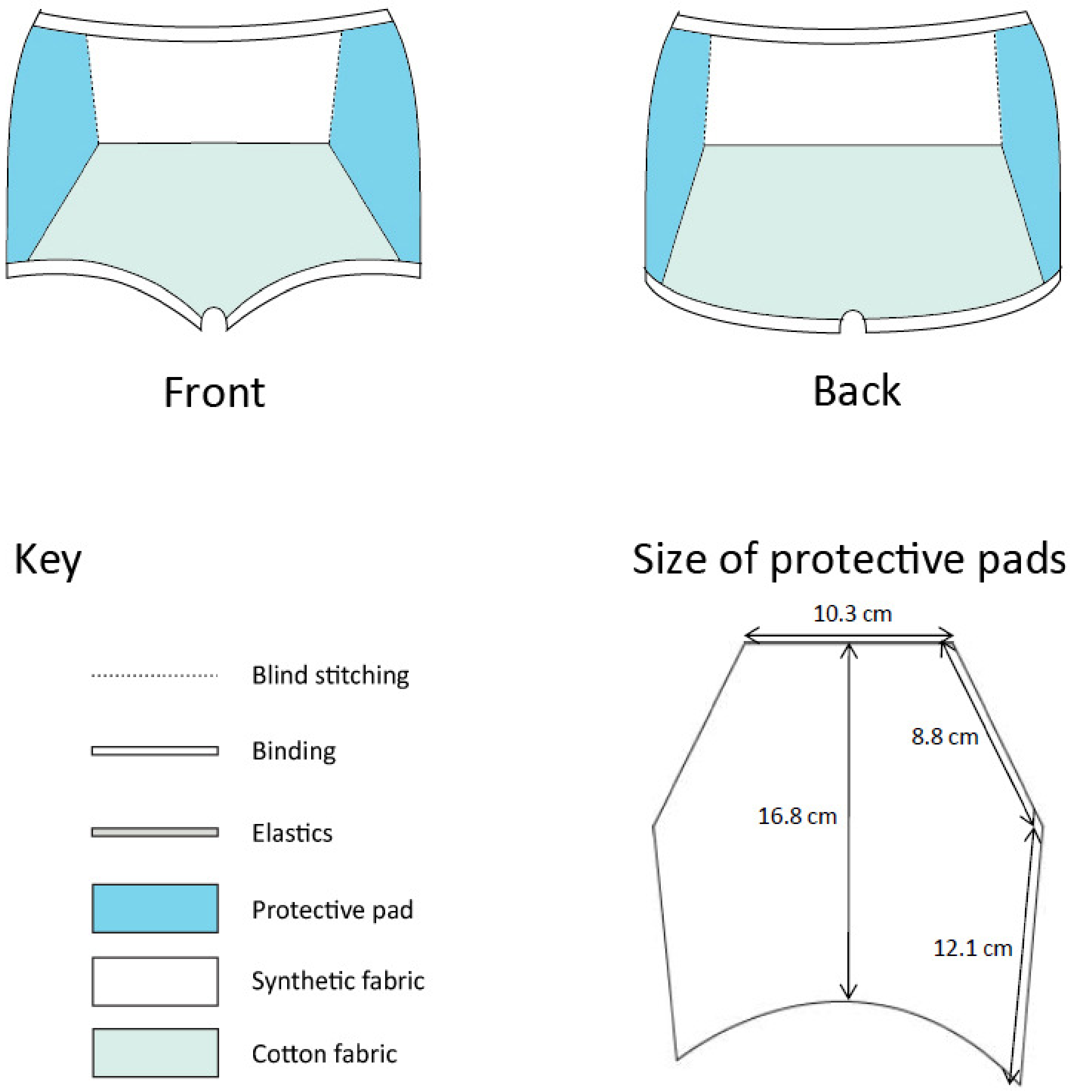


Figure 4-7 Production specification of hip protector style 5

This hip protector design has bigger detachable protective pads on two sides of the protector to protect the hip from fracture following a fall. Two detachable protective pads are being placed in pockets underneath the shell fabric, one on each side. This design has a normal waistline and there is an elastic waist band for the protector and binding for the hem finishing. The top part of the protector is made of knitted 55% polyester 40% cotton 5% spandex fabric while the bottom part is made of knitted 96% cotton 4% spandex fabric.

Features:

1. The fabric used for the top part is knitted 55% polyester 40% cotton 5% spandex fabric which can bring a very close fit and ensure that the protective pads are located at right positions over the hip areas in order to achieve the optimal protection as it has good recoverable stretch characteristics. Knitted 96% cotton 4% spandex fabric is used for the bottom part to give a better comfort, breathability and moisture absorbency (Ng, et al., 2011).

2. The protective pads are detachable and placed on top of the shell fabric of the hip protector so it can be detached during laundry for a longer life span of the pads. And the pads are fastened on the shell fabric by snap fasteners to give a stronger fastening which can hold the pads in position during a fall and the snap fasteners are also easy for elderly to use.

3. The normal waistline of the hip protector gives an appearance similar to the conventional underclothes for elderly and as a consequence can improve the acceptance of this protector (Ng, et al., 2011).

4. The protective pads are placed at position just above the thigh position so the user can move and walk easily without triggering any uncomfortable feeling.

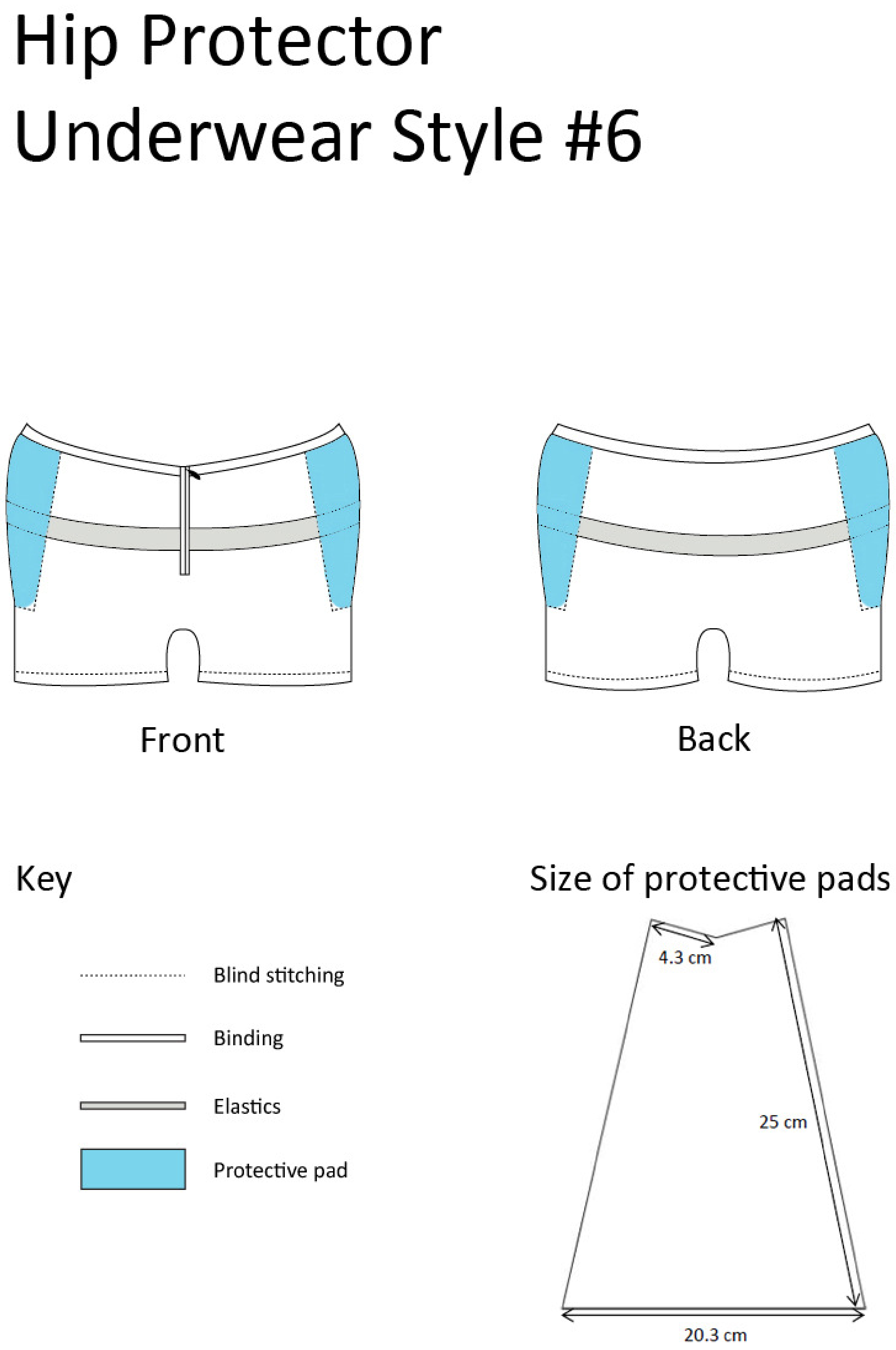


Figure 4-8 Production specification of hip protector style 6

This hip protector design has detachable protective pads on two sides of the protector to protect the hip from fracture following a fall. Two detachable protective pads are being placed in pockets underneath the shell fabric, one on each side. The protective pads are relatively small for easier movement. This design has a normal waistline and there are two elastics, one at the waistline and one at the high hip position to keep the position of the protective pads and to have better fit of the protector. There is binding for the hem finishing.

Features:

1. The fabric used is knitted 60% bamboo 35% cotton 5% spandex fabric to obtain a close fit and ensure that the protective pads are located at right positions over the hip areas in order to achieve the optimal protection. Knitted fabrics comprise blends of cotton and synthetic fibres that possess recoverable stretch characteristics (Ng, et al., 2011).

2. The protective pads are detachable and placed in pockets underneath the shell fabric of the hip protector so it can be detached during laundry for a longer life span of the pads.

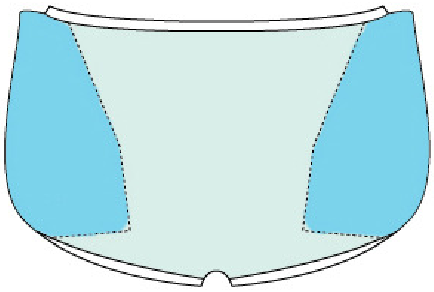
3. There are two elastic waist bands to keep the position of the protective pads and to have a better fit of the protector.

4. There is a zip opening in the centre front of the protector, so the protector can fit really well when it is zipped up. And it is easier for the elderly to put this protector off without others' assistance.

5. The normal waistline of the hip protector gives an appearance similar to the conventional underclothes for elderly and as a consequence can improve the acceptance of this protector (Ng, et al., 2011).

6. The protective pads are small in size and placed at position just above the thigh position so the user can move and walk easily without triggering any uncomfortable feeling.

Hip Protector
Underwear Style #7



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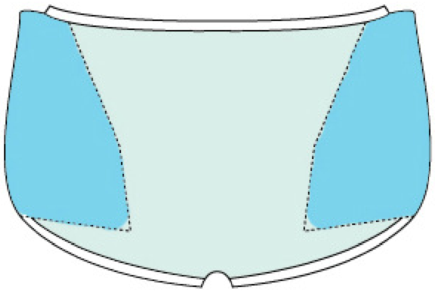

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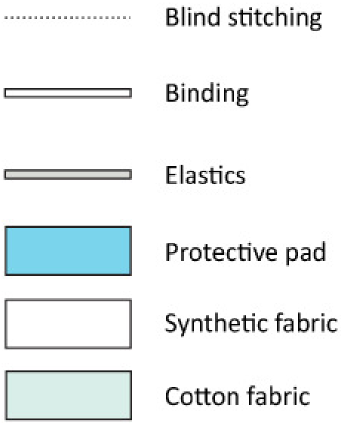


Size of protective pads

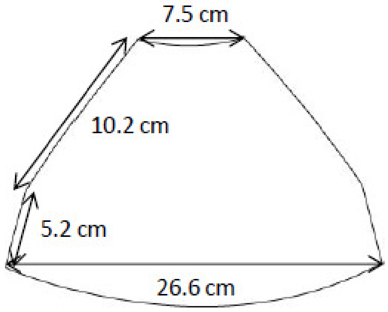


Figure 4-9 Production specification of hip protector style 7

This hip protector design has detachable protective pads on two sides of the protector to protect the hip from fracture following a fall. Two detachable protective pads are being positioned in pockets on top of the shell fabric, one on each side. The protective pads are relatively large for more protection. This design has a normal waistline and there is an elastic waist band. There is binding for the hem finishing. The side parts of the protector are made of knitted 55% polyester 40% cotton 5% spandex fabric while the middle part is made of knitted 96% cotton 4% spandex fabric.

Features:

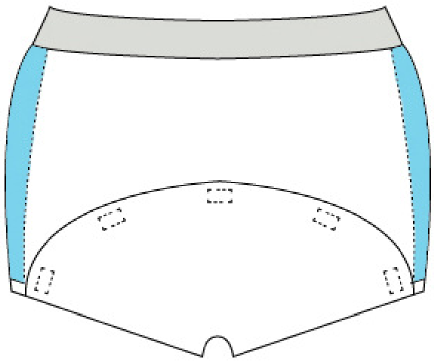
1. The fabric used for the middle part is knitted 96% cotton 4% spandex fabric for a better comfort, breathability and moisture absorbency. And the side parts are made of knitted 55% polyester 40% cotton 5% spandex fabric which can bring a very close fit and ensure that the protective pads are located at right positions over the hip areas in order to achieve the optimal protection as it has good recoverable stretch characteristics (Ng, et al., 2011).

2. The protective pads are detachable and placed in pockets on top of the shell fabric of the hip protector so it can be detached during laundry for a longer life span of the pads.

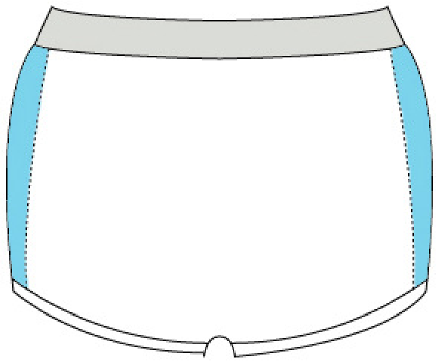
3. The normal waistline of the hip protector gives an appearance similar to the conventional underclothes for elderly and as a consequence can improve the acceptance of this protector.

4. The sizes of the protective pads are large in size to give more protection around the hip areas, especially during a fall, but the pads are placed just above the thigh position so the user can move and walk easily without triggering any uncomfortable feeling.

Hip Protector
Underwear Style #8

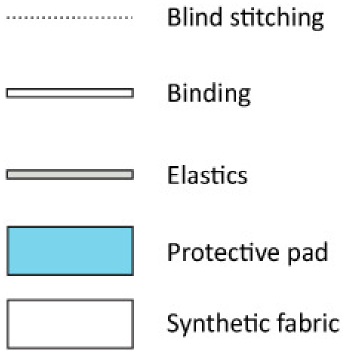


Front



Back

Key



Size of protective pads

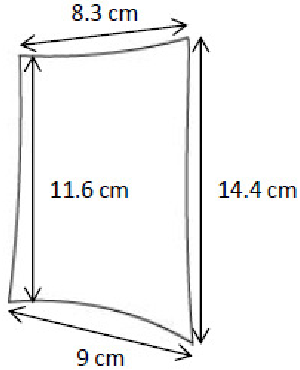


Figure 4-10 Production specification of hip protector style 8

This hip protector is designed for men and the front part of the protector can be pull down for toileting. This hip protector design has detachable protective pads on two sides of the protector to protect the hip from fracture following a fall. Two detachable protective pads are being placed in pockets underneath the shell fabric, one on each side. This design has a low waistline and there is an elastic waist band. There is binding for the hem finishing. The middle part of the protector is made of cotton fabric while the side part is made of polyester fabric.

Features:

1. The fabric used is knitted 96% polyester 4% spandex fabric which is ordinarily used for underclothes. It is generally adopted for making hip protectors in order to obtain a close fit and ensure that the protective pads are located at right positions over the hip areas in order to achieve the optimal protection.

2. The protective pads are detachable and placed in pockets underneath the shell fabric of the hip protector so it can be detached during laundry for a longer life span of the pads.

3. The low waistline allows the user to wear assorted types of pants without showing the hip protectors, so the user can have more versatile choices of clothing. And other people will not know if they are wearing a hip protector, hence the acceptance of this protector can be improved.

4. The protective pads are small in size and placed at position just above the thigh position so the user can move and walk easily without causing any uncomfortable feeling.

5. This protector is designed for man and the front middle part of the protector can be pull down for toileting.

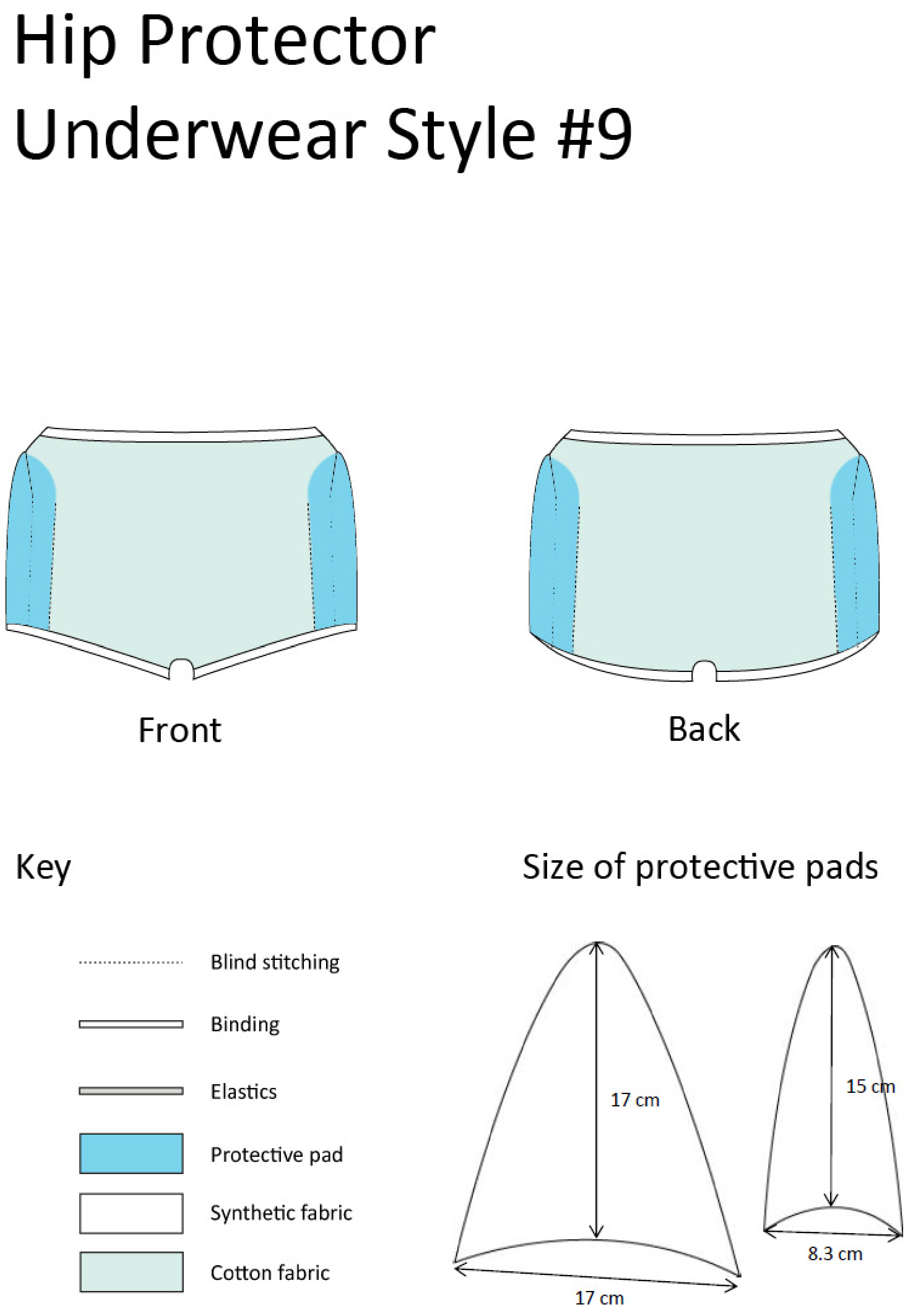


Figure 4-11 Production specification of hip protector style 9

This hip protector is designed for higher protection level. This hip protector design has double layers of protective pads on two sides of the protector to protect the hip from fracture following a fall. The protective pads are fixed on the protector for better positioning of the two layers of padding. This design has a normal waistline and there is an elastic waist band. There is binding for the hem finishing.

Features:

1. The fabric used for the middle part is knitted 96% cotton 4% spandex fabric for a better comfort, breathability and moisture absorbency.

2. There are two layers of protective pads on each side of the protector for an additional protection for hip areas.

3. The protective pads are sewn on the shell fabric of the hip protector for a fixed position and the pads can stay on the right position during movement or a fall to protect the hip areas and give optimal protection. And the users need not to spend time on placing the pads on the right position after taking it out for laundry.

4. The normal waistline of the hip protector gives an appearance similar to the conventional underclothes for elderly and as a consequence can improve the acceptance of this protector.

4.3. Products

With reference to the production specification mentioned above, prototype of the nine styles of hip protectors has been produced.

Figure 4-12 Prototype of hip protector style 1 (front and back view)

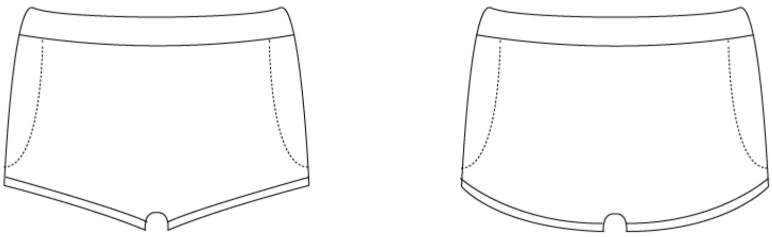


Figure 4-13 Original design of hip protector style 1 (front and back view)

Figure 4-14 Prototype of hip protector style 2 (front and back view)

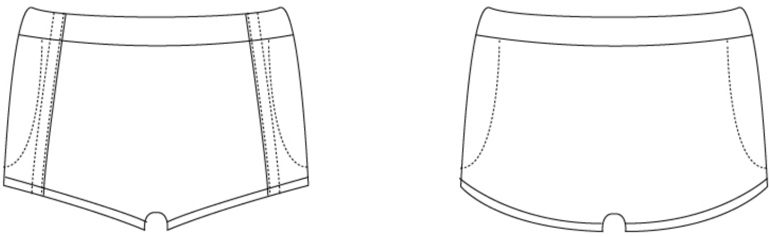


Figure 4-15 Original design of hip protector style 2 (front and back view)

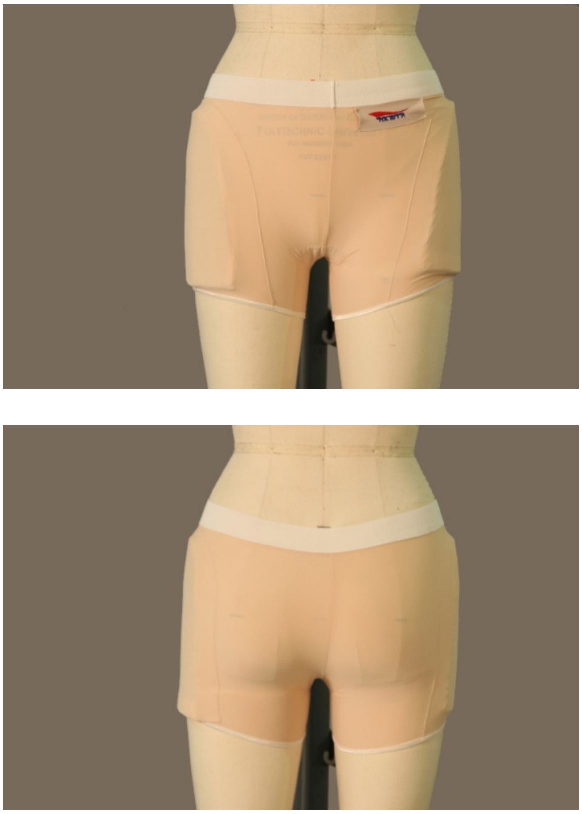


Figure 4-16 Prototype of hip protector style 3 (front and back view)

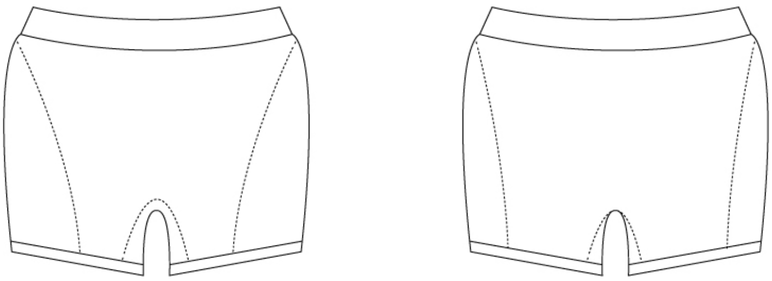


Figure 4-17 Original design of hip protector style 3 (front and back view)

Figure 4-18 Prototype of hip protector style 4 (front and back view)

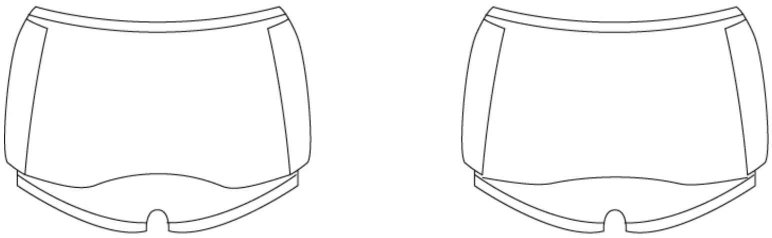


Figure 4-19 Original design of hip protector style 4 (front and back view)

Figure 4-20 Prototype of hip protector style 5 (front and back view)

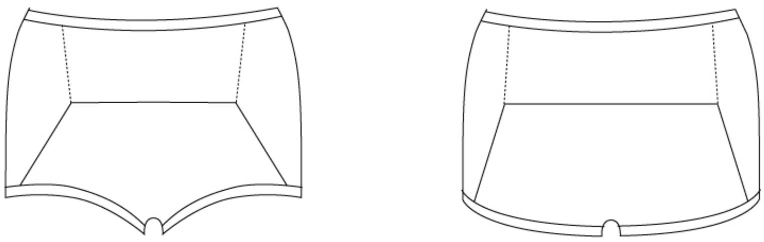


Figure 4-21 Original design of hip protector style 5 (front and back view)

Figure 4-22 Prototype of hip protector style 6 (front and back view)

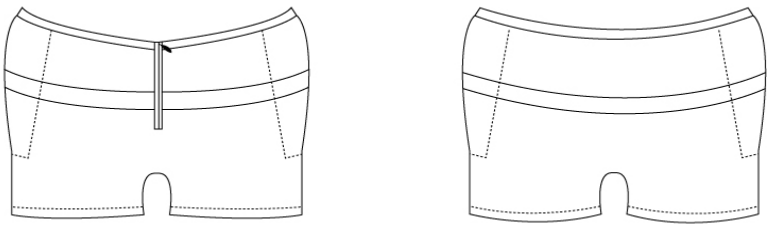


Figure 4-23 Original design of hip protector style 6 (front and back view)

Figure 4-24 Prototype of hip protector style 7 (front and back view)

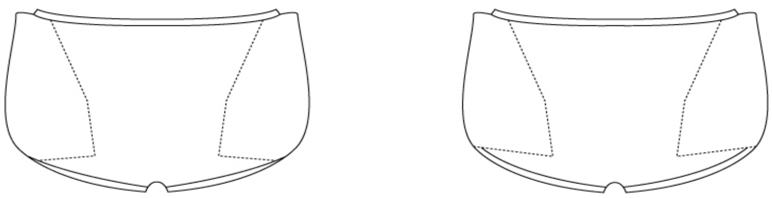


Figure 4-25 Original design of hip protector style 7 (front and back view)

Figure 4-26 Prototype of hip protector style 8 (front and back view)

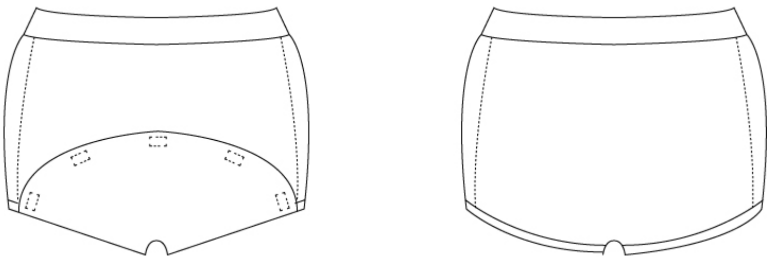


Figure 4-27 Original design of hip protector style 8 (front and back view)

Figure 4-28 Prototype of hip protector style 9 (front and back view)

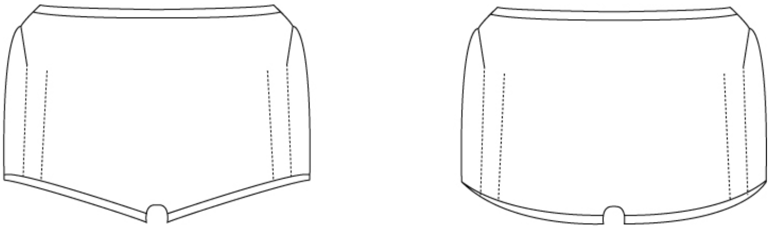


Figure 4-29 Original design of hip protector style 9 (front and back view)

4.4. Summary

Prototype of assorted styles of hip protectors has been designed with their design detail deliberated in this chapter. And products of assorted styles have been produced with reference to the production specifications given, and the material, cutting, edge finishing and sewing method selected in chapter 3.

CHAPTER 5 EVALUATION OF THE PROTOTYPE

5.1. Introduction

In this chapter, the properties of prototype of assorted styles of hip protectors have been evaluated by both objective testing and subjective testing. The pressure distribution of the hip protectors have been measured using Pliance systems from Novel and the shock absorbing performance of the hip protectors have been investigated and compared with current products in the market. Also, wear trial of the hip protectors have been carried out for the evaluation of their performance. The detail of objective testing and subjective testing has also been explained.

5.2. Objective testing

It has been believed that the level of comfort is one of the most important factor for the performance of hip protectors and it is very much related to the acceptance of the wearers for wearing the hip protectors for long hours, therefore the pressure at assorted points of hips have been measured to investigate the comfort in term of distribution of pressure under the hip protectors and to evaluate the relationships between assorted styles and fabrications of hip protectors and the reading of pressure.

Shock absorbing performance is also a very crucial factor for the evaluation of the hip protectors as the main function of the hip protectors is to protect the wearers from injuries after an impact, especially for a fall. It is a must for the hip protectors to have a good reasonable absorbing performance. Therefore, the shock absorbing performance of the hip protectors have been investigated and compared with a hip protector currently available in the local market.

5.2.1. *Pressure distribution under hip protectors*

Evaluations of The pressure distribution of the hip protectors have been carried out in both objective testing and subjective testing. For objective testing, the pressure distribution of the hip protectors have been measured using Pliance systems from Novel, and the shock absorbing performance of the hip protectors have been investigated and compared with current products in the market.

Pliance systems from Novel have been used to measure the pressure distribution in kPa under the nine hip protectors. The systems involved a flexible and elastic measuring mat, a multi-channel analyser, a calibration device and a software package for computer. Standard package of the Pliance systems have been used, and the package involved an acquisition and storage of dynamic pressure distribution data, view of absolute pressure values in sensor, presentation and playback of dynamic measurement, view maximum pressure, force and contact area, and storage of collected data with comments.

Previous study explained that pressure created by the garment on the body increases with body curvature (Denton, 1972). For women, the body curvature at the sides is roughly 3.5 times greater than that at the front, so that any unwanted pressure on the sides of the waist is 3.5 times greater than that at the front. Therefore, six points have been marked on the left side of hips of a size 10 dummy with an assumption that the configuration of the dummy is identical in both sides of it. The girth measurement of the dummy is 70 cm at waist, 88 cm at hip and 50 cm at thigh. six points are evenly distributed from low waist position to thigh position with intervals of 4cm ± 0.1cm between each of them to investigate the pressure level on different points around the hips; for the hip protectors with shorter side seams, only the pressure level at the first five points have been marked. 1000 data have been collected using a single sensor for the pressure distribution applications with limited hand area at each point under the hip protectors. The experiment has been carried out under the standard condition of 20°C and 65% relative humidity. And the measurement of pressure will be used for the evaluation of relationships between assorted styles and fabrications of hip protectors and the reading of pressure.

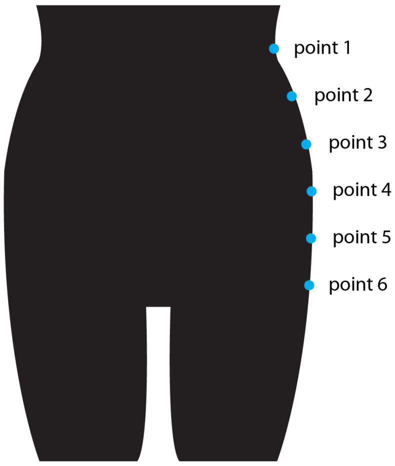
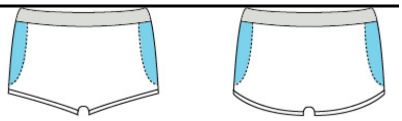
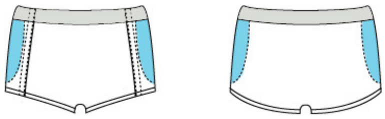
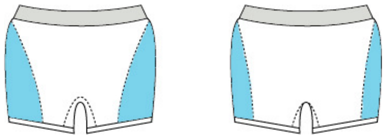
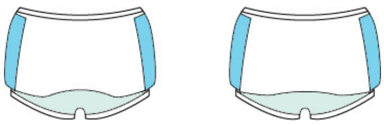
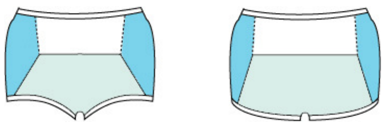
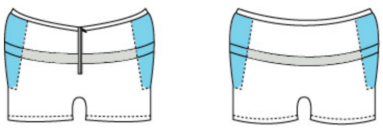
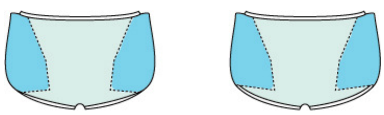


Figure 5-1 Markings on dummy

In this study, ninedifferent styles of hip protectors have been designed and produced using four different knitted fabrics, which are 96% polyester 4% spandex fabric, 96% cotton 4% spandex fabric, 60% bamboo 35% cotton 5% spandex fabric and 55% polyester 40% cotton 5% spandex fabric. Their production detail is listed in Table 5-1.

Styles	Fabrications	Production drawings (front and back view)
1	96% polyester 4% spandex	
2	96% polyester 4% spandex	
3	60% bamboo 35% cotton 5% spandex	
4	96% cotton 4% spandex 55% polyester 40% cotton 5% spandex	
5	96% cotton 4% spandex 55% polyester 40% cotton 5% spandex	
6	60% bamboo 35% cotton 5% spandex	
7	96% cotton 4% spandex	

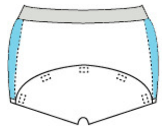
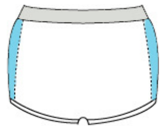
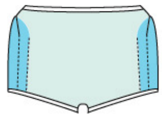
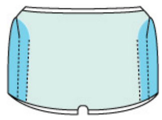
	55% polyester 40% cotton 5% spandex	
8	96% polyester 4% spandex	 
9	96% cotton 4% spandex	 

Table 5-1 Production detail

Style 1 is a basic design of hip protector with protective pads on two sides of the protector to protect the hips from fracture following a fall. This design has a low waistline. There is an elastic waist band for the protector and binding for the hem finishing. The hip protector is made of 96% polyester 4% spandex fabric.

Style 2 is a basic design of hip protector similar with the one above. However, it can be opened by unfastening the snap fasteners so user can put it on or off easily. There are protective pads on two sides of the protector to protect the hips from fracture following a fall. This design has a low waistline. There is an elastic waist band for the protector and binding for the hem finishing. The hip protector is made of 96% polyester 4% spandex fabric.

Style 3 is another basic design of hip protector with larger protective pads on two sides of the protector to protect the hip from fracture following a fall. This design has a normal waistline and has a large area of hips under the protection. There is an elastic waist band for the protector and binding for the hem finishing. The hip protector is made of 60% bamboo 35% cotton 5% spandex fabric.

Style 4 has detachable protective pads on two sides of the protector to protect the hip from fracture following a fall. Two detachable protective pads are being placed on top of the shell fabric, one on each side and fastened by snap fasteners. This design has a normal waistline and there is an elastic waist band for the protector and binding for the hem finishing. The top part of the protector is made of 55% polyester 40% cotton 5% spandex fabric while the bottom part is made of 96% cotton 4% spandex.

Style 5 has larger detachable protective pads on two sides of the protector to protect the hip from fracture following a fall. Two detachable protective pads are being placed in pockets underneath the shell fabric, one on each side. This design has a normal waistline and there is an elastic waist band for the protector and binding for the hem finishing. The top part of the protector is made of 55% polyester 40% cotton 5% spandex fabric while the bottom part is made of 96% cotton 4% spandex fabric.

Style 6 has detachable protective pads on two sides of the protector to protect the hip from fracture following a fall. Two detachable protective pads are being placed in pockets underneath the shell fabric, one on each side. The protective pads are relatively small for easier movement. This design has a normal waistline and there are two elastics, one at the waistline and one at the high hip position to keep the position of the protective pads and to have better fit of the protector. There is binding for the hem finishing. The hip protector is made of 60% bamboo 35% cotton 5% spandex fabric.

Style 7 has detachable protective pads on two sides of the protector to protect the hip from fracture following a fall. Two detachable protective pads are being placed in pockets on top of the shell fabric, one on each side. The protective pads are relatively large for more protection. This design has a normal waistline and there is an elastic waist band. There is binding for the hem finishing. The pocket part of the protector is made of 55% polyester 40% cotton 5% spandex fabric while the middle part is made of 96% cotton 4% spandex fabric.

Style 8 is designed for men and the front part of the protector can be pull down for toileting. This hip protector design has detachable protective pads on two sides of the protector to protect the hip from fracture following a fall. Two detachable protective pads are being placed in pockets underneath the shell fabric, one on each side. This design has a low waistline and there is an elastic waist band. There is binding for the hem finishing. The hip protector is made of 96% polyester 4% spandex fabric.

Style 9 is designed for higher protection level. This hip protector design has double layers of protective pads on two sides of the protector to protect the hip from fracture following a fall. The protective pads are fixed on the protector for better positioning of the two layers of padding. This design has a normal waistline and there is an elastic waist band. There is binding for the hem finishing. The hip protector is made of 96% cotton 4% spandex.

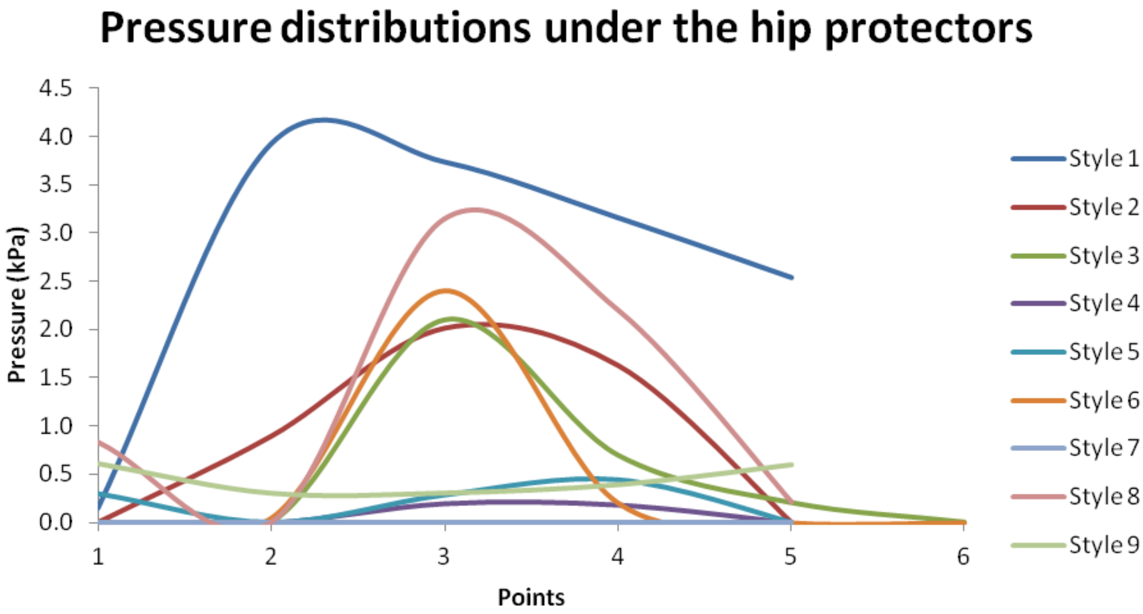
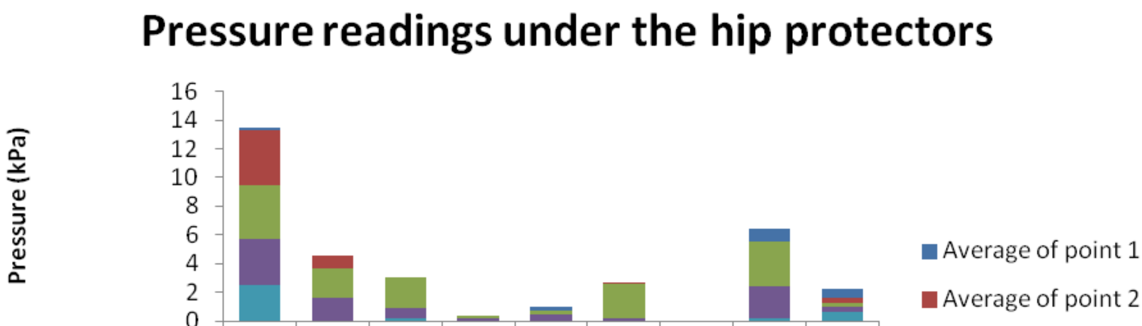


Figure 5-2 Pressure distributions under the hip protectors



	1	2	3	4	5	6	7	8	9
Average of point 1	0.15	0.00	0.00	0.00	0.30	0.00	0.00	0.83	0.61
Average of point 2	3.92	0.90	0.00	0.00	0.00	0.05	0.00	0.00	0.30
Average of point 3	3.73	2.02	2.10	0.20	0.28	2.40	0.00	3.15	0.30
Average of point 4	3.15	1.63	0.69	0.19	0.44	0.21	0.00	2.20	0.39
Average of point 5	2.54	0.00	0.20	0.00	0.00	0.00	0.00	0.21	0.60
Average of point 6			0.00			0.00			

Styles

Figure 5-3 Pressure readings under the hip protectors

For style 1, 2 and 8, they are made of the same 96% polyester 4% spandex fabric, and the patterns have been constructed base on the same figure, therefore, the effect of fabrication on the reading of pressure can be cancelled out, and the differences among the reading of pressure should be caused by the assorted designs of hip protectors. For style 1, it is a very basic design of hip protector and its peak reading of pressure is 3.92 kPa at point 2. For style 2 and 8, they have additional opening at the side position and the middle position of the hip protectors respectively. Both of their peak readings of pressure is lower than 3.92 kPa and at point 3 instead of point 2, therefore it has been proved that the additional openings on the hip protectors can lower the pressure existed as the additional opening may give more ease to the hip protectors.

For style 3 and 6, they are made of the same 60% bamboo 35% cotton 5% spandex fabric, and the patterns have been constructed base on the same figure, therefore, the effect of fabrication on the reading of pressure can be cancelled out, and the differences among the reading of pressure should be caused by the assorted designs of hip protectors. For style 3, it is a more basic design of hip protector and its peak reading of pressure is 2.10 kPa at point 3; for style 6, it has smaller protective pads at the side position and an additional elastics to hold the pads in position, and its peak reading of pressure is 2.40 kPa at point 3 which is a little higher than that of style 3 as there is an extra pressure created by the additional elastics.

For style 4, 5, 7 and 9, they are made of the same 96% cotton 4% spandex fabric and 55% polyester 40% cotton 5% spandex fabric, and the patterns have been constructed base on the same figure, therefore, the effect of fabrication on the reading of pressure can be cancelled out, and the differences among the reading of pressure should be caused by the assorted designs of hip protectors. Their peak readings of pressure are 0.20 kPa, 0.44 kPa, 0.0 kPa and 0.61 kPa respectively, which are all in a very low level, which proved that these designs of hip protector should not cause too much hard feeling to the patients during wear.

Style 1, 2 and 8 are made of the 96% polyester 4% spandex fabric, and their peak readings of pressure are between 2.02 kPa and 3.92 kPa. Style 3 and 6 are made of the 60% bamboo 35% cotton 5% spandex fabric, and their peak readings of pressure are 2.10 kPa and 2.40 kPa respectively. Style 4, 5, 7 and 9 are made of the 96% cotton 4% spandex fabric and 55% polyester 40% cotton 5% spandex fabric, and their peak readings of pressure are from 0.2 kPa to 0.61 kPa, which is the lowest among all the styles.

Since the pattern of all the styles have been constructed base on the same figure and with the same dimension, therefore, the differences in peak readings of pressure can be caused by the different fabrications in assorted styles. The styles made of the 96% polyester 4% spandex fabric have the highest average peak reading, followed by the styles made of the 60% bamboo 35% cotton 5% spandex fabric and the styles made of the 96% cotton 4% spandex fabric and 55% polyester 40% cotton 5% spandex fabric have the lowest average peak reading while the 96% polyester 4% spandex fabric have the best stretchability in the coursewise direction, followed by that of 60% bamboo 35% cotton 5% spandex fabric and that of the 96% cotton 4% spandex fabric and 55% polyester 40% cotton 5% spandex fabric. To conclude, the reading of pressure is inversely proportional to the stretchability of the fabrics used.

For the protective pads currently available in the market, the most common type is made of plastic and foam with moulded shapes.

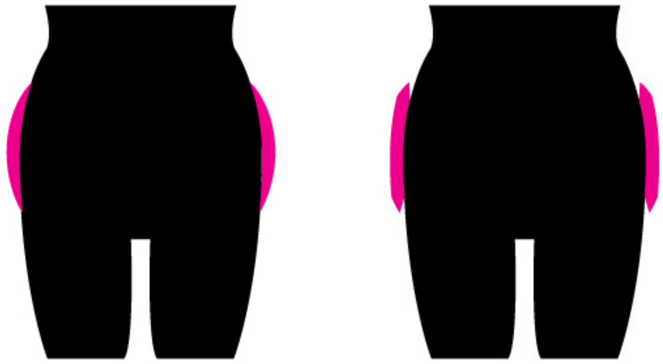


Figure 5-4 Shapes of pads (fitted)

In an ideal case, the shapes of the pads match the hips of patients perfectly and give the optimal functional properties and comfort.

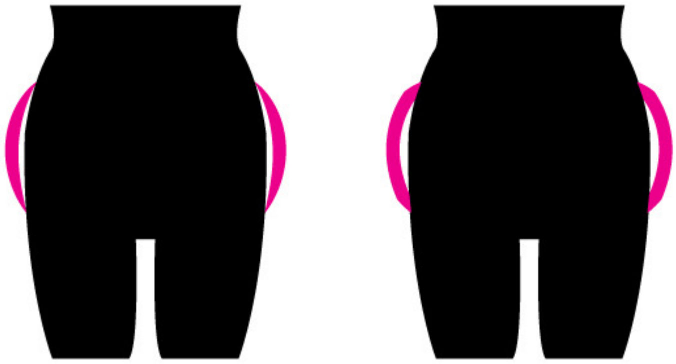


Figure 5-5 Shapes of pads (unfitted)

However, every patient has a different body figure and the pads may not match with their hips and then the pressure will be concentrate at the points of contact on patients' hips instead of even distribution of pressure on skin surface. If the constricting pressure around the human body is too high, blood passing through the veins will be stopped or impeded, and the fluid will be forced out of the veins into the tissues and cause swelling at the lower part of the legs (Pratt & West, 1995). This not only causes uncomfortable feeling to the patients during wear, but also leads to abrasion on patients' skin surface; therefore many patients are not willing to wear hip protectors. As a result, pressure created by the hip protector is an important concern for its application and is affected by its style, fit, and mechanical properties (Zhang, Yeung, & Li, 2010).

Pliance systems from Novel have been used to measure the pressure distribution in kPa under the nine hip protectors.

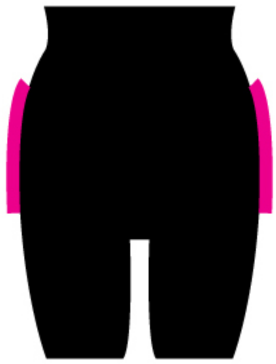


Figure 5-6 Shape of 3D spacer fabric pads

In the protective pads applied in this study, they are made of 3D spacer fabric, which is very flexible and have a much softer handle than the pads currently available, therefore it can have some dimensional changes to fit patients with different body figures. Also, the protective pads are very soft and will not cause too much uncomfortable feeling to the patients.

However, there are still a few exceptional cases found from the readings of pressure. For style 5, 8 and 9, there are significantly higher readings of pressure at point 1; it is mainly due to the extra pressure created by the waist band.

From the testing results, it can be seen that the readings of pressure are low at the low waist position, followed by a gradual rise in readings of pressure at the hip position, and the readings return to a low level at the thigh position. Previous study mentioned that the discomfort level of clothing pressure are between 5.8850 kPa and 9.8083 kPa depending on the individual and the part of the body concerned (Denton, 1972), which is similar to blood pressure in the capillary blood vessels near the skin surface. In this study, it have been found that the pressure is evenly distributed at the level lower than 5.8850 kPa for the hip protectors produced in this study and it can be concluded that these hip protectors give a good comfort to the patients.

Testing has also been carried out to investigate the distribution of pressure under a hip protector currently available in the market under the same condition to compare their pressure distributions. The hip protectors are made with 100% cotton knitted fabrics and plastic shields.

As shown in Figure 5-7, it has been found that the pressure distribution has been concentrated on point 3 and point 6 on the dummy and the readings are 7.84 kPa and 7.46 kPa respectively, which is within the discomfort level mentioned above. The testing result proved that the hip protectors produced in this study are having an improved comfort when compared with the current product in the market.

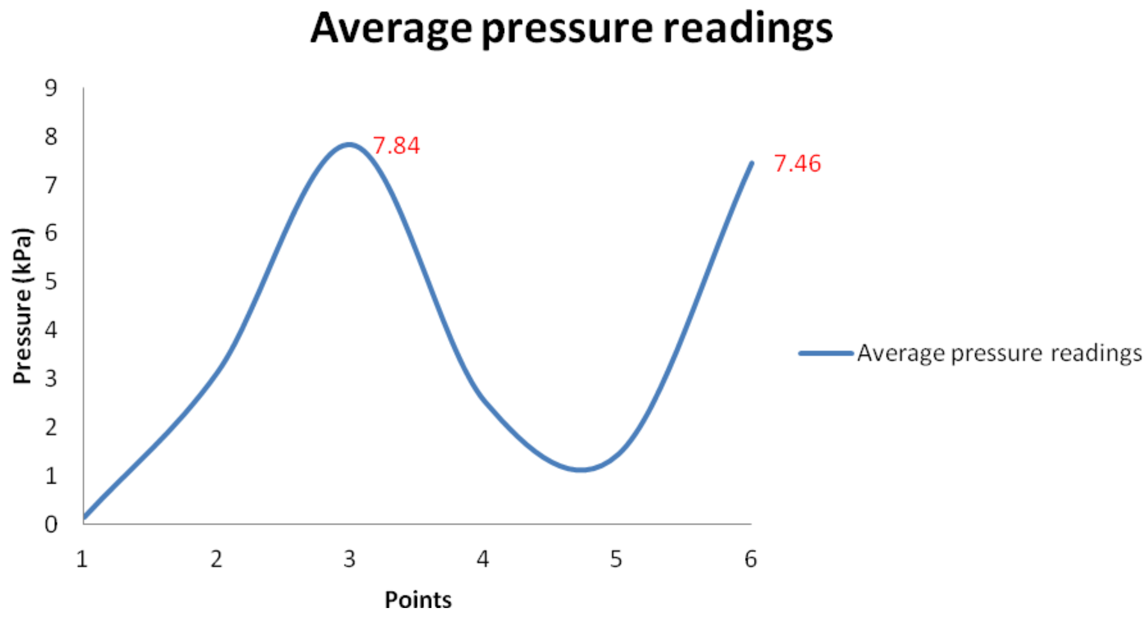


Figure 5-7 Pressure distributions under the current product

Apart from the discomfort at point 3 and point 6, there is also puckering on both front and back sides of the hip protector due to the poor fitting of the hip protector. There are a lot of extra fabrics around the waist position and the hip protector is not fitted around the crotch area. This is mainly because of the cutting and pattern of the hip protector, in which both the centre front seam and centre back seam are absent.

Figure 5-8 Current product

5.2.2. Shock absorbing performance of the hip protectors

The shock absorbing performance of the paddings used in hip protectors developed in this study and that used in current product have been evaluated with impact tests. The impact tests have been conducted using a drop-weight impact tester from King Design Company following Motorcyclists' protective clothing against mechanical impact. Requirements and test methods for impact protectors BS EN 1621–1:1998. The configuration of the tester has a mass of 5kg has been placed in a position 200mm above the anvil and the mass has been released and dropped vertically onto the sample placed on the anvil during the testing process. The centre of mass of the falling block lies above the centre of the anvil. The hemispherical anvil simulating the shape of hips was mounted on a massive base (1000 kg) through a load cell (1210AF–50KN from Interface Inc. with a sensitivity of 4.171 mV/V) in line with its sensitivity axis, to measure the transmitted force.

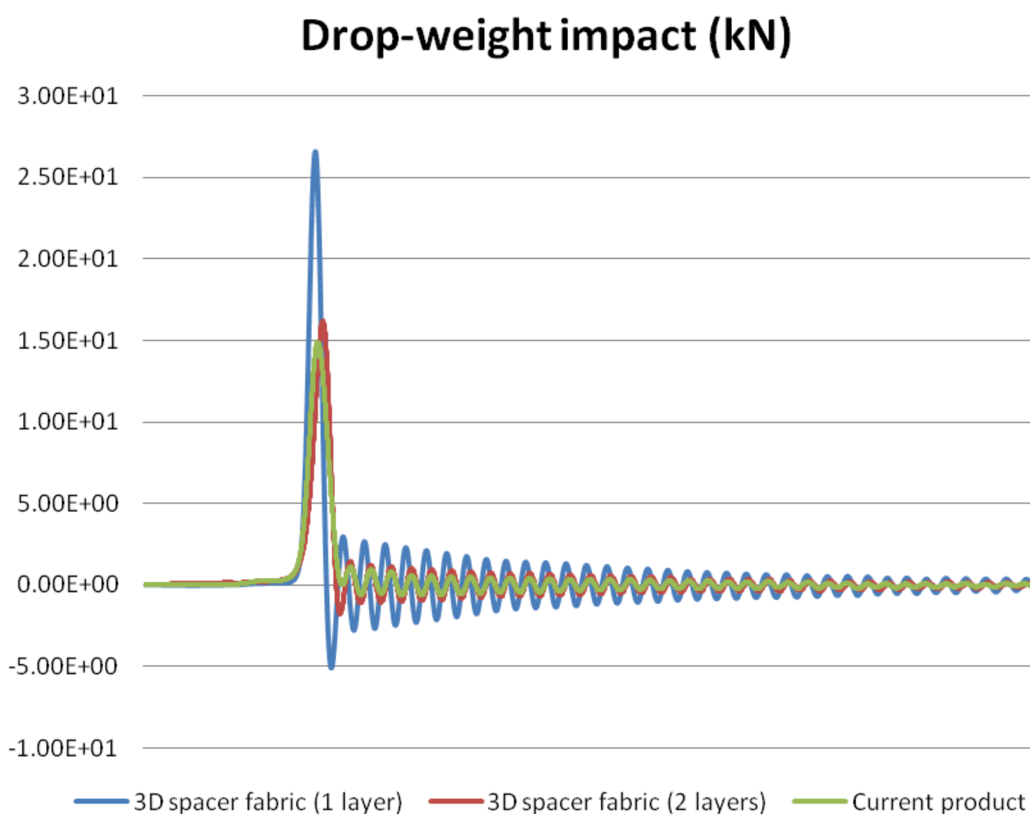


Figure 5-9 Results of drop-weight impact testing

The hip protectors padded with one layer of 3D spacer fabric (style 1, 2, 3, 4, 5, 6, 7 and 8) have a drop-weight impact for 26.614kN, hip protector padded with two layers of 3D spacer fabrics (style 9) has a drop-weight impact for 16.188kN, and the hip protector currently available in the market has a drop-weight impact for 14.891kN, which is the lowest among all the hip protectors being tested.

The lower the value drop-weight impact, the lower is the force transferred to the hips of the wearers and the better is the shock absorbing performance of the hip protectors. With improved pressure distribution in hip protectors padded with 3D spacer fabric, their shock absorbing performance are relatively lower than that of current hip protectors padded with plastics and foam. However, the hip protector padded with two layers of 3D spacer fabrics has a very similar shock absorbing performance with the current product and give a good result in the drop-weight impact testing.

5.3. Subjective testing

5.3.1. Wear trial of hip protectors

Wear trial has been carried out after the objective testing to investigate the feedback from wearers and to evaluate the relationships between different factors of the prototype. The wear trial has been carried out among twenty female research assistants, research students and technicians of size 10 or size S. In the wear trial, each wearer has been putting on ten samples (9 prototypes and one current product) one by one and a survey questionnaire was used as a data collection instrument. And the wearers have to complete a questionnaire for each sample after wearing each sample for 30 minutes and having several kinds of movements to investigate the performances and properties of different samples. The process of the wear trial has been shown in Figure 5-10.

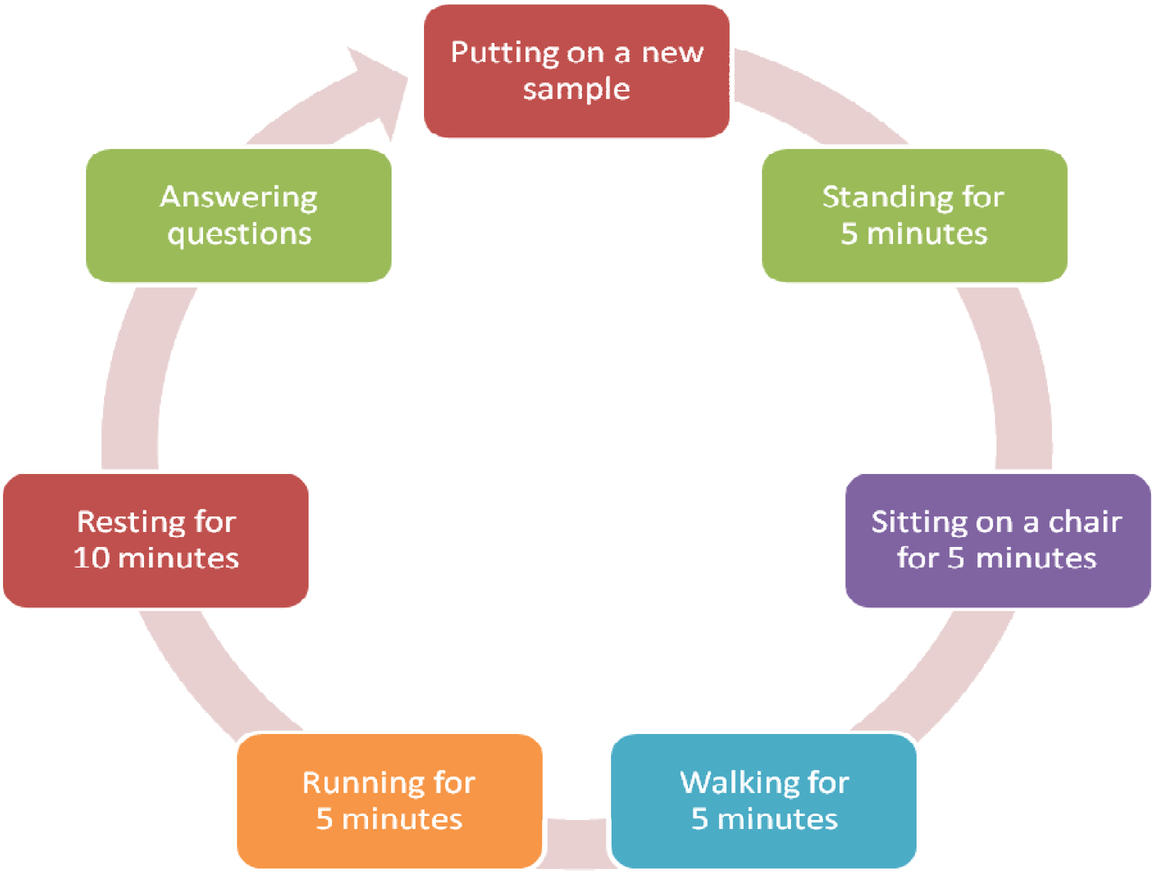


Figure 5-10 Wear trial process

In the beginning of the wear trial, each wearer has received standard underclothes as shown in Figure 5-11 to wear underneath any sample they put on in the following process. Then, they have to put on the samples one by one on top of the underclothes for hygiene. After that, the wear trial has been carried out as shown in Figure 5-10 until all the ten samples have been put on and all the questions have been answered for all the samples.

Figure 5-11 Standard underclothes

Figure 5-12 Sample 10 (current product) on top of standard underclothes

Twenty performance indicators for the ten samples were measured on a scale ranging from 1 = strongly disagree to 5 = strongly agree. A one-way analysis of variance (ANOVA) followed by Bonferroni's post hoc test was used to test the hypothesis on the possible differences among the three groups of hip protectors for their performances. Statistical analyses of the performances of the ten samples have been done. The mean distribution of each factor and the overall mean has been shown in Table A1.

For appearance, the ratings are between 1.86 and 3.55; sample 5 has the highest rating while sample 10 has the lowest rating. The overall mean is 2.68, which means the appearances of the samples need to be improved in order to have a better acceptance among the wearers.

For comfort, the ratings are between 1.79 and 4.37; samples 4, 5, 7 and 9 have the highest ratings while samples 1 and 10 have the lowest ratings. The overall mean is 4.03, which means the comforts of the samples are good. However, the standard deviation is very high, indicating deviated ratings among the ten samples and the comfort of some of the samples still need to be improved for a better performance.

For padding, the ratings are between 3.68 and 4.35; sample 3 has the highest rating while sample 10 has the lowest rating. The overall mean is 4.21, which means the wears believe that the padding can protect them from injuries and hip fractures. Although most of the samples have a high rating at this factor, sample 10 has a relatively low rating.

For fitting, the ratings are between 3.45 and 4.1; sample 10 has the highest rating while sample 8 has the lowest rating. The overall mean is 3.74 and the samples have a good performance at this factor in general.

For acceptance, the ratings are between 4.25 and 4.70; sample 10 has the highest rating while samples 4, 5, 7 and 9 have the lowest ratings. The overall mean is 4.37 and the samples have a very good performance at this factor in general.

The hypothesized expectation was that the ten samples have different ratings on different performance indicators and factors. To test the hypothesized differences on the performance indicators, one-way ANOVA was used. The ANOVA results show that there are significant differences ($p \leq 0.05$) among the factors as shown in Table A2. Therefore, study results provide partial support for the hypothesis.

To conclude, sample 10 which is the product currently available in the market has a better performance among fitting and acceptance, despite the fact the ninesamples developed in this study have a better appearance, comfort and padding and the results proved that this study has made an improvement on aesthetics, comfort and function performance of hip protectors.

5.3.2. Case study of elderly wearing hip protectors

Four female volunteers participated as human subjects in the case study. All subjects over 65 years of age and suffer from Osteoporosis. The detail of the subjects is listed in table 5-2. They were required to wear six different samples of hip protectors by random so that each subject has worn each sample of hip protector for 24 hours once. And the six samples tested by the subjects in this case study are samples 1, 4, 5, 7, 9 and 10, whereas 4, 5, 7 and 9 have the highest ratings of comfort in the wear trial and samples 1 and 10 have the lowest ratings.

Subject	**Age**	**Height (cm)**	**Weight (lbs)**	**Waist (cm)**	**Hip (cm)**	**Medical condition**
E1	78	156	110	75	93	Osteoarthritis, rheumatoid arthritis
E2	75	150	90	66	82	Osteoarthritis, heart disease
E3	69	156	95	71	86	Osteoarthritis, hypertension
E4	69	159	98	76	90	Osteoarthritis

Table 5-2 Detail of the subjects

The test was conducted in a room under the room condition of 25°C and 45% relative humidity. Totally six samples were tested by the subjects. In order to standardize the testing, the subjects have to put on standard underclothes of the same style before wearing the samples of hip protectors.

A questionnaire has been set to ask the subjects about their personal perception of comfort after wearing the sample for every 8 hours and a points system has been applied for a more comparable result. 10 is the highest rating while 1 is the lowest. The average ratings of comfort after wearing the samples of hip protectors for different period of time, i.e. 8 hours, 16 hours and 24 hours, are listed in Table 5-3, Table 5-4 and Table 5-5.

Sample	**1**	**4**	**5**	**7**	**9**	**10**
Lightness	7.25	7.25	8.50	7.00	8.75	5.75
Breathability	7.50	8.25	7.75	9.75	7.50	4.50
Coolness	5.25	6.50	5.75	6.00	5.50	6.50
Smoothness	6.25	6.75	6.50	6.50	6.25	6.50
Softness	7.50	7.75	6.75	7.50	7.00	6.50
Dryness	7.00	6.00	6.25	6.50	6.75	6.50
Movement	7.25	9.25	8.00	9.25	8.25	5.75

Overall comfort	6.00	6.47	6.19	6.56	6.25	5.25

Table 5-3 The average ratings of comfort after wearing the samples of hip protectors for 8 hours

Sample	**1**	**4**	**5**	**7**	**9**	**10**
Lightness	6.75	6.75	8.00	6.50	8.25	5.50
Breathability	7.00	7.50	7.25	8.50	6.75	4.00
Coolness	4.75	6.00	5.25	5.25	5.00	6.00
Smoothness	5.75	6.25	5.75	6.00	5.75	5.75
Softness	7.00	7.25	6.50	7.00	6.50	6.00
Dryness	6.50	5.50	5.75	6.00	6.25	6.25
Movement	6.75	8.75	7.50	8.75	7.75	5.50

Overall comfort	5.56	6.00	5.75	6.00	5.78	4.88

Table 5-4 The average ratings of comfort after wearing the samples of hip protectors for 16 hours

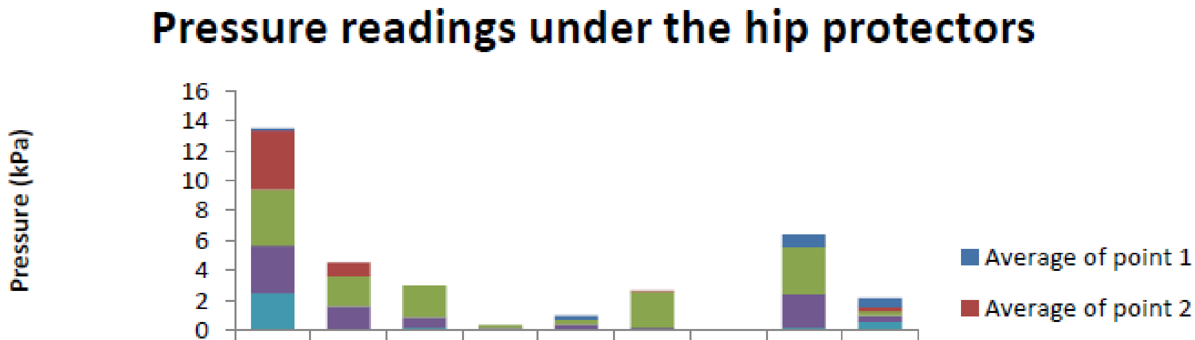
Sample	**1**	**4**	**5**	**7**	**9**	**10**
Lightness	6.25	6.25	7.50	6.00	7.50	5.00
Breathability	6.00	7.25	7.00	8.25	6.50	3.50
Coolness	4.25	5.50	4.75	4.75	4.50	5.50
Smoothness	5.00	5.75	5.25	5.50	5.25	5.25
Softness	6.00	6.75	6.00	6.50	6.00	5.50
Dryness	5.50	5.00	5.00	5.50	6.00	6.00
Movement	6.50	8.50	7.00	8.00	7.00	5.00

Overall comfort	4.94	5.63	5.31	5.56	5.34	4.47

Table 5-5 The average ratings of comfort after wearing the samples of hip protectors for 24 hours

Figure 5-12 illustrated the comparison of the average ratings of comfort for each sample of hip protectors. The differences in average ratings of comfort among samples 4, 5, 7 and 9 were not very significant, however, their ratings of comfort are higher than those of samples 1 and 10, and the rating of comfort for sample 10 was much lower than the ratings of comfort for the others.

Also, the average ratings of comfort decreased when the wearing time is prolonged. The subjects explained that the padding in hip protectors do not cause any scratchy feeling, but they felt little pressure on the skin surface around the hip areas and lead to uncomfortable feeling when the wearing time is prolonged.



	1	2	3	4	5	6	7	8	9
Average of point 1	0.15	0.00	0.00	0.00	0.30	0.00	0.00	0.83	0.61
Average of point 2	3.92	0.90	0.00	0.00	0.00	0.05	0.00	0.00	0.30
Average of point 3	3.73	2.02	2.10	0.20	0.28	2.40	0.00	3.15	0.30
Average of point 4	3.15	1.63	0.69	0.19	0.44	0.21	0.00	2.20	0.39
Average of point 5	2.54	0.00	0.20	0.00	0.00	0.00	0.00	0.21	0.60
Average of point 6			0.00			0.00			

Styles

Figure 5-13 Average ratings of comfort for samples of hip protectors

From the results, samples 1, 4, 5, 7 and 9 have a better overall comfort than sample 10. All the samples have a similar performance in the areas of coolness, smoothness, softness and dryness.

For lightness and movement, samples 1, 4, 5, 7 and 9 have much higher ratings than sample 10. Subjects explained that the padding of sample 10 is very a little heavy and very hard; it is mainly due to the high density and rigidity of the plastic shields used in sample 10, whereas 3D spacer fabrics used in the other samples are very lightweight, soft and flexible, they do not limit the movement of the subjects.

For breathability, the ratings for samples 1, 4, 5, 7 and 9 are between 6.00 and 9.75 and the ratings for sample 10 are 4.50, 4.00 and 3.50 respectively at different time, which are much lower than the acceptable level. Subjects have also commented that the padding of sample 10 is not breathable at all and they suggested that the performance of padding should be improved.

The results from the case study proved that the hip protectors developed in this study have made an improvement on comfort of hip protectors and the acceptance of hip protectors made with 3D spacer fabrics are higher than that with plastic shields.

5.5. Limiting conditions

Due to limited time and resources, only four subjects have been involved in this case study and they have only worn each of the six samples for 24 hours.

5.6. Summary

The properties of prototype of assorted styles of hip protectors have been evaluated by both objective testing, wear trial and case study and subjective testing in this chapter. The detail of objective testing: pressure distribution of the hip protectors and shock absorbing performance of the hip protectors; and subjective testing: wear trial and case study have also been explained and the results proved that this study has made an improvement on aesthetics, comfort and function performance of hip protectors.

CHAPTER 6 CONCLUSIONS AND FURTHER WORK

6.1. Conclusions

Several types of protective materials offered in the market have been explored for their features and protective functional garments offered in the market have been investigated for their performance. The reason for fall and injury has been explored as well as their prevention. Numerous apparel technologies, including cutting, edge finishing and sewing methods, have been carried out on 3D spacer fabrics to evaluate their performances and optimize the applications of 3D spacer fabrics on hip protectors with appropriate apparel technologies. Numerous cutting and edge finishing methods have been compared by subjective assessment and sewing methods have been compared by objective assessment from results of the compression test. Based on the experimental results, appropriate material, cutting method and sewing method for the production of hip protectors using 3D spacer fabrics have been selected, followed by the development of prototype of hip protectors. At the end of the study, objective testing and subjective testing of prototype have been carried out and the relationships between different factors of the prototype have been evaluated.

6.2. Further work

Apart from hip protectors, 3D spacer fabrics can also be applied on sportswear and further work can be done on the design and application of 3D spacer fabrics on other kind of protective clothing. And the prototype can be showcased in different exhibitions and trade shows to promote the application of 3D spacer fabrics.

APPENDICES

	Sample	N	Mean	Standard deviation	Standard error
Appearance	1	20	2.1250	0.25327	0.05663
	2	20	2.1250	0.25327	0.05663
	3	20	2.2750	0.23508	0.05257
	4	20	3.5063	0.24493	0.05477
	5	20	3.5500	0.25131	0.05620
	6	20	2.3500	0.23156	0.05178
	7	20	3.5500	0.23786	0.05319
	8	20	1.8750	0.22580	0.05049
	9	20	3.5438	0.25737	0.05755
	10	20	1.8563	0.20389	0.04559

	Total	200	2.6756	0.75720	0.05354
Comfort	1	20	4.3000	0.22685	0.05073
	2	20	4.3000	0.22685	0.05073
	3	20	4.3250	0.19099	0.04271
	4	20	4.3667	0.25131	0.05620
	5	20	4.3667	0.25131	0.05620
	6	20	4.2333	0.21898	0.04897
	7	20	4.3667	0.25131	0.05620
	8	20	3.8750	0.22862	0.05112
	9	20	4.3667	0.25131	0.05620

	10	20	1.7917	0.19403	0.04339
	Total	200	4.0292	0.79351	0.05611
Padding	1	20	4.3167	0.55646	0.12443
	2	20	4.3167	0.55646	0.12443
	3	20	4.3500	0.42543	0.09513
	4	20	4.2500	0.57098	0.12768
	5	20	4.2500	0.57098	0.12768
	6	20	4.3000	0.45756	0.10231
	7	20	4.2833	0.57507	0.12859
	8	20	4.0667	0.53639	0.11994
	9	20	4.2667	0.53639	0.11994

	10	20	3.6833	0.35002	0.07827
	Total	200	4.2083	0.54135	0.03828
Fitting	1	20	3.7500	0.55012	0.12301
	2	20	3.7500	0.55012	0.12301
	3	20	3.9500	0.51042	0.11413
	4	20	3.6000	0.59824	0.13377
	5	20	3.6000	0.59824	0.13377
	6	20	3.9500	0.51042	0.11413
	7	20	3.6000	0.59824	0.13377
	8	20	3.4500	0.60481	0.13524

	9	20	3.6000	0.59824	0.13377
	10	20	4.1000	0.55251	0.12354
	Total	200	3.7350	0.58865	0.04162
Acceptance	1	20	4.4250	0.40636	0.09087
	2	20	4.4250	0.40636	0.09087
	3	20	4.3750	0.39320	0.08792
	4	20	4.2500	0.38044	0.08507
	5	20	4.2500	0.38044	0.08507
	6	20	4.3000	0.41039	0.09177
	7	20	4.2500	0.38044	0.08507
	8	20	4.5000	0.42920	0.09597

	9	20	4.2500	0.38044	0.08507
	10	20	4.7000	0.34028	0.07609
	Total	200	4.3725	0.40721	0.02879

Table A1 Mean distribution of factors

		Sum of Squares	df	Mean Square	F	Sig.
Appearance	Between Groups	103.159	9	11.46206	199.09809	0.000
	Within Groups	10.938	190	0.05757		
	Total	114.097	199			
Comfort	Between Groups	115.234	9	12.80378	241.62743	0.000
	Within Groups	10.068	190	0.05299		
	Total	125.302	199			
Padding	Between Groups	7.203	9	0.80031	2.97474	0.002
	Within Groups	51.117	190	0.26904		
	Total	58.319	199			

Fitting	Between Groups	7.605	9	0.84500	2.61695	0.007
	Within Groups	61.350	190	0.32289		
	Total	68.955	199			
Acceptance	Between Groups	3.886	9	0.43181	2.81814	0.004
	Within Groups	29.113	190	0.15322		
	Total	32.999	199			

Table A2 ANOVA test for the performance indicators

SURVEY

This survey aims to investigate the performance of different samples.

Please spend a few minutes to answer the following questions.

For each of the following samples, please rate your satisfaction by giving a tick on the adjoining scale.

Rating	Description
1	Definitely not satisfied
2	Not satisfied
3	Neutral
4	Satisfied
5	Definitely satisfied

Sample ( )

	1	2	3	4	5
• Comfort of the edge					
• Neatness of the edge					
• Appearance of the edge					
• Effectiveness in edge finishing					
• Durability in edge finishing					

Are there any difference between the edge in the wale direction and the edge in the course direction?

If so, please describe.

WEAR TRIAL

This survey aims to investigate the performance of different samples. Please spend a few minutes to answer the following questions.

I. Personal Information

Age:

□ 18 or below

□ 18-21

□ 22-25

□ 26-29

□ 30 or above

II. Please circle a number on the scale to represent your agreement.

1 - Strongly Disagree

2 - Disagree

3 - Neutral

4 - Agree

5 - Strongly Agree

Sample ( )

1	The hip protector is comfortable to wear.	1	2	3	4	5
2	The hip protector looks good.	1	2	3	4	5
3	I like the cutting of the hip protector.	1	2	3	4	5
4	I think the hip protector can protect me from injury following a fall.	1	2	3	4	5
5	I do not like the hip protector because it looks bulky.	1	2	3	4	5
6	The workmanship of the hip protector is good.	1	2	3	4	5
7	The hip protector fits my body well.	1	2	3	4	5
8	I am willing to wear the hip protector for a whole day, even when I sleep.	1	2	3	4	5
9	The hip protector is too loose for me.	1	2	3	4	5
10	I do not want to wear the hip protector for long hours.	1	2	3	4	5

11 The paddings are too thick.	1	2	3	4	5
12 The hip protector is easy to wear.	1	2	3	4	5
13 I believe the hip protector can save me from hip fractures after a fall.	1	2	3	4	5
14 I think the paddings can act as a cushion when I fall.	1	2	3	4	5
15 The paddings are hard and rigid.	1	2	3	4	5
16 My movement has been limited by the hip protector.	1	2	3	4	5
17 The hip protector causes abrasion on my skin.	1	2	3	4	5
18 I can wear the hip protector without others' assistance.	1	2	3	4	5
19 The handle of the hip protector is good.	1	2	3	4	5
20 I feel confident when I am in the hip protector.	1	2	3	4	5

Thank you for your participation in this study.

CASE STUDY

This survey aims to investigate the performance of different samples. Please spend a few minutes to answer the following questions.

Personal Information

Age:

Height (cm): Weight (lbs):

Waist (cm): Hip (cm):

Medical condition:

<u>Sample ( )</u>	**Rating Scale**									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Lightness										
Breathability										
Coolness										
Dryness										
Smoothness										
Softness										
Movement										
Overall comfort										

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