THE DEVELOPMENT OF TEXTILES FOR PARAPLEGIC AND QUADRIPLEGIC PATIENTS IN PAEDIATRIC HOSPITALS

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The Development of Textiles for Paraplegic and Quadriplegic Patients in Paediatric Hospitals

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

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Dedicate to: My family,

the most special people in my life

ABSTRACT

The thesis is concerned with a user-oriented approach in accordance with the product development process to design and develop textile materials for bedding and clothing for paraplegic and quadriplegic patients in paediatric hospitals. Problems related to comfort sensation and handling issues are found in the hospital patients' bedding and clothing which are offered to the child patients aged 16 and under in the Developmental Disabilities Unit (DDU) of Caritas Medical Centre (CMC), Hong Kong, China.

Special requirements of the patients' bedding and clothing including comfort, good moisture management property, anti-bacterial property, safety and durability were established with reference to the literature research; supervised hospital visitation and observation as well as questionnaire survey distributed to the patients' guardians and the professional medical personnel. Sixteen different fabrics were initially designed and developed by means of various yarn combinations and weave structures according to the yarns' beneficial functions so as to meet the established requirements of the products. The fabrics were then evaluated by a series of experimental tests. An indexing method was adopted for fabric evaluation by combining both objective and subjective measurements.

The 2/2 twill fabric with the weft Nu-Torque cotton yarns was selected for the patients' bedding prototype by the professional medical personnel and the project team members. Furthermore, the 2/1 twill weft backed fabric with the weft Coolmax yarns and Nu-Torque cotton yarns was also selected for the patients' clothing prototype.

The anti-bacterial property was achieved by the application of anti-bacterial finishing. The anti-bacterial property was evaluated by anti-bacterial tests to be suitably applied to the new prototypes of the patients' bedding and clothing.

The final bedding and clothing prototypes were then evaluated by a series of tests related to the requirements of comfort, moisture management property, safety and durability. The experimental results obtained were compared with the current hospital patients' bedding and clothing before the user trial in the hospital. It was found that the newly developed bedding and clothing prototypes were suitable with better performance than the current ones. The performance of the newly developed bedding and clothing prototypes was also evaluated through the user trial in the hospital. The skin temperature of the patients was measured during the user trial. As a result, there was a great improvement of the newly developed bedding and clothing prototypes when compared with the current ones. The results of the skin temperature measurement indicated that the skin temperature of the subjects was more consistent using the newly developed bedding and clothing than the current hospital bedding and clothing.

PUBLICATIONS ARISING FROM RESEARCH PROJECT

Referred journals

[1] **Kwok HN**, Chan CK, Kan CW, Yuen CWM. Development of a bedding material for profoundly disabled young patients. International Journal of Arts & Sciences. 2011;4(2):17-24.

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Chapter 1 Introduction

1.1 Research background

The types of children disability commonly found in Hong Kong include restriction in body movement, seeing difficulty, hearing difficulty, speech difficulty, mental illness, autism or intellectual disability [1]. The illness might present significant challenge to the daily life of children especially those with complex health needs. An estimated 10% of the world's population, i.e. about 200 millions, is disabled children [2]. There were about 13400 children aged between 0 and 14 years-old registered as disablement in Hong Kong, constituting 3.7% of all persons with disabilities but excluding those with intellectual disability [1]. The number of disabled persons with restriction in body movement rose from 1.52% to 2.7% among the total population between 2001 and 2007 in Hong Kong [1, 3].

Maynard et al. [4] defined quadriplegia as impairment or loss of motor and sensory function in the cervical segments of the spinal cord due to the damage of neural elements within the spinal canal. Paraplegia was defined as complete paralysis of both limbs [5]. The causes for the paraplegia and quadriplegia have been identified as diseases or injuries in their childhood or at birth [6, 7]. Various problems which the paraplegic and quadriplegic patients face are associated with their physical conditions. In other words, the special needs of paraplegic and quadriplegic patients depend on their level of disabilities.

The paraplegic and quadriplegic patients in the paediatric hospital have very fragile skin and can be easily injured by the slightest abrasion. They have some adverse characteristics such as spasticity, eczema and tracheostomy with the problems of salivating and sweating. They may have eczema at their backs due to constant contact on the bed without good ventilation, especially for the young patients who sweat heavily. Their clothing can cling to their bodies due to the perspiration which makes them feel very uncomfortable. In addition, all young patients wear diapers in the paediatric hospital and so they may suffer a great discomfort because of urine leakage from diapers. These young patients with spasticity have difficulties in transportation, feeding, toileting and dressing due to their rigid limbs [8]. Muscular weakness, joint limitations as well as limitations in different range of motor and paralysis also contribute to the problems of dressing and undressing. In addition to the daily living problems, many suffer from over-salivating and need protection for their clothing. As far as the rigid limbs of the spastics are concerned, the shape problems of limbs can arise. Since the clothing and bedding of patients are the same in all Hong Kong hospitals, there is no specific requirement for the textile materials used in the hospital for the paediatric paraplegic and quadriplegic patients.

Wong et al. [9] have examined the weaknesses of an existing child patients' garment and generated ideas to develop a new patients' garment in terms of physical and psychological functions. The design requirements were established in terms of style, size, fasteners, fabric and colour. Later, Kwok et al. [10] studied the functional requirements of the bedding materials for the elderly patients and showed that fabric absorbency was important to incontinence. The silklike bedding has been specially designed for patients with Atopic Dermatitis [11]. Recent studies have revealed the development of clothing for disabled people with limbs disorder by combining the knowledge of human engineering, textile materials and apparel technology [12, 13]. To date, little attention has been devoted to the special needs for the paraplegic and quadriplegic child patients. There is clearly a need to develop new materials for textiles suitable for these young patients. In the present study, textile fabrics suitable for the patients in terms of comfort, good moisture management property, durability, safety and anti-bacterial property will be developed for the clothing and bedding of patients while in the hospitals.

The present research study is a joint research project initiated by the Institute of Textiles and Clothing, The Hong Kong Polytechnic University and the Developmental Disabilities Unit (DDU) of Caritas Medical Centre (CMC). A discussion was made between the consultant paediatrician of a government hospital specializing in the care of paraplegic and quadriplegic patients and the industrialists came from the textiles clothing industries together with the researchers from The Hong Kong Polytechnic University. The needs for the textile materials to be used in the hospitals for the paediatric paraplegic and quadriplegic patients were presented in the seminar held by the Hong Kong Research Institute of Textiles and Apparel (HKRITA) in July 2008. Subsequently, a visit was made to the paediatric ward of the DDU of CMC to observe the patient conditions. Finally, the research was started and supported by the HKRITA, Innovation Technology Commission, CMC with the joint supervision of the Hospital Authority (HA) and the Institute of Textiles and Clothing at The Hong Kong Polytechnic University.

1.2 Objectives

The present project is focused on the development of textile materials for paraplegic and quadriplegic patients in paediatric hospitals. The principle objectives of the thesis are summarised as follows:

1. To investigate and understand the special needs of paraplegic and quadriplegic patients in paediatric hospitals, including the functional, sanitary and physical requirements for the textile materials such as the clothing and bedding of patients.
2. To develop textile materials especially for garment and bedding use that are suitable for paraplegic and quadriplegic patients in paediatric hospitals and meet the stringent environmental conditions by means of advanced textile technology implementation.
3. To evaluate the performance between the current textile materials used especially for garment and bedding in paediatric hospital and the newly developed textile materials.

1.3 Project originality

The newly developed textile materials including bedding and clothing used for young patients were designed through a careful consideration of their special needs on physical and physiological comfort during hospitalization. The product development process was adopted to identify the weaknesses of the current patients' bedding and clothing. Innovative textile technology development in fibre and yarn, fabric construction and anti-bacterial finishing technology were applied in the present study to achieve an improvement of comfort, durability and moisture management as well as anti-bacterial functions.

1.4 Project significance and values

Since the paraplegic and quadriplegic patients in paediatric hospitals have very sensitive skins, their skin can be easily injured by abrasion and get infected in the hospital. However, there are no specially designed bedding and clothing for the patients in Hong Kong. The new bedding and clothing have been designed in the present study to improve comfort, durability as well as moisture management properties. The anti-bacterial property can be achieved by considering the special needs of physical and physiological comfort as well as the practical issues of carers and nurses. The specification required for the bedding and clothing of the paraplegic and quadriplegic child patients will be generated to maintain the quality and performance which can meet their special needs. Hence, the present research study has a vital significance to the paraplegic and quadriplegic child patients. The results of the research can contribute significantly to the mass production of patients' bedding and clothing for hospitals in Hong Kong and elsewhere.

1.5 Outlines of the study

The thesis consists of six chapters.

Chapter 1 introduces the research background and objectives of the thesis. Project originality, significance and values are also highlighted.

Chapter 2 provides a comprehensive review of the literature concerning the care of the paraplegic and quadriplegic patients, and the problems faced by the patients, the carers and nursing staff in hospitals such as comfort, anti-bacterial mechanism and properties. Recent developments of functional yarns which can enhance comfort sensation and physical properties are reported.

Chapter 3 presents the research methodology in details. The product development process adopted is explored namely (1) identification of problem area, (2) problem analysis, (3) formulation of objective and project, (4) formulation of the demands of the user, (5) data processing and analysis, (6) specification of the use-demands and transformation of these into technical terms, (7) development of ideas and technical solution, (8) evaluation, modification and selection of prototype, and (9) evaluation of the final solution in relation to the objectives.

Chapter 4 discusses the establishment of the requirements for the development of the patients' bedding and clothing through the supervised hospital visitation and observation, discussion with medical staff and the patients' guardians as well as questionnaire survey.

Chapter 5 explains the design and development of fabrication and anti-bacterial finishing methods; experimental designs for fabric evaluation; questionnaire survey on the importance of the fabric attributes with respect to the performance of the patients' bedding and clothing; an index measurement based on the results of the questionnaire and the experiments as well as fabric selection.

Chapter 6 compares the performance of the current and the new fabrics used for the bedding and clothing of patients in terms of different experimental tests and user trial as well as the skin temperature measurements. The questionnaire has been conducted to evaluate the performance of the new fabrics by comparing with the current ones.

Chapter 7 summarizes the major results as well as findings and draws the final conclusion of the present study. The limitations of the present study are examined and some future research work is also recommended.

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Chapter 2 Literature Review

2.1 Introduction

Functional clothing becomes extremely important to the people with physical impairments because it is specially designed according to their physical limitations [1]. Knowledge of the needs of paraplegic and quadriplegic patients in relation to the clothing and bedding can be very useful to the carers in order to meet the needs of patients. However, only a very limited research has been conducted on the clothing and bedding materials for paraplegic and quadriplegic patients. This chapter presents a review of research and literature on the paraplegic and quadriplegic patients and their clothing and bedding needs as well as the application of the advanced textile technology. There are four major sections including (1) an examination of the care of the paraplegic and quadriplegic patients, (2) the definition of comfort, thermophysiological comfort, aesthetic comfort and garment fit, (3) the mechanism of different anti-bacterial properties, and (4) the recent development of functional yarns.

2.2 Care of paraplegic and quadriplegic patients

In order to understand more fully about the needs of the paraplegic and quadriplegic patients for clothing and bedding, the definition, causes, rehabilitation and problems faced of paraplegia and quadriplegia were studied.

2.2.1 Definition of paraplegia and quadriplegia

‘Paraplegia is defined as complete paralysis of both limbs’ [2]. Maynard et al. [3] defined quadriplegia as ‘impairment or loss of motor and sensory function in the cervical segments of the spinal cord due to the damage of neural elements within the spinal canal.’ The mobility levels of quadriplegia are summarized generally in Table 2.1.

Table 2.1 Mobility of quadriplegia

Mobility Level	Chair Transfer	Locomotion
C4	Dependent	Dependent while using powered equipment
C5	Assisted	Independent while using manual chair and adapted hand rims within limited distances
C6	Independent with transfer board	Independent while using manual chair and adapted hand rims
C7	Independent	Independent while using manual chair with curbs
C8	Independent	Independent while using manual chair

Source: Yarkony et al., 1988 [4, 5], Staas et al., 1993 [6]

2.2.2 Causes of paraplegic and quadriplegic patients

Brown et al. [7] found that 52% of 103 pediatric patients with cervical spine injuries were injured in the motor vehicle-related incidents. The sports-related activities were accounted for 27%, and 15% were caused by falls. The remainder of injuries resulted in child abuse (3%) and unknown factors (3%). Recent researches demonstrated that the spinal cord injuries occurred at birth [8, 9]. In addition, many cases of paraplegia and quadriplegia were due to the spinal cord injury and spinal surgery [8-14]. Researchers [15-17] also found that aortic dissection caused paraplegia. According to Luk and Krishna [18], paraplegia resulted from tuberculosis of the spine and cord compression was caused by active disease. Robinson [19] stated that the brain malformation of children due to cerebral palsy also contributed to quadriplegia.

2.2.3 Rehabilitation of young paraplegic and quadriplegic patients

Gibson et al. [20] explored that children with developmental motor impairments such as cerebral palsy and spina bifida typically received the most intensive therapy intervention during the pre-school ages. The rehabilitation generally used for children with paralysis is mainly concerned with the prevention of complications and maintenance of functions. The treatment is similar to the adult patients with paralysis which is divided into different stages. Extra attention is paid to the skin, urinary tract, contractures and effects of inactivity during the early stage. However, children need the surveillance of the back, skin, bladder and bowel as well as contractures and posture to prevent complications throughout the whole rehabilitation. Later on, exercises are begun to strengthen the upper limbs and the back of the young patients. They are trained with mobilization, muscle re-education programmes, wheelchair programmes and activities of daily living in the prolonged period in hospital. The muscle re-education programmes include self-supported sitting, single arm exercises and bilateral arm exercises. The occupational therapist plays with them and the teacher provides education for them during rehabilitation [21, 22].

Hence, the fabrics should not cause any complications to the skin and back of patients when designing and developing the new bedding and clothing for paraplegic and quadriplegic patients in paediatric hospital.

2.2.4 Special needs for paraplegic and quadriplegic patients

The paraplegic and quadriplegic patients are physiologically different depending on the level of injury when compared with the other able-bodied patients. Various problems which they face are associated with their physical conditions. In other words, the special needs for the paraplegic and quadriplegic patients depend on their level of disabilities and syndromes.

As mentioned in Section 2.2.2, spinal injuries are the major causes for these patients. Spasticity is a major disorder characterized by the velocity-dependent increase in the tonic stretch reflex with exaggerated tendon jerks resulting from the hyperexcitability of the stretch reflexes and also a crucial problem resulting from the spinal injuries [23]. The patients with spasticity have difficulties in transportation, feeding, toileting and dressing due to their rigid limbs. Muscular weakness, joint limitations as well as limitations in range of motor and paralysis also contribute to the problems of dressing and undressing. In addition to daily living problems, many patients over-salivate and so they need protection for their clothing. As far as the rigid limbs of the spastic are concerned, shape problems of limbs can arise as well. Apart from spasticity, incontinence may also be present in the paraplegic and quadriplegic patients. The effectiveness of heat distribution with the thermo-regulation of the body under the conditions of prolonged immobilization depends on the place where sweat is emitted as well as heat transportation from muscles to the skin. Hence, they are not capable of controlling their body temperature resulting in suffering from excessive sweating [24]. Other special considerations include the management of fecal soilage and sweat absorption [25].

Paraplegic and quadriplegic patients also experience the clothing problems due to the use of wheelchair. Nessley and King [26] investigated the specific clothing and textile needs of paraplegics and quadriplegics. The results of their research indicated that there was a need for special alterations of ready-made clothing to accommodate aids such as wheelchairs. They preferred the clothing to be made of specific classes of fibres. Their research suggested that an ideal fabric used for clothing was a blend of fibres with tightly woven and smooth surfaces. The fabric should be breathable, absorbent and lightweight for the sake of added comfort for clothing. The researchers [27] also reported that the position of closure, types of closure and fit made the disabled persons using wheelchairs encounter unpleasant feeling while dressing.

The factors which have considerable influences on the suitability of the clothing for the paraplegic and quadriplegic patients include warmth, weight, fit, absorption, strength, feel and safety with their details being summarized as follows [28-31]:

Warmth and weight: The persons with a lack of mobility have decreasing blood circulation. Due to the reduced sensation, they are unable to feel the cold and hence must be warmly clothed. Nevertheless, more garments are worn to create warmth but this will increase the weight of clothing and restrict movement, causing difficulties for dressing. As far as paralysis is concerned, heavy clothes aggravate pain at joints caused by movement. Hence, the combination of warmth and lightness of weight in a fabric is of special advantage for the patients propelling their wheelchairs.

Fit: The elasticity of fabric not only contributes to fit and comfort by allowing a greater freedom of movement but also makes dressing easier and conforms to the seated figure without feeling tight. However, elastic webbing used around limbs may result in the restriction of circulation. Tight garments may create the same threat too.

Absorption: For those patients who have an inability to swallow saliva causing over-salivating, their upper clothing gets wet and damp easily leading to discomfort and even chest infection. The ability of a fabric to absorb saliva should be considered. The patients with excessive perspiration problems may experience discomfort if the perspiration is not absorbed and evaporated through their clothing.

Strength: One of the special needs for these patients is fabric strength which can withstand the strain caused by reaching and pulling in the daily activities due to their mobility problems. Moreover, the extra wear and tear should also be considered for those disabled people with difficulties in getting dressed. The fabric should resist the abrasion caused by the constant friction of a sleeve against the side of a wheelchair.

Feel: The patients spend much of their time during the day in sleeping and sitting positions; thus their clothes should be comfortable for both positions. The patients can slip whilst being lifted or can slip from a bed or chair if the surface of clothing is too slippery. A precaution should be taken to avoid two slippery surfaces getting in contact such as the seat cover and the clothing. It is vital to avoid wearing clothes that cause friction or pressure on their skin. Stiff fabrics contribute to discomfort for the patients, especially for those sitting and sleeping for longer periods. The patients suffering from a certain skin complaint get hurt when rubbing against rough clothing. Hence, smooth fabrics for clothing are preferable but very slippery clothes should be avoided. The type and position of seams should not cause discomfort to sit or lie in, especially for those patients with tender skin. In other words, how tightly the seams press on their skin or rub against it will affect the clothing comfort.

Safety: People with disabilities may have a greater risk from fire because they are unable to move away quickly from the source of the fire. Therefore, it is essential to assess the flammability of the fabrics for clothing.

Hence, the clothing needs of paraplegic and quadriplegic patients can be satisfied by fabric selection, location and construction of openings, types, number and location of fastenings as well as garment design for comfort and ease of movement [30].

In addition to the needs for clothing, a sheet with a slippery surface is useful as the patients with quadriplegia need to be transferred from the bed by sliding [32].

Another significant problem that the paraplegic and quadriplegic patients face with is pressure sores which are especially common for immobile patients in hospitals. Prolonged pressure elicits the deprivation of nutrient as well as oxygen supply of the skin and underlying tissue resulting in pressure sores [33, 34]. The injury mechanism is that the underlying skin layers move with the patient when the epidermal skin layers adhere to the surface of bed or chair leading to an increase of shearing force of the tissues under the skin [35].

A lot of research works have demonstrated that friction and shear forces are additional factors for pressure sores [36-41]. Patients' skin rubbing on stiff bed linens affects the elbows, heels and knees because of the friction-induced skin damage [35]. Excess friction elicits skin irritation when the patients are transferred from the bed to a wheelchair and repositioned in bed. Extensive studies in the past reported that yarn types and fabric's morphology, weave structure, rubbing direction as well as finishing methods varied the fabric friction [42-45].

Another major factor for pressure sores is the micro-climate around the skin while moisture and wetness will make the skin become too soft resulting in skin damage. A proper micro-climate around the body of patients can be established by the desirable thermal and tactile properties of textile products which are in direct contact with the skin of patients, especially the patients' bed clothes and bedding [46]. Fabric materials carry the excess of humidity from the skin surface to the external environment effectively are proved to be physiologically beneficial for immobile patients [47].

Pryczynska et al. [48] have examined the bio-physical properties of the bed sheet fabrics with anti-bedsore mattresses. They prove that hospital textiles should be air permeable and can carry sweat away from the skin surface to provide a dry micro-climate on the skin surface. Vigilant skin care is of vital importance to prevent pressure sores such as wearing clothing with moisture-wicking properties [49, 50]. The prototype of bed sheet has been developed for hospital to reduce friction and shear forces at the skin surface of bedridden patients by absorbing and distributing interfacial water within the fabric structure [51].

These studies have a clinical significance to understand the special needs for the bedding of the paraplegic and quadriplegic patients. Comfort and good moisture management property are the major factors for bedding selection as far as the paraplegic and quadriplegic patients are concerned.

2.3 Comfort

Textile comfort is significantly important from the point of view of the consumers especially for functional textiles. The purpose of defining comfort is to provide an understanding of previous research in this area, as well as providing a rationale to improve the patients' clothing and bedding comfort.

2.3.1 Definition of comfort

Comfort is a nebulous term generated from the view of textile and clothing aspects and is difficult to define. In the past, a considerable number of researches had been made. Fourt and Hollies [52] made an attempt to explore and incorporate the literature relating to comfort. They stated that comfort was influenced by thermal components and non-thermal components as well as wear conditions such as working, non-critical conditions and critical conditions. Comfort is also related to the ability of the body to maintain a constant core temperature under different environmental conditions at different work rates for the body [53].

Comfort restricted to clothing has a number of different aspects proposed by the physicists, psychologists and sociologists [54]. Comfort is qualified in terms of aesthetic factors such as handle and drape as well as performance factors including warmth and moisture transport [55]. Comfort is defined as everything contributing to the well-being and convenience of the material aspects of life based on a psychological standpoint [56].

Slater [57] defined comfort qualitatively as “a pleasant state of physiological, psychological and physical harmony between a human being and the environment”. Slater [58] also examined the importance of comfort came from the physiological, psychological and physical aspects. Physiological comfort is related to the ability of human body to maintain life. Psychological comfort is the ability of mind to keep it functioning satisfactorily without external help. Physical comfort is about the influence of the external environment on the body.

The comfort of wearing clothing is a neutral sensation which is different from various people. Smith [59] divided discomfort into two categories namely psychological discomfort and physiological discomfort. Psychological discomfort is related to aesthetics such as colour, garment style flattering the body figure and fitting properly, fashion, fabric construction and finishes, suitability for an occasion and prejudice. Physiological discomfort pertains to sensorial discomfort and thermophysiological discomfort as well as garment fit. Allergy, abrasion of the skin, tickle, shed loose fibres, prickle, wet fabric clinging to the skin, and initial cold feel of the fabric causing sensorial discomfort. Overall tight fit and tight local areas contribute to physiological discomfort.

2.3.2 Thermophysiological comfort

Thermophysiological comfort also relates to the heat and moisture transport properties of clothing as well as the maintenance of heat balance of the body at different levels of activity provided by clothing [60]. Khodakarami and Knight [61] showed that the levels of clothing and metabolism of patients in hospitals influenced their thermal comfort requirement. According to Hwang et al. [62], the physical strength of the hospital patients has a significant effect on their thermal comfort sensation while the gender, age and acclimatization do not. The thermal conditions of the hospital wards including air temperature and relative humidity influence the thermal comfort of patients [63].

2.3.2.1 Thermal insulation

The insulation value of clothing is affected by six factors [64]:

1. Wind speed – the zone of insulation is influenced by the increased wind speed.

2. Body movements – the zone of insulation is influenced by the pumping actions of arms and legs.

3. Chimney effect – loosely fit clothing ventilates the trapped air layers from the body.

4. Bellows effect – vigorous body movements causes an increase in the ventilation of air layers to conserve body heat.

5. Water vapour transfer – clothing resists the water vapour transfer and hence decreases body heat loss by evaporation.

6. Permeation efficiency factor – sweat is transferred away from the body surface by wicking which reduces the cooling effect of evaporation while improving the effectiveness for conserving body heat.

Sheneider et al. [65] investigated the effect of moisture regain on the thermal conductivity of woven fabrics. They showed the heat transfer in the moist fabrics through conduction, radiation and distillation whereas only conduction and radiation were present in the dry fabrics. An increase in fabric humidity causes a reduction in thermal resistance due to the substitution of air in pores by water [66]. There is a reduction in clothing thermal insulation during perspiration [67].

Frydrych et al. [68] showed that the thermal resistance was proportional to the fabric structure. An increase in fabric thickness reduces heat loss for the space insulated by the textile, thereby increasing the thermal insulation. The thermal resistance of plain fabrics generally is lower than the fabrics with twill and canvas weaves because the fabric structures of twill and canvas weaves are generally thicker than the plain fabrics [69, 70]. Fabrics with smooth reflective surfaces influence heat transfer by thermal radiation whereas the tightly woven fabrics and designs restrict air movement that controls thermal convection [71]. The multiple-layers of fabrics also influence the thermal insulation [72].

The thermal conductivity of fabrics is influenced adversely by the presence of air rather than the fibres while the thermal absorptivity depends on the nature of contact surface of fabrics [73]. Researches on thermal comfort revealed that the application of ventilation features to the clothing design such as garment openings influenced the heat transfer performance where excess body heat could pass into the environment through this ventilation [74-76].

2.3.2.1.1 Heat balance

The human body temperature is about 37℃ which is achieved by balancing the amount of heat produced in body with the amount of lost. Figure 2.1 shows the pathways for heat loss from the body including conduction, convection, electro-magnetic radiation, sweat evaporation as well as respiration [77].

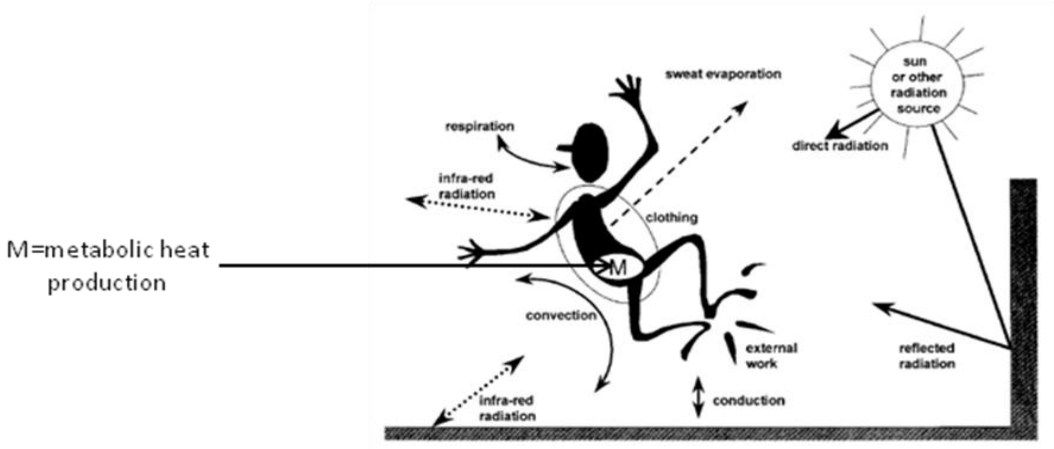

Figure 2.1 Schematic representation of the pathways for heat loss from the body Source: Havenith, 1999 [77]

Heat conduction occurs between two contacting surfaces. Convection relates to the physical exchange of heat between the body and an adjacent moving medium like air and water. Thermal radiation is a radiant energy which is emitted by a medium. Evaporation occurs from the skin and also the respiratory tract [78].

2.3.2.1.2 Relevant unit

Several terms are used for quantifying heat transfer such as thermal transmittance, thermal conductance, thermal resistance and the comfort-associated term, clo [79].

Thermal transmittance means the rate of heat energy transferred per unit area between two environments. The following formula is used for calculation (ASTM D 1518-85 (2003)):

$$U = W/m^2\Delta K, \quad (2.1)$$

where U = thermal transmittance,

W = watt, a unit of power equals to one joule per second,

m^2 = the unit area between the two environments in metre square,

Δ K = the temperature difference between two environments in Kelvins.

Thermal conductance is a lesser-used synonym for thermal transmittance which is defined by the same formula as thermal transmittance, $C = W/m^2\Delta K$, where C is thermal conductance. Thermal resistance is the inverse of thermal transmittance; r=1/U, where r is the thermal resistance. ‘clo’ is defined as the measurement of thermal resistance due to clothing. One clo is the resistance or insulation to keep a resting man who produces heat at the rate of 58 W/m^2W comfortable at 21℃ and at an air movement rate of 0.1/s. clo equals to 0.1548r or equals to U/0.1548 [79].

2.3.2.2 Air permeability

It has been established that the fabric structure is the major factor influencing the air permeability of fabrics while the fibre type, fabric construction and finishing methods have secondary effects [80]. Air permeability varies with the surface density, thickness, bulk density and filling of the cloth by the fibre [81-83].

Attempts made by Mohamed and Lord [84] to compare the physical properties of different woven fabrics showed that increasing pick density caused a considerable increase in fabric rigidity and a sharp reduction in air permeability. Furthermore, the lower fibre tensions generated in spinning increased the yarn bulk and reduced the fabric air permeability.

Yarn production method is another structural parameter which influences significantly air permeability. The fibre packing in siro spun yarns is less dense than ring spun yarns resulting in more air permeable because of yarn twist [85]. Lord [86] and Tokarska [87] pointed out that the main factor responsible for the air permeability was the yarn twist multiple which attributed to a high twist multiple of fabric resulting in a poor cover factor. The twistless yarn of woven fabric tends to spread out to increase fabric cover thereby reducing fabric air permeability [88].

Many studies showed that air permeability of fabric materials was greatly affected by fibre swelling as the air flew through the intra-yarn porosity within the yarn where most of the flow took place [89-92]. The sizes and shapes of the fabric's pores as well as the weft crimp influence the air flow resistance of the fabric [93, 94]. Davis [95] showed that the low air permeability of the fabric was partly due to the high density as well as the low fibre diameter while the fibre denier was the major controlling factor.

2.3.2.3 Liquid-moisture transmission

The movement of moisture in the vapour or liquid state through a garment is an important factor related to clothing comfort perceptions [57, 96]. An unpleasant cool feeling is caused by the sweat evaporation when the sweat keeps adhering to the skin [97]. Liquid transportation in fabrics occurs in three situations such as initial contact of a dry fabric with liquid, liquid flows through a fully saturated medium, and removal of liquid from a fabric by wetting and wicking [98]. Wetting is a dynamic process which is the displacement of a solid-air (vapour) interface with a solid-liquid interface whereas wicking is a result of spontaneous wetting in a capillary system [99]. The capillary action is determined by the interaction of liquid and the fabric material. Liquid properties include viscosity, surface tension, geometric structure of the pores, and the size and shape of the fibres [100].

Increasing the total surface area of a unit length of a yarn caused by decreasing filament diameter in the yarn will facilitate a better wettability due to an increase in the interaction area of fibre and liquid as well as the interaction energy [101]. The presence of surfactants such as spin finishes will influence the wicking properties of the fabrics [102, 103]. Hydrophilic finishes improve the wickability of fabrics [104]. Hydroscopic fabrics can move moisture away without building up of liquid sweat on the skin while hydrophilic fabrics can take up liquid and evaporate away from the skin [105]. Wicking is influenced by yarn twist [103, 106]. The moisture transfer of fabric is affected by the thickness and porosity of fabrics [90]. Moisture management property can be achieved by changing the fibre polymer chemistry and fabric chemical treatments [108].

2.3.3 Aesthetic comfort

The aesthetic properties of a fabric can be readily measured by the physical tests and judged by the way how it feels or looks subjectively. The usual terms indicating these factors include hand or handle, softness, drape, stiffness, luster and colour [109].

2.3.3.1 Psychological comfort

Daters [110] surveyed the importance of clothing comfort of adolescents among three situations such as social, school and leisure. The results indicated that adolescents perceived clothing comfort was more important in social and school situations while clothing comfort was less important in leisure situations.

2.3.3.2 Handle

Handle is made of different sensations such as stiffness, limpness, hardness or softness, and roughness or smoothness [111]. The performance of fabric quality about the mechanical comfort is evaluated by fabric handle judgement subjectively where a fabric is touched and bent by finger and stretched lightly by hand [112]. Subjective assessments of fabric quality have been traditionally applied in the textile and clothing industries by individual judges as the method of fabric evaluation [113]. Fabric handle can be analysed by common word pairs for communication namely harsh-soft, rough-smooth, full and lean [114]. The subjective evaluation method for fabric handle is essential as it is based on human sensitivity and experience. Peirce [111] measured fabric handle in terms of physical properties such as fabric bending and compression. Afterwards, many attempts have been carried out in the textile industries to evaluate fabric handle objectively [115-120].

Frydrych et al. [121] investigated the mechanical components of fabric handle influencing the fabric drape. They showed that the fabric weaves and weight had significant impacts on the fabric drape. Drape is related to fabric bending rigidity as well as fabric deformability. Fabrics made of fine fibres such as miro-denier fibres contribute to sooth, soft and fine appearance [122].

The low stress mechanical properties are important in determining fabric handle [123]. The effects of weave construction, yarn structure, area density and blend composition on low stress mechanical properties were examined [124-129]. Chan et al. [130] evaluated the mechanical properties of uniform and showed that the spandex fibre would contribute to a high extensibility of woven fabrics. The low stress mechanical properties of fabrics were altered after the chemical treatment due to the fabric surface modification [131-133]. These mechanical properties could be applied to fabric specification in textile manufacture [134].

2.3.3.2.1 Kawabata Evaluation System for Fabrics (KES-F)

Kawabata and his co-workers [135-137] started their research on fabric handle based on their concepts as well as the analysis of the judgement of fabric handle as carried out by experts in textile mills. Fabric characteristics such as stiffness, smoothness and fullness were identified and given the title of primary handle for each category. This work led to the development of Kawabata Evaluation System for Fabrics (KES-F) instruments for the objective measurement of fabric low stress mechanical properties [138]. KES-F system could be used for product development and process optimization [139]. There are total sixteen parameters representing the mechanical and surface properties of fabric including tensile, shearing, bending, compression and surface properties [140]. The meaning of the parameters is shown in Table 2.2.

Table 2.2 Mechanical and surface properties

Properties	Symbol	Definition	Unit
Tensile Linearity Tensile Energy	LT WT	Linearity of the load-extension curve Energy in extending fabric to 500 gf/cm width	None gf cm/cm^2
Tensile Resilience	RT	Percentage energy recovery from tensile deformation	%
Extensibility	EMT	Percentage extension at the maximum applied load of 500 gf/cm specimen width	%
Shear Rigidity	G	Average slope of the linear regions of the shear hysteresis curve to $\pm$ 2.5° shear angle	gf/cm degree
Shear Stress at 0.5°	2HG	Average width of the shear hysteresis loop $\pm$ 0.5° shear angle	gf/cm
Shear Stress at 5°	2HG5	Average width of the shear hysteresis loop $\pm$ 5° shear angle	gf/cm
Bending Rigidity	B	Average slope of the linear regions of the bending hysteresis curve to 1.5 cm^{-1}	gf cm^2/ cm
Bending Moment	2HB	Average width of the bending hysteresis loop at 0.5 cm^{-1} curvature	gf cm/ cm
Fabric Thickness at 50 N/m^2 Pressure	T	Fabric thickness at 50 N/m^2 pressure	mm
Compressional Linearity	LC	Linearity of compression-thickness curve	None
Compressional Energy	WC	Energy in compressing fabric under 50 gf/cm^2	gf cm/cm^2
Compressional Resilience	RC	Percentage energy recovery from lateral compression deformation	%
Compressibility	EMC	Percentage reduction in fabric thickness resulting from an increase in lateral pressure from 0.5 gf/cm^2 to 50 gf/cm^2	%
Coefficient of Friction	MIU	Coefficient of friction between the fabric surface and a standard contactor	None
Geometrical Roughness	SMD	Variation in surface geometry of the fabric	micron

Source: Kawabata et al., 1994 [122]

2.3.4 Garment fit

Chen [141] noted that the loose fitting garments tended to trap more air and had larger openings at places like the neck, waist, wrist and ankles causing a greater reduction in their thermal insulation and moisture vapour resistance during the windy conditions and body movement. Since loose fitting ensembles can entrap more air, the effect of movement, posture and wind becomes more severe than tight fitting [142]. Lower pressure in tight garments results in better comfort especially for the parts of breast, upper side, waist and hip [143].

2.4 Anti-bacterial property

Few studies have suggested that the bacteria are not only found in moist sites but also in the dry hospital environment [144, 145]. Staphylococci, Pseudomonas and Escherichia coli especially Staphylococcus aureus are the most common pathogens in hospitals [146]. Nosocomial infections through direct-contact transmission between two patients are frequent. However, the most common infections are mainly caused by healthcare workers who do not wash their hands thoroughly before attending patients [147, 148]. The textiles with anti-bacterial property have been investigated in community hospitals [149, 150].

2.4.1 Textiles as a source of bacteria in hospitals

As far as hospitals are concerned, micro-organisms aggravate problems in environments by transmitting diseases and infections through clothing and bedding [151-153]. Textiles provide an excellent medium for the growth of micro-organisms when nutrients, moisture, oxygen and appropriate temperature are present. Synthetic fibres are more resistant to attack by micro-organisms than natural fibres because of their high hydrophobicity. Protein fibres and cellulosic fibres can act as a nutrient source for micro-organisms under appropriate conditions. Apart from fibres, soil, dust, sweat and some textile finishes can also be a source of nutrients for micro-organisms. The growth of micro-organisms on textiles may cause an increased likelihood of contamination; particularly the bed linens and the patients' gowns [154, 155].

In a clinical setting, the textile micro-environment such as moisture and temperature promotes the bacterial growth when a bacterium is shed into a textile fabric between the patient and the bed, in his bed clothes or directly on the bed sheet [156]. The amount of recovered bacteria obtained from sheets was higher in the infected patients than in the non-infected patients [157].

2.4.2 Anti-bacterial treatment of textiles

Various methods have been developed on textile products with anti-bacterial properties by using different mechanisms including [158]:

(1) impregnation of the fibrous material with a solution or emulsion of the bactericidal product,

(2) padding of an anti-bacterial product from its soluble state into an insoluble state on the fibrous material,

(3) binding of an anti-bacterial product on the fibre by chemical bonding such as ionic and covalent force, and

(4) immersion of a bacterial product in the spinning solution or melt during the preparation of the chemical fibres.

Silver, polyhexamethylene biguanide, quaternary ammonium compounds and triclosan are currently used in the commercial anti-bacterial textiles made of synthetic fibres including nylon, polyester, cellulose acetate, polypropylene and natural fibres such as wool and cotton, while chitosan is in the development stage [159].

For the sake of obtaining an ideal anti-bacterial treatment of textiles, there are four basic requirements [154, 158]. Firstly, the treatment should provide safety in the form of low toxicity to the consumers, i.e. causing no toxicity, allergy or irritation to the skin. The second requirement is the compatibility with the common textile processing especially the durability of repeated laundering. Thirdly, the application of treatment should not influence adversely the textile properties or appearance. Finally, the application of treatment is preferable to be carried out in an environmentally friendly production process.

2.4.2.1 Chitosan

Chitosan shown in Figure 2.2 is the deacylated derivative of chitin. It is commercially obtained from shellfish sources and has unique biological characteristics for a wide variety of applications in the food and cosmetics industries especially in the bio-medical sector due to its bio-degradability, bio-compatibility and non-toxicity [150, 160-162].

The inhibitory activity of chitosan occurs to Gram-negative bacteria *Staphylococcus aureus* due to its chemical and structural properties [163]. Positively charged chitosan molecules and negatively charged microbial cell membranes interact and cause the leakage of proteinaceous and other intracellular constituents, while chitosan reacts mainly on the outer surface of the bacteria [164-167].

Chitosan also acts as a chelating agent to inhibit microbial growth [168]. Chitosan penetrates into the nuclei of the micro-organisms and induce interferences with RNA and protein synthesis to achieve anti-bacterial property [169].

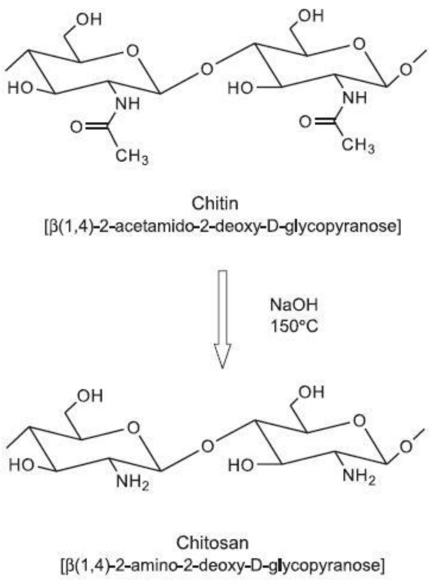

Figure 2.2 Deacetylation of chitin to chitosan
Source: Gao et al., 2008 [159]

2.4.2.2 Triclosan

Triclosan shown in Figure 2.3 is used in an extensive range of products such as soaps, detergents, pillows, clothing and toothpastes because of its broad-spectrum anti-bacterial properties [170]. Triclosan is actively predominant against Gram-positive bacteria as well as some Gram-negative bacteria [171]. Triclosan acts as an anti-bacterial agent which is applied by the conventional exhaust and pad-dry-cure processes on natural fibres as well as synthetic fibres [172]. Triclosan resists microbial growth by blocking lipid biosynthesis [173].

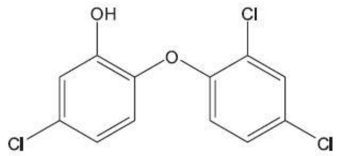

Figure 2.3 Structure of triclosan
Source: Gao et al., 2008 [159]

2.4.2.3 Silver

Silver is widely applied in medical applications [174-176] and silver ions are commonly used as anti-microbial agents for wounds [177]. Gram-negative bacteria are found to be more sensitive than Gram-positive bacteria due to the negatively charged bacterial cell wall [178]. Several mechanisms have been proposed for the anti-bacterial effects of silver as summarized in Table 2.3.

Table 2.3 Anti-bacterial Mechanisms

Anti-bacterial Actions	References
Silver ions bind with negatively charged bacterial cell walls and membranes.	[178]
Silver binds with cellular proteins including enzymes resulting in their inactivation.	[179]
Silver binds with DNA preventing the replication of the DNA of bacteria	[180]
Silver binds with electron donor groups containing nitrogen, oxygen and sulphur.	[180]

2.5 Recent development of functional yarns

The fabric development process begins with a thorough understanding of the structure of a fibre and its properties. Since fibres are the building blocks for the functional textile products, the structure of fibres contributes to the performance properties of a fabric and its end product. Fabrics can be woven, knitted or non-woven in general. Woven fabrics are made by interlacing two sets of yarns perpendicularly to each other. In this section, the functional yarns will be addressed namely Coolmax yarn, Thermolite yarn, Nu-Torque yarn, Murata vortex spun (MVS) yarn, twistless yarn and Lycra yarn.

2.5.1 Coolmax yarn

Coolmax yarns are made from the four-channeled or six-channeled polyester fibres with increasing surface area. The four-channeled Coolmax fibres have 20-25% higher surface area as compared to the fibres with a similar round cross-section and diameter to improve moisture movement [181]. Fabrics produced by the Coolmax yarns are proved to enhance human comfort by the transportation of moisture. Coolmax fibre transports moisture away from the skin to the outer layer of the fabric effectively and then evaporates moisture via capillary action along the fibre channels causing fabrics to become dry. Figure 2.4 shows the evaporative cooling system of the fabrics made of Coolmax yarns. Coolmax fabrics are commonly used in sportswear, intimate apparel, workwear and ready-to-wear to provide faster moisture transportation.

Extensive studies have proved that Coolmax fabrics improve textile properties with regard to water absorption. Coolmax fabrics improve pleasant contact feeling and thermal comfort properties in the conditions of sweating when comparing with pure cotton woven fabrics owing to the fibre constructions [182, 183]. The resistance to fabric pilling of Coolmax fibres is higher than cotton fibres, which is attributed to stronger fibres and delayed pill wear [184]. Coolmax fabrics not only perform faster wicking property than cotton fabrics but also better than the fabrics made of man-made fibres. Fangueiro et al. [185]

studied the wicking behaviour and drying capability of knitted fabrics. They showed that Coolmax fibres demonstrated the best drying capability and good wicking ability when comparing with other functional fibres such as polyester trilobal flat, polypropylene, polyamide, elastane and viscose. The main contributing factor for this result is that Coolmax has irregular cross-sectional shapes and more capillaries than the others. Research also showed that the fabrics made of Coolmax fibres had a 15% faster drying time as compared to acrylic fibres [186].

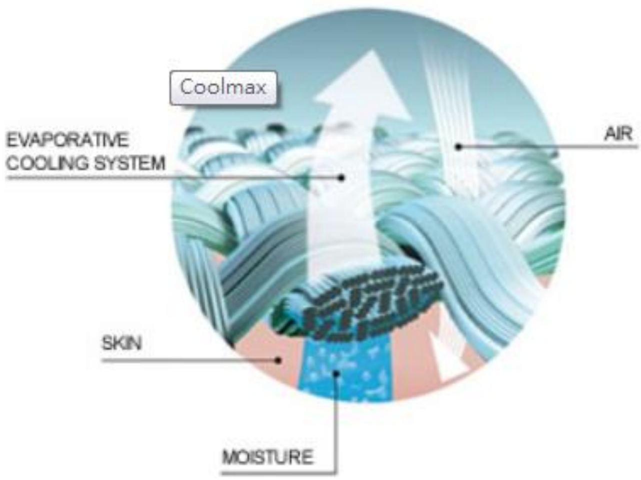

Figure 2.4 Evaporative cooling system of Coolmax fabric
Source: Mechanism of Coolmax fabric [181]

2.5.2 Thermolite yarn

Thermolite yarns composed of fibres with a hollow core are similar to those found in polar bear fur and hence provide comfort on a variety range of temperature and different activity levels [187]. Thermolite fabrics can reduce the number of layers of fabric to maintain comfort by wicking moisture away from the skin and trapping warm air efficiently. The hollow fibre core results in minimizing radiant heat loss and retaining warmth. The mechanism is shown in Figure 2.5. Thermolite fabrics are proved to dry 20% faster than other insulating fabrics and 50% faster than cotton [188].

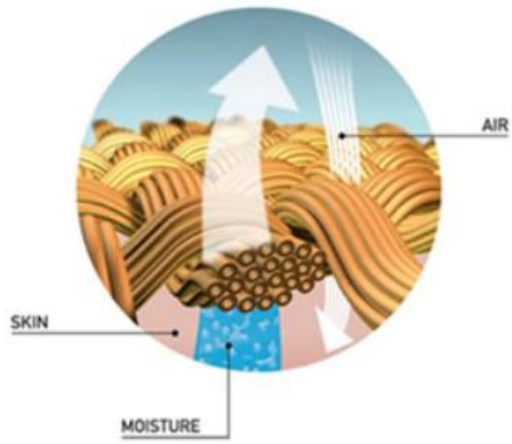

Figure 2.5 Mechanism of Thermolite fabric
Source: Coolmax-thermolite [187]

Hollow fibres are commonly used to impart heat insulated property in textile industries [188, 189]. Some studies showed that hollow fibres performed fast moisture absorption and adsorption and enabled heat transfer [190, 191].

2.5.3 Nu-Torque yarn

A new spinning technology 'Nu-Torque' was proposed by Tao et al. to produce a low-twist yarn on a ring spinning machine [192, 193]. The conventional single ring spun yarn usually has fibre migration owing to its concentric helices with a uniform twist in the yarn cross-section. Therefore, the yarn structure of 'Nu-Torque' is modified but the yarn twist is reduced without diminishing the strength [194]. Fabrics made of 'Nu-Torque' spinning method are claimed to be softer and smoother when comparing with the fabrics made by the conventional ring-spun yarns [195]. On the other hand, 'Nu-Torque' yarns are believed to demonstrate low yarn residual, less yarn hairiness, good tearing strength property and better surface appearance. The yarns are also applicable to low grade materials with high spinning productivity.

The modification system of ‘Nu-Torque’ spinning method consists of the torque reduction device and the transmission system which can be attached to the existing ring spinning machine to make a false twist. This then results in twist redistribution in the fibre substrates and obtains a subtly entangled structure of substrates [196-198]. Finally, true twist is obtained by the conventional ring spinning machine. The balancing method is especially benefit to pure cotton yarn because no chemicals are consumed as they may affect the fibre properties.

2.5.4 MVS yarn

Murata vortex spinning (MVS) is considered to be a refinement of air-jet spinning in general [199]. In air-jet spinning, the twisting system consists of two nozzles where the swirling air currents are in opposite directions. The front and delivery roller nip grips the protruding fibres from the main fibre strand to wind around the strand to from a spun yarn. However, the twisting system in Murata vortex spinning only has one nozzle and the open-end fibres separated at the inlet of the hollow spindle are forced to wind around the strand to form a spun yarn [200-202].

MVS is a relatively new spinning technology providing low hairiness, good abrasion and pilling resistance [203]. Tyagi [204] explored the thermal comfort namely air permeability and water vapour diffusion of woven fabrics made from the polyester-cotton MVS yarns. The results indicated that the air permeability and water vapour diffusion rates were higher for the woven fabrics made of MVS yarns by adjusting a higher level of twisting jet pressure. Researchers [205] also examined the properties of MVS yarns and the air-jet spun yarns. They showed that MVS yarns had superior evenness, fewer thick places and lower hairiness values.

Ortlek and Ulku [206] studied the influence of different parameters such as delivery speed, nozzle pressures and yarn count on the properties of cotton produced by MVS. They concluded that the hairiness and tensile properties of MVS yarns could be enhanced significantly with an increased nozzle pressure. Later, Ortlek and Onal [207] studied the effect of yarn spinning system on the physical properties by comparing the knitted fabrics made from vortex spun yarn with the ring spun, compact spun and open-end rotor spun yarns made from viscose. It is evident that MVS fabrics show the lowest pilling tendency and the highest abrasion resistance.

2.5.5 Twistless yarn

Considerable data showed the principles of a yarn production from untwisted staple fibres. The procedure for producing twistless yarn may involve a wet spinning method using water soluble adhesives or binders such as poly-vinyl alcohol (PVA) to hold the fibres temporarily until the yarns are woven into fabric [208-210].

An alternative method of producing twistless yarns uses a soluble filament wrap yarn which is dissolved later through the fabric's wet processing state [211]. The twistless yarn is produced by a single cotton yarn in Z-twist doubled with a PVA yarn. The doubled yarns are then twisted in the reverse direction with the same amount of yarn twist as the single cotton yarn. Hence, the cotton yarn becomes untwisted during the wet processing method and the PVA yarn is eliminated.

Fabrics manufactured from the twistless yarns have many desirable fabric properties including the improved fabric cover, bulk, softness, luster, pilling resistance and absorbency. The fabrics woven from the twistless cotton yarns may be used in velveteens, terry cloths, napped fabrics and other end use which requires high bulk, softness and good cover [212].

Lord and Stuckey [213] studied the twistless warp yarns and the effects of changing the filling of the woven fabrics. They concluded that a reduction in the twist level of the fabrics improved fabric cover but reduced air permeability. Researchers [214] showed that the warp and filling crimp balance was affected by the twistless yarns. Hence, the luster and handle of the fabrics could be improved by using the twistless yarns of low crimp level in the finished fabric which affected the topography of the surface. The twistless fabrics are regarded as flexible and drapey from the texture respect owing to the effective bulkiness of the twistless yarns once released of adhesive [215].

The fabrics made of twistless yarns have many favorable properties as compared to the conventional ring spun yarns. Ring spun yarns are more hairy at low twist multiples but the twistless yarns can be non-hairy [216]. Therefore, twistless fabrics can be very pill-resistant. However, the ring spun yarns of low twist multiple pills badly because hairs play an important role in the formation of pills. Furthermore, it is possible to make fabrics with a lighter weight than the conventional ones for the same cover factor by using the twistless yarns due to the superior organization of the fibres in the twistless yarns.

The woven fabrics made from the twistless yarns in the weft show the best wicking property when compared with the hollow fibrous assemblies and core-sheath type DREF-III yarn in the weft because of the parallel-channeled fibrous assembly in the weft [208].

The tearing strength of fabrics woven from the twistless yarns is weaker than those made from the ring spun yarn because of the local fibre slippage [212]. Different weave structures appear to affect significantly the tensile and tearing strength of fabrics made by the twistless filling yarns and ring spun yarns including plain, twill and sateen fabrics [217]. The strength of the twistless fabrics of looser weave including twill and sateen is found to be weaker than the fabrics made by the ring spun yarns. However, the strength of the twistless fabrics with a plain weave is almost the same as the fabrics made by the ring spun yarns.

2.5.6 Lycra yarn

Lycra yarns provide finer elastic fibres which permit the stretch fabrics with a light weight. Lycra yarns are commonly constructed for swimwear, lingerie and outerwear [218].

2.5.7 Blended cotton/chitosan yarn

Chitosan fibres are blended with cotton fibres and then spun into yarns to form blended cotton/chitosan yarns to achieve anti-bacterial effect [219, 220]. Blended cotton/chitosan yarns are applied in clinical, medical and hygienic fields [159, 221].

2.6 Conclusion

Although the needs of the paraplegic and quadriplegic patients have been stated in the above-mentioned literatures, the special needs of bedding and clothing required for the child patients and the practical handling issues in hospitalization in Hong Kong may be different from the information mentioned in the literature due to their mobility and illness levels. Hence, it is vital to conduct some hospital visits for observation in order to fully understand the needs of the child patients and seek opinion of the medical and nursing personnel.

With the aim of manipulating the advanced textile technology to develop the fabrics for the patients' garment and bedding use, a fundamental knowledge of the material was developed. Comfort and anti-bacterial properties have been reviewed prior to the application of the functional yarns. This is the foundation of the understanding of the fabric properties for enhancement. Therefore, the fabrics required for the patients' clothing and bedding will be developed by using different combinations of weave structures and yarn compositions including Coolmax yarn, Thermolite yarn, Nu-Torque yarn, Murata vortex spun yarn, twistless yarn, Lycra yarn and blended cotton/chitosan yarn in the weft in the present study in order to obtain the optimal results for the development of the patients' bedding and clothing.

The next chapter will explain the experimental details used to achieve the research objectives.

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Chapter 3 Experimental Details

3.0 Introduction

Since the objective of the present study was to develop the bedding and clothing for the paraplegic and quadriplegic young patients during hospitalization, the product development process was adopted by focusing on their special needs in terms of psychological and physiological comfort [1-4]. The present study consisted of qualitative and quantitative research methods. The qualitative methods included literature review, hospital visitation and observation while the quantitative methods applied were composed of questionnaire surveys, experimental tests and user trial. After a description of the literature research together with the supervised hospital visitation and observation, this chapter continues to explain the design of the questionnaire, the development of fabric samples, experimental processes and the final evaluation of the newly developed fabrics as well as the performance comparison between the newly developed fabrics and the current ones.

Product development is a complex task involving a design process to meet specific needs [5]. Rosenblad-Wallin [1] proposed a user-oriented approach in developing the functional clothing. The product development process consists of nine steps as shown in Table 3.1.

Table 3.1 Product development process

Stage	**Operational**
1. Identification of problem area	● Medical staff and patients' guardians experienced some problems concerning the performance of the patients' bedding and clothing
2. Problem analysis	● Literature search for research projects related to paraplegic and quadriplegic paediatric patients and the patients' bedding and clothing materials ● Supervised hospital visitation and observation ● Distribution of the questionnaire to identify the importance of the patients' characteristics and the weakness of the current patients' bedding and clothing
3. Formulation of objective and project	● Formulation based on Stages 1 and 2
4. Formulation of the demands of the user	● Formulation based on Stage 2
5. Data processing and analysis	● Proceed based on Stage 2
6. Specification of the use-demands and transformation of these into technical terms	● Develop specifications matrix based on the results obtained from Stages 2, 3, 4 and 5
7. Development of ideas and technical solution	● Develop new bedding and clothing materials based on the results obtained from Stage 6 through the experimentation of using different materials by varying the raw materials, yarns and fabric weave constructions as well as anti-bacterial finishing methods
8. Evaluation, modification and selection of prototype	● Experimental tests ● Distribution of questionnaire to evaluate the importance and influence of fabric attributes on the performance of the patients' bedding and clothing ● Indexing method used to evaluate the suitability of the developed fabric samples ● Reiteration of stages as needed to obtain satisfactory performance of the bedding and clothing ● Fabric selection for the bedding and clothing
9. Evaluation of the final solution in relation to the objectives	● Comparison between the performance of the new and current fabrics or the patients' bedding and clothing as well as the standard requirement ● User trial in hospital

3.1 Identification of problem area

Medical staff and the patients' guardians experienced some problems concerning the current patients' bedding and clothing in the paediatric ward of the Developmental Disabilities Unit (DDU) of Caritas Medical Centre (CMC). A discussion on the special need of the paraplegic and quadriplegic patients' bedding and clothing during hospitalization was made between a consultant paediatrician and nursing staff of hospital specializing in the care of paraplegic and quadriplegic patients, industrialists from the textiles and clothing industry and the research team from the Institute of Textiles and Clothing (ITC), The Hong Kong Polytechnic University. A visit was made to the paediatric ward of the DDU of CMC to study the patients' conditions and discuss with the doctors, nurses and the patients' guardians about the problems of the current patients' bedding and clothing.

3.2 Problem analysis

The problems of the current patients' bedding and clothing in the paediatric ward were analysed to understand the requirements and need of the paraplegic and quadriplegic patients' bedding and clothing in the paediatric hospital.

Literature research

A comprehensive literature research concerning the care of the paraplegic and quadriplegic patients as well as comfort was studied to strengthen the background knowledge concerning the requirements of the bedding and clothing for the paraplegic and quadriplegic patients as discussed in Chapter 2.

Supervised hospital visitation and observation

In order to understand the special requirements of the bedding and clothing for these young patients, hospital visitation and observation as well as discussion with medical staff were conducted in order to study the patients' daily activities and the daily routine work of medical staff in the wards of the DDU of CMC. The visits were carried out under the supervision of medical staff with permission obtained from the DDU of CMC as explored in Chapter 4.

In the present study, the hospital visits, questionnaire surveys and the user trial were conducted with the consent of CMC and the Kowloon West Cluster Clinical Research Ethics Committee of the Hospital Authority (HA).

The ward environment in the DDU and the handling procedures of the patients' bedding and clothing as well as the child patients' characteristics were also investigated and observed during the hospital visits. The patients' bedding and clothing of the DDU provided by the HA were also obtained through the visits for analysis and evaluation by experimental tests.

Questionnaire conducted on the current patients' bedding and clothing

A set of questionnaire was designed to obtain more information about the importance of young patients' characteristics affecting the textiles, and the associated problems expressed in terms of comfort and handling aspects of the patients' bedding and clothing used in the hospital as discussed in Chapter 4. The questionnaire is listed in Appendix A.

3.3 Formulation of objective and project

The research project was supported by the Hong Kong Research Institute of Textiles and Apparel (HKRITA), Innovation Technology Commission, the DDU of CMC under the HA and the Institute of Textiles and Clothing, The Hong Kong Polytechnic University. The objectives of the present study were generated from the results of Stage 1 – "Identification of problem area" and Stage 2 – "Problem analysis" as explored in Chapter 1.

3.4 Formulation of the demands of the user

Literature research conducted in Chapter 2 was studied to understand the patients' needs of the bedding and clothing. The demands of the user were then explored through the hospital visits and questionnaire survey conducted in Stage 2 – "Problems analysis" as discussed in Chapter 4.

3.5 Data processing and analysis

The qualitative results obtained from the literature review, hospital visitation and observation as well as the quantitative results obtained from the questionnaire survey conducted in Stage 2 – "Problem analysis" were then analysed in Chapter 4.

3.6 Specification of the use-demands and transformation of these into technical terms

The requirements of the patients' bedding and clothing for the paraplegic and quadriplegic patients in paediatric hospital were formulated from the results of Stages 2 to 5 including “Problem analysis”, “Formulation of objective and project”, “Formulation of the demands of the user” and “Data processing and analysis” as concluded in Chapter 4.

3.7 Development of ideas and technical solution

The requirements of the patients’ bedding and clothing for the paraplegic and quadriplegic patients in paediatric hospital were generated and transformed into different fabric properties after technical discussing with the consultant paediatrician in the previous stage, i.e. “Specification of the use-demands and transformation of these into technical terms”. The fabrics were subsequently designed and developed through different combinations of raw materials, yarns and fabric weave constructions as well as using anti-bacterial finishing methods to achieve the established requirements of the patients’ bedding and clothing. The fabric development process is discussed in Chapter 5.

3.8 Evaluation, modification and selection of prototype

The fabrics developed from the previous stage – “Development of ideas and technical solution” were evaluated and modified for improvement by the experimental tests and questionnaire survey. The fabric materials suitable for the patients’ bedding and clothing were selected by the professional medical personnel of the DDU and the research team members for mass prototype production. Stage 8 – “Evaluation, modification and selection of prototype” is explained in Chapter 5.

Experimental tests

The developed fabrics were evaluated by the handle tests, physical tests and anti-bacterial tests. All the tests were designed in accordance with the established requirements for the patients' bedding and clothing as illustrated in Chapter 4. The handle tests included compression, bending, surface and shear tests while the physical tests included thermal resistance, air permeability, water vapour permeability, wickability, absorbency, flammability, pilling propensity, dimensional stability, tearing strength and tensile strength tests. The anti-bacterial tests included an anti-bacterial activity assessment of textile materials using parallel streak method and an assessment of anti-bacterial finishes on textile material. The correlation between the fabric attributes and the fabric properties were analysed by means of SPSS version 17.0. The results of the experimental tests acted as supplementary references during the fabric selection meeting.

Questionnaire survey - Importance and influence of the fabric attributes on the performance of the patients' bedding and clothing

A questionnaire survey was conducted in the hospital to examine the importance and influence of the fabric attributes on the performance of the patients' bedding and clothing. The details of questionnaire are shown in Appendix B. The weighting for each fabric attribute was measured from the score obtained from the questionnaire. The index of each developed fabric was then calculated by combining the experimental test results and the weighting for each fabric attribute obtained from the questionnaire. The index of each developed fabric acted as a reference for the fabric selection meeting.

3.9 Evaluation of the final solution in relation to the objectives

The prototype fabrics used for the patients' bedding and clothing were evaluated against the standard requirement for comparing with the current hospital patients' bedding and clothing by the experimental laboratory tests and the user trial to confirm the suitability of the newly developed fabrics. The results are discussed in Chapter 6.

Experimental tests

The experimental tests included compression, bending, surface, shear, thermal resistance, air permeability, water vapour permeability, wickability, absorbency, flammability, abrasion, dimensional stability, tearing strength and tensile strength tests.

User trial

The user trial was conducted on both the newly developed patients' bedding and clothing prototypes and the current hospital patients' bedding and clothing by eight child patients in the hospital on the alternate day with the consent of CMC, the Kowloon West Cluster Clinical Research Ethics Committee of the HA and the patients' parents or guardians.

Questionnaire survey was conducted in the hospital aiming to evaluate the performance of the newly developed prototypes of the patients' bedding and clothing and compare with the performance of the current ones. The questionnaire is listed in Appendix C.

The skin temperature was measured for each subject at 8 different measuring points such as forehead, right scapula, left upper chest, right arm in upper location, left arm in lower location, left hand, right anterior thigh and left calf during the user trial to evaluate the thermal comfort of the user.

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Chapter 4 Specifications Required for Patients' Bedding and Clothing

4.1 Introduction

The care of paraplegic and quadriplegic patients was studied in order to understand their needs for the patients' bedding and clothing as mentioned in Chapter 2. The requirements of the patients' bedding and clothing will be explored in this chapter. Five stages of the product development process including "Problem analysis", "Formulation of objective and project", "Formulation of the demands of the use", "Data processing and analysis" and "Specification of the use-demands and transformation of these into technical terms" are illustrated in Figure 4.1. The requirements were formulated for the development of the patients' bedding and clothing according to the results of supervised hospital visitation and observation, discussions with medical staff and the patients' guardians, and questionnaire survey.

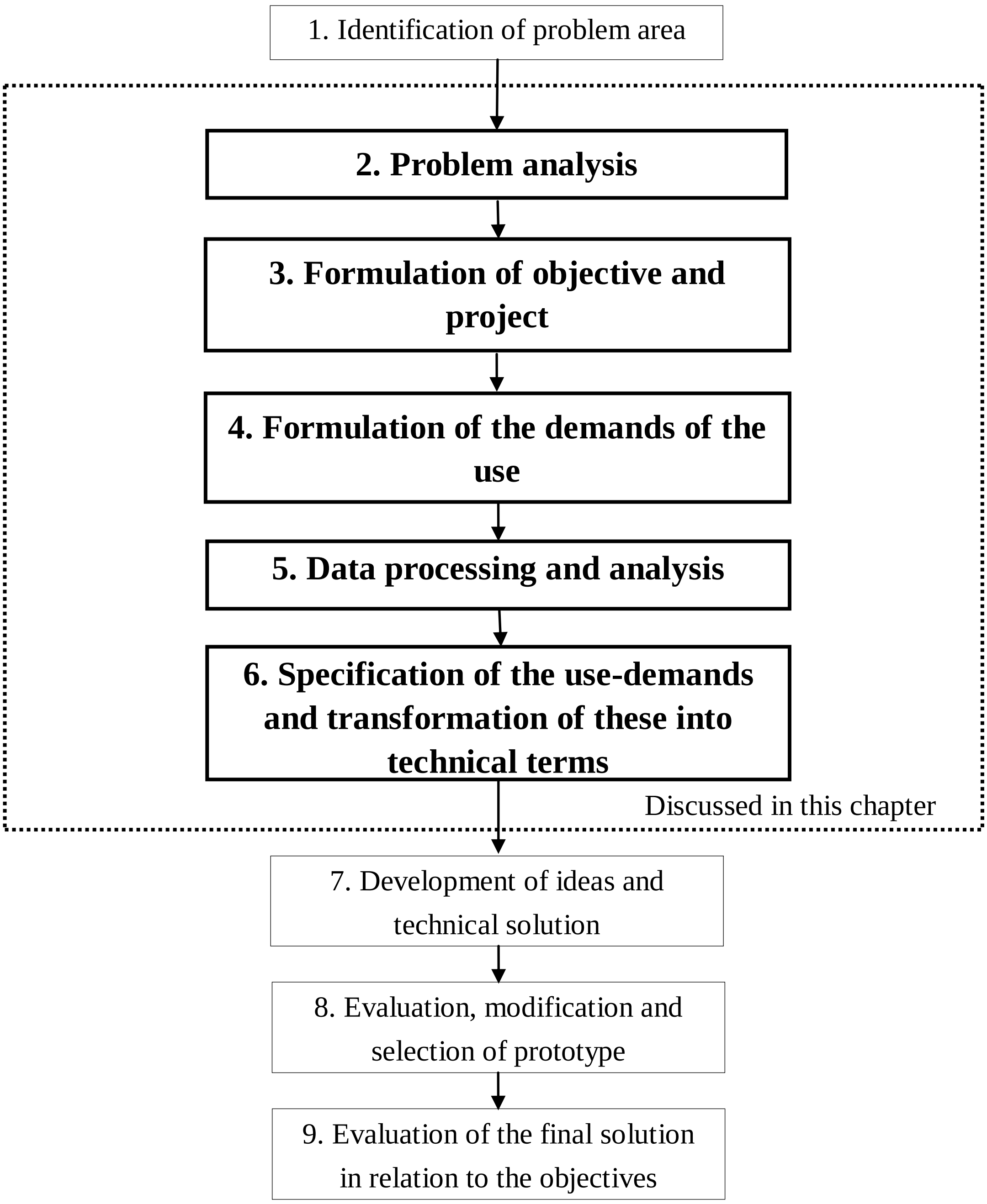


Figure 4.1 Stages 2 to 6 of the product development process

4.2 Supervised hospital visitation and observation

Caritas Medical Centre (CMC) is a general hospital in Hong Kong, China which has been established since 1953. CMC mainly provides medical services for the population of over 400 thousand in Shamshuipo. It also has the largest Developmental Disabilities Unit (DDU) in Hong Kong. DDU provides a long-term residential care linked with schooling for severely, mentally handicapped child patients aged 16 and under. In the present study, all clinical activities including the hospital visitation and observation, discussions with the medical staff and the patients' guardians and conduct of questionnaire surveys and the user trial in the DDU with medical staff assistance including the consultant paediatrician, department operations manager, nurses and nursing assistants according to the approvals from CMC and the Kowloon West Cluster Clinical Research Ethics Committee of the Hospital Authority (HA).

The setting of the DDU shown in Figure 4.2 is intended to be homelike rather than a clinical environment for treatment of any illness that the child residents may suffer. The child patients will stay in the DDU for treatment and recovery when they suffer from minor illness. They will be transferred to the paediatric ward of the hospital if they suffer from any diseases which require hospitalization. Figure 4.3 shows the ward environment of the DDU. There are 111 children admitted in the ward. The children are allocated to four floors with four dormitories and two isolation rooms on each floor based on their medical conditions. The ward is air-conditioned all year around. The ward temperature is kept at 20℃ to 22℃ and the humidity is between 57% and 69% based on the advice of the medical staff.

Figure 4.2 Colourful painting in the DDU

Figure 4.3 Ward environment in the DDU

4.2.1 Current patients' bedding and clothing used in the DDU

The general ideas relevant to the current patients' bedding and clothing used in the DDU were obtained through the hospital visitation and observations as well as discussions with the medical staff and the patients' guardians.

The patients' bedding used in the DDU is provided by the HA while the patients' clothing is either provided by the HA or purchased from the market or brought from home by the patients' families. The patients' bedding and clothing provided by the HA are shown in Figures 4.4 and 4.5 respectively. The patients' bedding and clothing used in the DDU are provided by the HA and they are the same as those used in the public hospitals in Hong Kong. However, the medical staff allows the child patients to wear their own clothes during day time in order to provide a homelike environment. On the other hand, the child patients wear the hospital patients' clothing at night especially when they sleep.

Figure 4.4 Hospital patients' bedding

Figure 4.5 Hospital patients' clothing

The medical staff believed that the standardized hospital patients' bedding and clothing made their job easier such as dressing and undressing, medical assessment and treatment. In addition, the personnel from the laundering section of CMC suggested that the child patients clothing should be standardized with the aim to withstand the high temperature washing and drying conditions.

New sets of current patients' bedding and clothing provided by the HA were collected from the DDU for analysis and experimental evaluation. The experimental results of the current patients' bedding and clothing will be discussed in Chapter 6. Table 4.1 shows the specification of the current patients' bedding and clothing. The fabric swatches of the current patients' bedding and clothing are shown in Appendix D. Although the patients' bedding and clothing could be a source of nutrients for microorganisms which might cause infection according to the literature review, the doctor still allowed the current patients' bedding and clothing that had no anti-bacterial effect to be used.

Table 4.1 Specification of the current patients' bedding and clothing (provided by the HA)

	Current Patients' Bedding	Current Patients' Clothing
Fibre Content	100% cotton	65% polyester, 35% cotton
Fabric Weight	126.0 g/m^2	185.1 g/m^2
Weave Structure	plain	2/2 twill
Thread Density	25 ends/cm 22 picks/cm	38 ends/cm 26 picks/cm

4.2.2 Child patients' characteristics

The children are medically fragile in the DDU. Their needs for the patients' bedding and clothing depend mainly on their medical conditions which should be considered for the design and development process. The details of child patients' characteristics are discussed as follows:

Most patients have spasticity resulting in limited range of movement. Their limbs may suddenly become tense. They also have involuntary movement due to hypertonia or dystonia which increases the friction against the bed surface through rubbing actions.

Majority of children cannot walk independently and only few of them can walk with assistance in wards. The mobility level of the children is shown in Table 4.2. As a result, they spend much of their time lying in bed. Some of them have eczema at their back due to the poor wickability of their clothing, especially for the patients who sweat heavily. Their clothing may also cling to their bodies due to the perspiration which makes them very uncomfortable. All of them need the assistance of medical staff for dressing and undressing as there is a stretching force applied to the clothing. The bedding is also stretched when the medical staff changes it. In addition, some patients like tearing their clothes and bedding. Hence, the strength should be considered when developing new materials for the clothing and bedding.

Table 4.2 Mobility level of the child residents

Mobility Level	Number of Child Residents
Ambulant	4
Chair bound	99
Walk with aids and assistance	8

Source: The consultant paediatrician of the DDU ward (Data obtained from: 2009 Oct 7)

Some patients have tracheostomy. They are totally dependent on daily care and bedridden which may cause the alternation of their skin integrity if subject to prolonged pressure especially lying in bed.

Majority of the patients' skins are very tender because of the limitation of body movement or the paralysis of the body. The risk for skin impairment arises in the presence of moisture, prolonged pressure, friction and shear. Hence, their skins can be injured and infected easily by a slight abrasion of bedding and clothing. The slightest presence of germs in the hospital environment may cause the infection of their exposed skins due to the sake of their poor state of health.

Most of the young patients have poor oromotor function which causes persistent drooling. Their upper clothing gets wet and damp easily.

Some patients encounter deformity problems. They require various splintage and orthosis. In addition, they need extra pillows for positioning while lying in bed which causes sweating.

All patients wear diapers in the paediatric hospital because they are incontinence and some of them may even experience overflow occasionally. Their clothing and bedding will get wet when there is leakage of urine from their diapers. The damp environment facilitates the growth of bacterial resulting in the infection of their fragile skin.

The characteristics of patients and the problems that they faced during residential care are summarized in Table 4.3

Table 4.3 Summary of patients' characteristics and problems

Patients' Characteristics	Problems that the Patients Faced
Spasticity	Involuntary movement increases friction during rubbing
Eczema	Skin redness and itching. A damp environment may cause deterioration of eczema
Tracheostomy	Limited mobility and bedridden
Fragile skin	Skin impairment
Sweating or serious saliva	The clothing and bedding become damp easily

4.2.3 Practice of the handling processes for patients' bedding and clothing

The daily practice of the handling process for the patients' bedding and clothing in the DDU was investigated through hospital visits and observation as well as visiting the laundering section of CMC. Figures 4.6, 4.7 and 4.8 show the laundering machines, drying machines, and the ironer in the laundering section respectively. It is important to study the clinical handling practice for the patients' bedding and clothing since the daily practice affects the durability of textiles.

Figure 4.6 Washing machines in the laundering section

Figure 4.7 Drying machines in the laundering section

Figure 4.8 Flatwork ironer in the laundering section

The medical staff changes the clothing of the child residents twice a day at 7:00 in the morning and at 6:00 at night and then the bedding once a day at 6:00 at night. The patients' bedding and clothing are then collected and washed in the laundering section of CMC. The conditions of laundering and drying for the patients' clothing and bedding have been also investigated. The patients' clothing is washed at 70℃ for 10 minutes using the commercial washing detergent and then dried at 90 ℃ for 20 minutes by a tumble dryer. On the other hand, the patients' bedding is washed at 70℃ for 10 minutes using the commercial washing detergent and softener to eliminate the formation of static charge and then ironed by a flatwork ironer.

4.3 Questionnaire about the current patients' bedding and clothing

Information relevant to the current patients' bedding and clothing, patient characteristics and the handling processes of the bedding and clothing was obtained through the hospital visits and observation as well as discussions with the medical staff and the patients' guardians. It helped generate ideas to design questionnaire concerning the current patients' bedding and clothing in order to obtain information using rating. There were two parts in the questionnaire about the current patients' bedding and clothing – part A and part B. Questionnaire of the current patients' bedding and clothing is attached in Appendix A. Part A of questionnaire was designed to examine how important the patients' characteristics affected the desire of their bedding and clothing. Part B of questionnaire was designed to identify the problems of the current patients' bedding and clothing.

Since the patients' needs for the bedding and clothing may vary based on their medical conditions, the patients' characteristics should be taken into account during the design and development process. The patients' characteristics were explored through the hospital visitation and discussion with medical staff as summarized in Table 4.3 of Section 4.2.2. As a result, the desire of the patients' bedding and clothing was evaluated in terms of sweating, spasticity, eczema, tracheostomy, fragile skin and serious saliva in order to examine their importance in part A of questionnaire about the current patients' bedding and clothing. The assessment scale was a five-point Likert scale, i.e. 5-Most important; 4-Important; 3-Neutral; 2-Less important and 1-Least important.

According to the discussions with medical staff and the patients' guardians, medical staff was concerned about the handling issues for the patients' bedding and clothing while the patients' guardians were concerned about the comfort sensation. Hence, the comfort sensation and the handling issues were designed for part B of questionnaire about the current patients' bedding and clothing. The comfort sensation of the bedding included quick dry property, breathability, un-prickle, fineness, comfort, smoothness and softness while the handling issues included launderability, abrasion resistance, strength and weight. The comfort sensation of the clothing included non-stickiness, thermal insulation, quick dry property, breathability, un-prickle, fineness, comfort, smoothness and softness while the handling issues included launderability, abrasion resistance, strength and weight. The ratings with a five-point scale were adopted, i.e. 5-Very good; 4-Good; 3-Fair; 2-Bad and 1-Very bad. Comments were also invited and obtained for the current patients' bedding and clothing as well as the recommendation.

As the child patients in the DDU are mentally handicapped and cannot provide comments, their guardians, parents or medical staff will represent their choices instead. Questionnaire was conducted on the current patients' bedding and clothing in the way where the respondents were interviewed when they were available. Hence, the sample size of questionnaire about the current patients' bedding and clothing was obtained by the convenience sampling method in order not to disturb the normal duties of the medical staff and the child patients' daily schedule. The child parents and guardians were not actively involved in the questionnaire survey since less than 50 children had active family contact and the rest of children were belonged to the wards of the Welfare Department. In addition, the visiting hours of the DDU were restricted. The questionnaire surveys were also conducted in the following chapters using the same convenience sampling method.

Questionnaire about the current patients' bedding and clothing was conducted in the hospital with 92 respondents including 90 medical staff and 2 patients' parents. The general information of the respondents is shown in Table 4.4.

Table 4.4 General information of the respondents

	Description	**Number of Respondents**
Occupation	Nurse	36
	Nursing assistant	54
	Patients' parents	2
Age	Below 25	3
	26-35	13
	36 or above	76
Gender	Male	1
	Female	91
Experience*	1-5 years	28
	6-10 years	13
	Above 10 years	49
	Not applicable	2

* The working experience of medical personnel

4.3.1 Part A: Importance of patients' characteristics of questionnaire about the current patients' bedding and clothing

Figure 4.9 shows the distribution of each patient's characteristic affecting the desire of the current bedding and clothing used in the DDU. The mean ratings of sweating, spasticity, eczema, tracheostomy, fragile skin and serious saliva are 3.91, 4.16, 3.68, 3.80, 3.97 and 4.17 respectively. It seems that serious saliva affects the desire of the current textile products most adversely while eczema is the least important factor. However, all the patients' characteristics have an average rating higher than 3.5, suggesting that all these characteristics are the special needs of the young patients and should be taken into consideration when developing new materials for the patients' clothing and bedding.

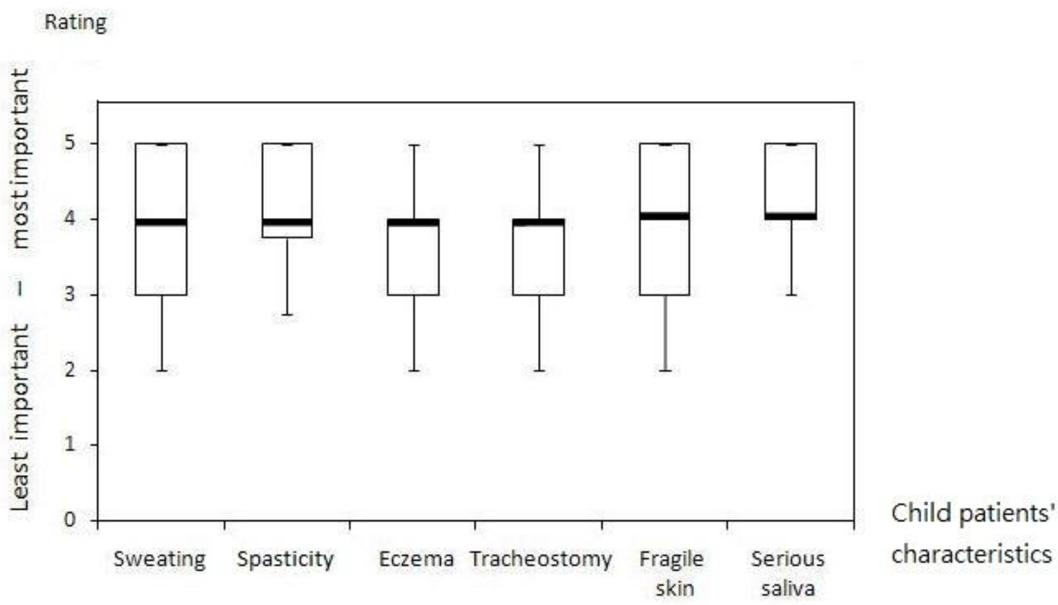


Figure 4.9 Importance of patients' characteristics affecting the desire of the current textile products

Serious saliva and sweating

Serious salivating and sweating will make the patients' clothing and bedding wet especially for those patients who are confined to bed. The damp environment results in discomfort and bacterial growth. A fabric with good moisture management property and anti-bacterial property can be used to keep the clothing and bedding dry and also inhibit bacterial growth.

Spasticity

Spastic patients' limbs may rub with the bed surface as well as their clothing fabric. Therefore, a smooth surface of the patients' clothing and bedding can reduce friction and prevent skin impairment. Their limbs may suddenly become tense causing difficulty and generating a stretching force during dressing and undressing. The patients' clothing should withstand the stretching force.

Fragile skin

The patients' clothing and bedding should be comfortable in order to minimize the chance for skin impairment. The clothing and bedding with an anti-bacterial property can prevent skin infection that may be caused by the presence of bacteria in the hospital environment.

Tracheostomy

As the patients who have tracheostomy are totally dependent on daily care and confined to bed, the clothes and bedding should be comfortable when they lie in bed.

Eczema

As most of the patients have to lie in bed for a long period, they may have eczema at their back especially for those who always sweat. Their clothing should provide a good moisture management in order to maintain a dry environment between their skins and the clothing fabrics. The fabrics used for the clothing and bedding should also be comfortable to prevent skin irritation.

4.3.2 Part B: Problems of current patients' bedding and clothing of questionnaire about the current patients' bedding and clothing

4.3.2.1 Comfort sensation of the current patients' bedding

The questionnaire results about the comfort sensation of the current patients' bedding are presented in Figure 4.10. It was seen that nearly 75% of the respondents rated the un-prickle of the current patients' bedding from fair to very bad with a mean score of 3.18. It should be noted that almost 90% of the respondents rated the comfort and fineness from fair to very bad with a mean score of 2.84 and 2.92 respectively. About 80% of the respondents rated the quick dry property, breathability, smoothness and softness from fair to very bad with a mean score of 3.01, 3.02, 2.97 and 2.96 respectively.

To conclude, the patients' bedding should be improved in terms of softness, smoothness, comfort, fineness, un-prickle, breathability and quick dry property. When developing the new bedding material, it is particularly important to take into the account of the child paraplegic and quadriplegic patients.

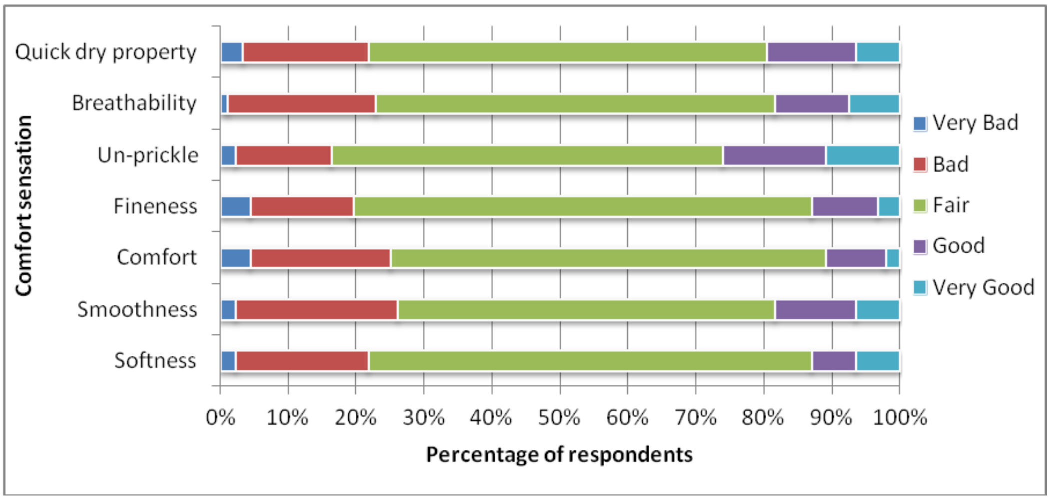


Figure 4.10 Comfort sensation of the current patients' bedding

4.3.2.2 Comfort sensation of the current patients' clothing

The results of the comfort sensation of the current patients' clothing are shown in Figure 4.11. It was obvious that no respondents perceived the quick dry property with a mean score of 2.95 as very good, and about 5% of the respondents rated the quick dry property as good. However, about 80% of the respondents rated the breathability, un-prickle, fineness, comfort, smoothness and softness from fair to bad with a mean score of 3.14, 3.17, 2.99, 3.15, 3.08 and 3.15 respectively. Nearly 70% of the respondents rated the non-stickiness from fair to bad with a mean score of 3.39. In contrast, about 55% of the respondents rated the thermal insulation from good to very good with a mean score of 3.52.

To conclude, there is a strong need for the improvement of non-stickiness, quick dry property, breathability, un-prickle, fineness, comfort, smoothness and softness for the development of the new patients' clothing.

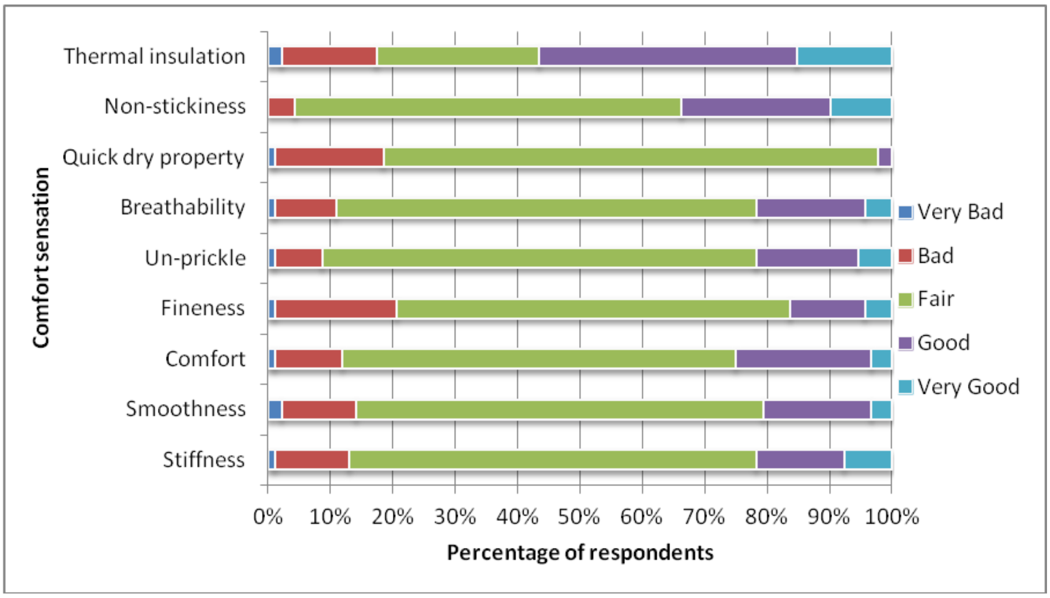


Figure 4.11 Comfort sensation of the current patients' clothing

4.3.2.3 Handling issues of the current patients' bedding

Regarding the handling issues of the current patients' bedding, about 85% of the respondents rated the weight from fair to very bad with a mean score of 3.02. About 65% of the respondents rated the launderability, abrasion resistance and strength from fair to very bad with a mean score of 3.38, 3.32 and 3.30 respectively. On the other hand, the results suggested that the patients' bedding should be improved in terms of weight, launderability, abrasion resistance and strength when developing the new material. Figure 4.12 illustrates the results about the handling issues of the current patients' bedding.

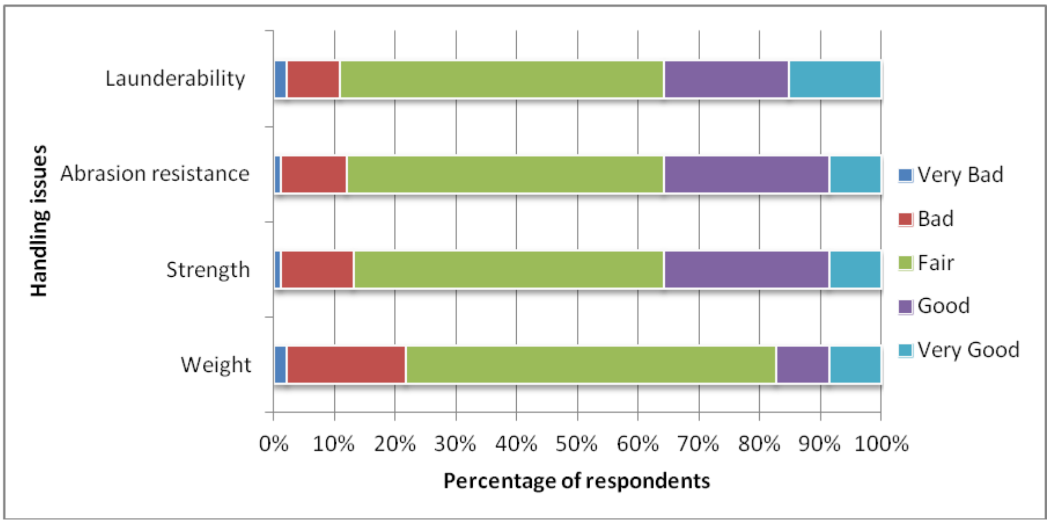


Figure 4.12 Handling issues of the current patients' bedding

4.3.2.4 Handling issues of the current patients' clothing

The results of the handling issues of the current patients' clothing are shown in Figure 4.13. Nearly 80% of the respondents rated the weight from fair to bad with a mean score of 3.14. About 75% of the respondents rated the luanderability, abrasion resistance and strength from fair to very bad with a mean score of 3.30, 3.24 and 3.25 respectively. Similar to the results of the current patients' bedding, the patients' clothing should be improved in terms of weight, launderability, abrasion resistance and strength.

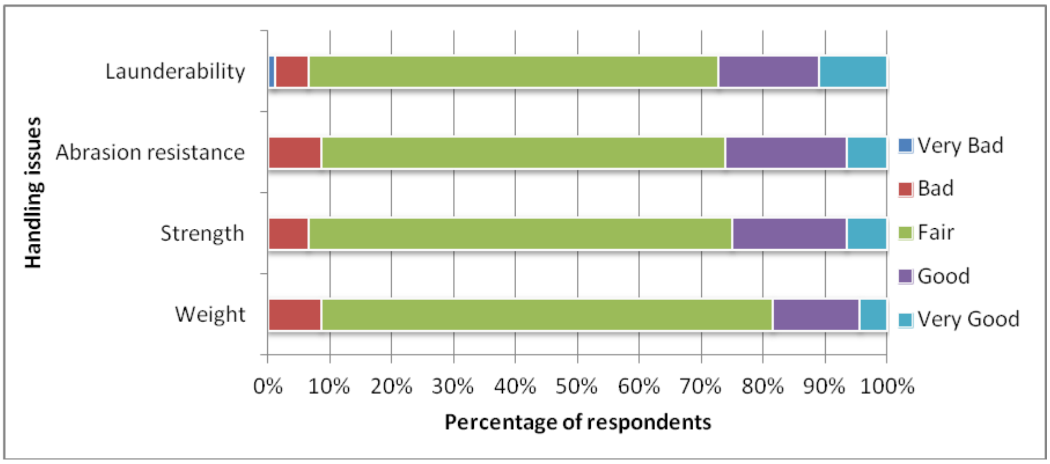


Figure 4.13 Handling issues of the current patients' clothing

4.4 Requirements of the patients' bedding and clothing

Based on the literature research in Chapter 2, the following requirements have been established after technical discussion with the consultant paediatrician, hospital visitations and observation as well as questionnaire survey:

(1) Comfort

The physiological and physical comfort of the fabrics includes high breathability, good fabric handle and thermal insulation property.

(2) Good moisture management property

The fabrics should have good water vapour permeability and wickability as well as fast water absorbency.

(3) Anti-bacterial property

Anti-bacterial finishes should be applied to the fabrics to achieve anti-bacterial property.

(4) Safety

The flammability of the fabrics should be considered.

(5) Durability

The fabrics should be durable with good tensile and tearing strength.

4.5 Conclusion

In this chapter, several important factors including hospital environment, the current patients' bedding and clothing, patients' characteristics and handling practice for the bedding and clothing in the DDU of CMC were discussed. Questionnaire survey was conducted to evaluate how important the patients' characteristics affect the desire of their bedding and clothing, and identify the problems of the current patients' bedding and clothing. Sweating, spasticity, eczema, tracheostomy, fragile skin and serious saliva were identified as the patients' characteristics which should be considered for the development of the patients' bedding and clothing. The weaknesses of the current patients' bedding were classified as quick dry property, breathability, un-prickle, fineness, comfort, smoothness, softness, launderability, abrasion resistance, strength and weight. On the other hand, the weaknesses of the current patients' clothing were classified as non-stickiness, quick dry property, breathability, un-prickle, fineness, comfort, smoothness, softness, launderability, abrasion resistance, strength and weight. The objectives of the present study were defined at this stage as described in Chapter 1. The important parameters required for the development of the patients' bedding and clothing were formulated including comfort, good moisture management property, anti-bacterial property, safety and durability. The results obtained in this chapter did help generate ideas for the next stages of the product development process which will be discussed in Chapter 5.

Chapter 5 Development of Functional Fabrics for Patients' Bedding and Clothing

5.1 Introduction

This chapter concentrates on Stage 7, i.e. "Development of ideas and technical solution", and Stage 8, i.e. "Evaluation, modification and selection of prototype" of the product development process as shown in Figure 5.1. The processes involved in these two stages are illustrated in Figure 5.2. The fabrics were designed and developed to achieve the established requirements for the young paraplegic and quadriplegic patients' bedding and clothing. The experimental tests were also designed to evaluate the performance of the fabrics and modified for improvement. A set of questionnaire survey was also conducted in the hospital to examine the importance and influence of the fabric attributes on the performance of the patients' bedding and clothing. The indices of the fabrics were measured based on the results of the questionnaire and the experiments. Finally, the fabric materials suitable for the child patients' bedding and clothing were selected by the professional medical personnel came from the Developmental Disabilities Unit (DDU), Caritas Medical Centre (CMC) and the research team from the Institute of Textiles and Clothing, The Hong Kong Polytechnic University.

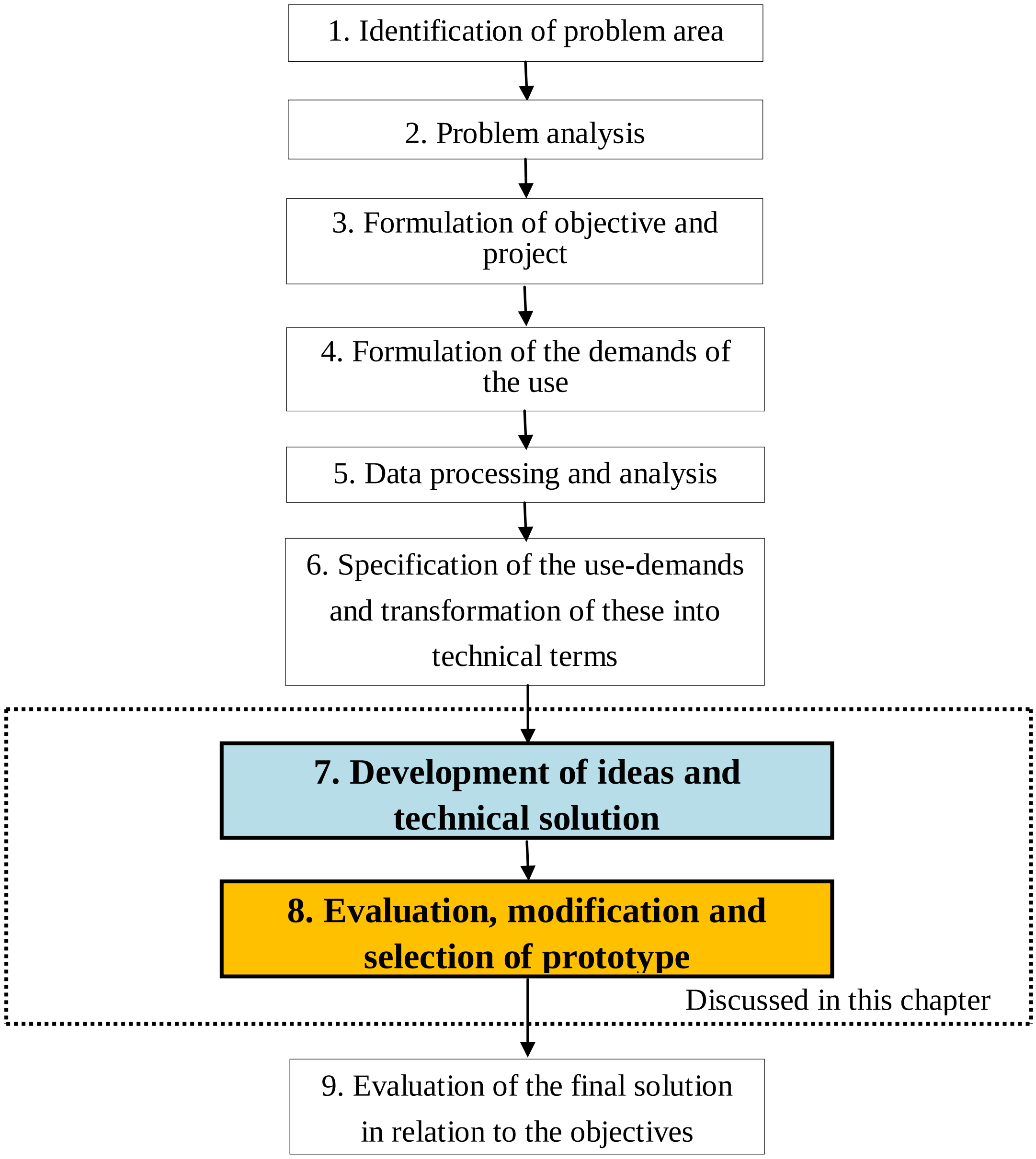


Figure 5.1 Stages 7 to 8 of the product development process

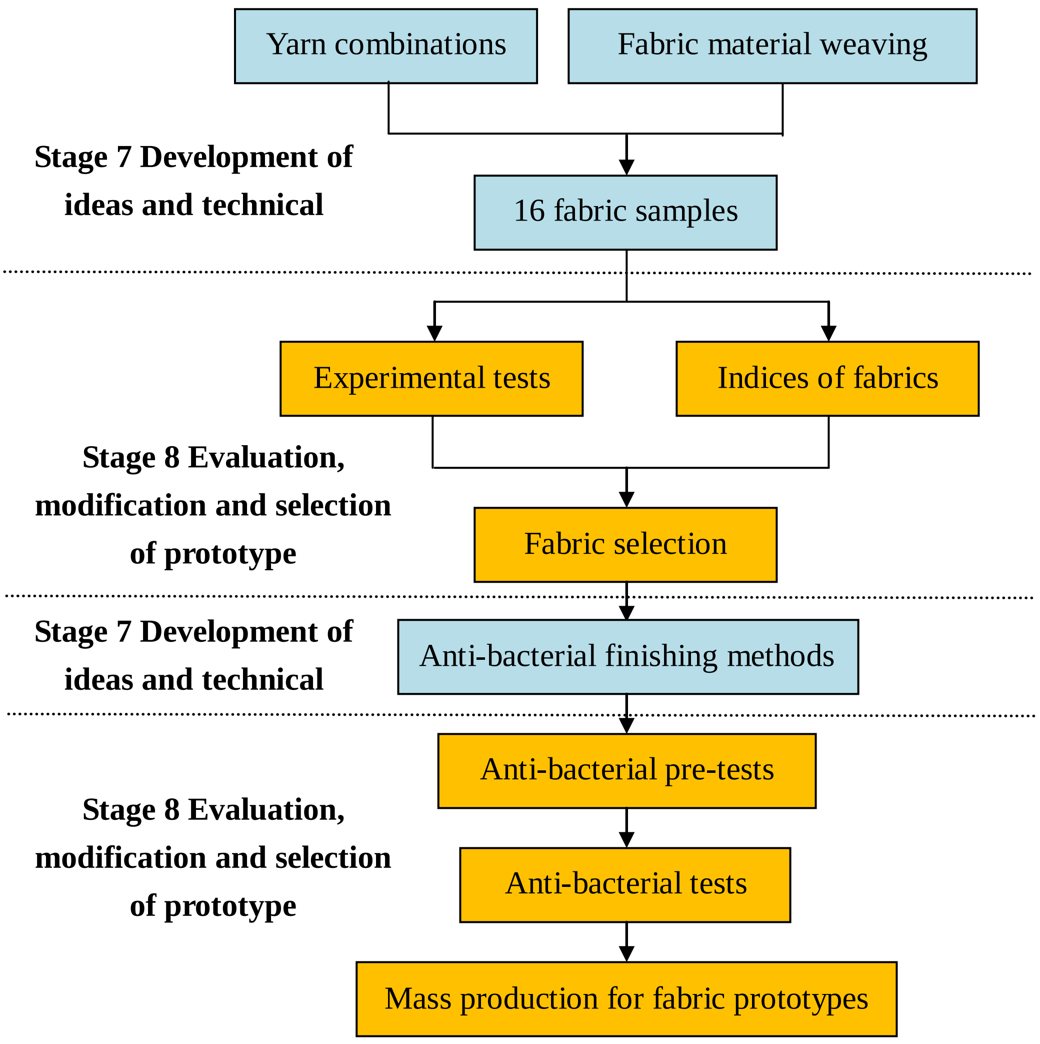


Figure 5.2 Flowchart of the development of ideas and technical solution as well as evaluation, modification and selection of prototype

5.2 Design and development of new fabric

The manufacturing process of fabric composes of the selection of the yarns, weave structure and finishing methods [1]. The fabrics used for the child patients' bedding and clothing were developed through different yarn combinations, weave structures and anti-bacterial finishing methods.

5.2.1 Yarn combinations

In order to achieve the established requirements for the child patients' bedding and clothing, the yarns were sourced by considering their functions. The yarns including Coolmax yarn, Thermolite yarn, Nu-Torque cotton yarn, Murata vortex spun (MVS) cotton yarn, twistless cotton yarn and Lycra yarn were chosen for the development of new fabric because of their individual advantages as mentioned in Section 2.5 of Chapter 2. In addition, blended cotton/chitosan yarn was also chosen as it contained chitin which was claimed to inhibit bacterial growth [2-12]. Summary of the selected yarns and their functions is shown in Table 5.1. Experimental Coolmax yarns, Thermolite yarns, Nu-Torque cotton yarns, MVS cotton yarns, Lycra yarns and ring spun cotton yarns were bought from the Central Textiles, Hong Kong while the twistless yarns and blended cotton/chitosan yarns were bought from Swicofil, Switzerland. Since all the yarns are commercially available in the textile industry, there will be no sourcing problem for the future mass production by the hospitals.

Table 5.1 Selected yarns and beneficial functions

Yarns	Beneficial Functions
Coolmax yarn	Pleasant contact feeling Thermal comfortable Durable Fast wicking
Thermolite yarn	Warmth retaining Comfortable Fast wicking
Nu-Torque cotton yarn	Soft Smooth Lower yarn twist but maintaining strength Good tearing strength
Murata vortex spun cotton yarn	Good abrasion resistance Lower pilling tendency
Twistless cotton yarn	Soft Good pilling resistance Good water absorbency
Lycra yarn	Elastic
Blended cotton/chitosan yarn	Anti-bacterial property

5.2.2 Fabric material weaving

The fabrics were woven instead of knitted so as to meet the durability requirement such as dimensional stability [1]. A total of sixteen woven fabrics with different weave structures and weft yarn combinations were produced to help evaluate their performance. Since the professional medical personnel from the DDU of CMC found difficulty to select the fabrics suitable for the child patients' bedding and clothing from a large pool in accordance with their limited knowledge of textiles, sixteen different kinds of fabrics were produced from three weave structures. All these fabrics were woven using the same cotton warp yarns but varying the weft yarns made of Coolmax yarn, Thermolite yarn, Nu-Torque cotton yarn, MVS cotton yarn, twistless cotton yarn, Lycra yarn and blended cotton/chitosan yarn. Among these fabrics, ten of them were 2/2 twill fabrics, five were plain fabrics and one was 2/1 twill weft backed fabric. 2/2 twill and plain weave structures were selected for comparison as the current child patients' bedding and clothing were also woven using these weaves. 2/1 twill weft backed structure was chosen as the multiple layer fabrics with hydrophobic yarns in inner layer and hydrophilic yarns at outer layer to assist in water transportation from the skin to the outer layer so as to keep the body dry [13, 14]. The construction details of after finished fabrics are listed in Table 5.2.

Table 5.2 Construction details of after finished fabric samples

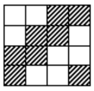
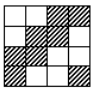
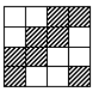
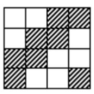
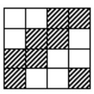
Fabric Sample Number	Fabric Construction	Warp	Weft	Weight (g/m^2)	Ends/ cm	Picks/ cm
1	2/2 twill 	29.5 tex/1 100% cotton	36.9 tex/1 Nu-Torque 100% cotton	204	29	26
2	2/2 twill 	29.5 tex/1 100% cotton	36.9 tex/1 blended cotton/chitosan (88% cotton, 12% chitin)	189	27	27
3	2/2 twill 	29.5 tex/1 100% cotton	28.1 tex/1 twistless 100% cotton	170	27	25
4	2/2 twill 	29.5 tex/1 100% cotton	36.9 tex 100% cotton/ 7.7 tex 100% Lycra	349	44	29
5	2/2 twill 	29.5 tex/1 100% cotton	19.7 tex/2 100% Coolmax	216	29	27

Table 5.2 Construction details of after finished fabric samples (cont'd)

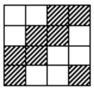
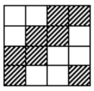
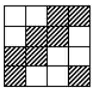
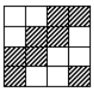
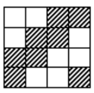
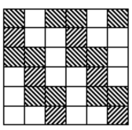
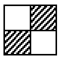
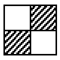
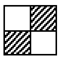
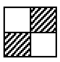
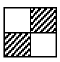
Fabric Sample Number	Fabric Construction	Warp	Weft	Weight (g/m^2)	Ends/ cm	Picks/ cm
6	2/2 twill 	29.5 tex/1 100% cotton	36.9 tex/1 100% Coolmax	207	28	26
7	2/2 twill 	29.5 tex/1 100% cotton	19.7 tex/2 100% Thermolite	212	27	27
8	2/2 twill 	29.5 tex/1 100% cotton	36.9 tex/1 MVS 100% cotton	213	30	29
9	2/2 twill 	29.5 tex/1 100% cotton	19.7 tex/2 MVS 100% cotton	215	30	28
10	2/2 twill 	29.5 tex/1 100% cotton	36.9 tex/1 100% Coolmax and 28.1 tex/1 twistless 100% cotton	187	23	27
11	2/1 twill weft backed 	29.5 tex/1 100% cotton	36.9 tex/1 100% Coolmax and 28.1 tex/1 twistless 100% cotton	194	28	26

Table 5.2 Construction details of after finished fabric samples (cont'd)

Fabric Sample Number	Fabric Construction	Warp	Weft	Weight (g/m^2)	Ends/ cm	Picks/ cm
12	Plain 	29.5 tex/1 100% cotton	29.5 tex/1 100% cotton and 28.1 tex/1 twistless 100% cotton	156	29	18
13	Plain 	29.5 tex/1 100% cotton	19.7 tex/2 100% Thermolite and 28.1 tex/1 twistless 100% cotton	168	28	19
14	Plain 	29.5 tex/1 100% cotton	36.9 tex/1 Nu-Torque 100% cotton and 28.1 tex/1 twistless 100% cotton	170	30	19
15	Plain 	29.5 tex/1 100% cotton	36.9 tex/1 100% cotton and 28.1 tex/1 twistless 100% cotton	146	28	20
16	Plain 	29.5 tex/1 100% cotton	36.9 tex/1 Nu-Torque 100% cotton and 19.7 tex/2 100% Thermolite	168	27	20

All woven fabrics produced by the Picanol air jet machine, were scoured and bleached in the Rongl winch dyeing machine as shown in Table 5.3. The fabrics were placed in the dyeing machine at the temperature of 50℃ which was then raised to 90℃ over 30 minutes. The fabrics were bleached for 1 hour and then rinsed with 0.5% acetic acid for neutralization. Finally, the fabrics were rinsed and dried.

Table 5.3 Bleaching and scouring recipe

Hydrogen peroxide 30% 12ml/L
Stabilizer SIFA 0.5g/L
Detergent Sandopan DTC 0.5g/L
Sodium meta silicate (penta-hydrate) 0.5g/L
Caustic Soda to pH 10
Liquor ratio: 50:1

On the other hand, the fabrics produced by the twistless yarns required extra boiling processes in order to remove the PVA filaments before scouring and bleaching. These fabrics were boiled twice at 90℃ for 15 minutes and 1.5 hours respectively, and then rinsed with warm water in the Rongl winch dyeing machine. Finally, the fabrics were scoured and bleached in the Rongl winch dyeing machine in accordance with Table 5.3.

5.3 Experimental tests

Experiments related to the requirements formulated in Section 4.4 of Chapter 4 included comfort property, moisture management property, safety and durability. They were evaluated in this section while the anti-bacterial property was evaluated in Sections 5.5.2 and 5.5.3. The newly developed fabrics were assessed objectively through the laboratory handle tests including compression, bending, surface and shear tests as well as physical tests such as thermal resistance, air permeability, water vapour permeability, wickability, absorbency, flammability, pilling propensity, dimensional stability, tearing strength, tensile strength test and anti-bacterial tests.

Subjective evaluation in terms of a questionnaire survey was designed to evaluate the importance and influence of the fabric attributes on the overall performance of the patients' bedding and clothing. The rating of fabric attributes obtained from the questionnaire survey would act as a supplementary reference in addition to the results of objective experiments.

5.3.1 Objective experiments

The objective experiments were designed according to the requirements of the patients' bedding and clothing as shown in Section 4.4 of Chapter 4. Table 5.4 summarizes the objective experiments used for assessment of the patients' bedding and clothing. The number of replicates conducted was according to the standard test methods. The results shown in the following sections were the mean value of measured data.

Table 5.4 Categorization of objective experiments used for assessment of the patients' bedding and clothing

Requirements	Objective Experiments
(1) Comfort	● Compression test (KES-FB-3) ● Bending test (KES-FB-2) ● Surface test (KES-FB-4) ● Shear test (KES-FB-1) ● Thermal resistance test (ASTM D 1518-85 (2003)) ● Air permeability test (ISO 9237:1995)
(2) Moisture Management Property	● Water vapour permeability test (BS 7209:1990) ● Wickability test ● Absorbency test (AATCC TM 79-2007)
(3) Safety	● Flammability test (ASTM D 1230-94 (2001))
(4) Durability	● Pilling propensity tests (EN ISO 12945-1:2001 and EN ISO 12945-2:2001) ● Dimensional stability test (AATCC TM 135-2004) ● Tearing strength test (ASTM D 1424-09) ● Tensile strength test (EN ISO 13934-1:1999)
(5) Anti-bacterial Property	● Anti-bacterial activity assessment of textile materials: parallel streak method (AATCC TM 147:2004) ● Assessment of anti-bacterial finishes on textile material (AATCC TM 100: 2004)

The results of objective experiments for the sixteen fabric samples are discussed in the following sections.

5.3.1.1 Compression test (KES-FB-3)

The compression property of fabrics was measured by the Kawabata Evaluation System for Fabrics (KES-FB-3). The procedure of pre-conditioning and conditioning was conducted according to the ASTM D 1776-08. The testing procedure followed the KES-F testing manual.

The compression test is usually used to assess the compression properties which are highly related to fabric handle such as fabric softness and fullness. In addition, high values of compression properties correlate with the comfort of the fabric. Since most of the young patients are bed-ridden, the compression properties are important to the patients' bedding and clothing as they will affect the comfort of the fabric

The compressional energy means the compressional energy per unit area (WC) and the compressional resilience (RC) reflects the recovery ability of the fabric from compressional deformation. Fabric compression especially provides a feeling of bulkiness [15]. Table 5.5 shows the results regarding the compression properties.

Table 5.5 The mean values of compression properties and thickness of fabric samples

Fabric Sample Number	Compressional Energy, WC (g.cm /cm^2)	Compressional Resilience, RC (%)	Thicnkness (mm)
1	0.646	29.15	1.527
2	0.374	35.47	1.157
3	0.523	30.13	1.450
4	0.338	37.58	1.440
5	0.248	42.52	1.012
6	0.217	38.69	0.890
7	0.260	46.73	0.942
8	0.310	34.63	1.167
9	0.289	36.60	1.107
10	0.364	32.39	1.290
11	0.632	40.05	0.893
12	0.266	29.37	0.975
13	0.376	31.25	1.293
14	0.395	30.52	1.197
15	0.335	28.41	1.193
16	0.392	29.75	1.133

It was clear that Fabric Sample No. 1 had the highest WC value while Fabric Sample No. 6 had the lowest WC value among the sixteen different fabrics. As expected, the fabrics with higher thickness values would have higher values for WC with more fluffy feeling. According to Table 5.5, Fabric Sample No. 1 was the thickest. The highest thickness value could be due to the low twist Nu-Torque yarn structure. It was worthwhile to note that Fabric Sample No. 11 had a comparatively low thickness value and a high WC value. Both Fabric Sample No. 10 and Fabric Sample No. 11 comprised of twistless cotton weft yarns and Coolmax weft yarns. However, the WC value of Fabric Sample No. 11 was almost twofold of Fabric Sample No. 10. The twofold WC value could be attributed to different weave structures. Fabric Sample No. 10 was a 2/2 twill fabric while Fabric Sample No. 11 was a 2/1 twill weft backed fabric.

When the values of RC were increased, the fabric would have a better recoverability after compression deformation [15]. As seen in Table 5.5, Fabric Sample No. 7 showed the largest RC value but Fabric Sample No. 15 showed the smallest RC value. This might be caused by the weft yarn structures. Fabric Sample No. 7 with Thermolite (the hollow fibrous assembly) in weft might result in the maximum RC value. This was particularly important to the patients' clothing and bedding since Fabric Sample No. 7 would recover much of its original thickness to maintain its thermal insulation which was related to the thickness. On the other hand, Fabric Sample No. 15 with the ring spun cotton weft yarns and twistless cotton weft yarns forming the twistless assembly with a flattened structure might spread out under compression.

5.3.1.2 Bending test (KES-FB-2)

The Kawabata Evaluation System for Fabrics (KES-FB-2) was used for testing the bending property. The procedure of fabric pre-conditioning and conditioning was conducted in accordance with the ASTM D 1776-08. The testing procedure followed the KES-F testing manual.

Apparently, fabric handle has a close correlation with the bending properties. Low bending properties are supposed to be desirable in order to achieve a better fabric handle. Bending rigidity (B) used to measure the bending property represents the ability of the fabric to resist bending deformation. In addition, the larger the bending rigidity, the higher the fabric stiffness will be. Hence, the fabric with a smaller bending rigidity value must be chosen for the patients' clothing because the fabric should be soft enough to accommodate the limb movements of the young patients, particularly the patients with spasticity. Nonetheless, the stiff fabrics used for patients' bedding and clothing will result in uncomfortable feeling especially for those lying in bed for a long period. Therefore, the bending property was chosen for evaluation of the newly developed fabrics.

The bending property of the fabrics is summarized in Table 5.6. It was seen that the B value of Fabric Sample No. 4 was the largest among the sixteen different fabric samples. The result suggested that Fabric Sample No. 4 was the stiffest. The noticeably high B value might be due to the presence of the weft Lycra yarns in Fabric Sample No. 4. The shrinkage of Lycra yarns caused the warp thread density to increase significantly from 32 ends per cm to 44 ends per cm after the processes of scouring and bleaching. Therefore, Fabric Sample No. 4

had the highest warp thread density among all the fabric samples resulting in the largest B value in the warp direction.

Table 5.6 Bending property of fabric samples

	Bending Rigidity, B (gf cm^2/ cm)		
Fabric Sample Number	Warp	Weft	Mean
1	0.093	0.120	0.106
2	0.094	0.071	0.083
3	0.084	0.095	0.089
4	0.550	0.277	0.413
5	0.092	0.094	0.093
6	0.085	0.064	0.075
7	0.093	0.146	0.119
8	0.124	0.184	0.154
9	0.130	0.185	0.157
10	0.101	0.078	0.089
11	0.109	0.110	0.110
12	0.092	0.061	0.077
13	0.099	0.084	0.091
14	0.105	0.086	0.095
15	0.088	0.070	0.079
16	0.073	0.097	0.085

Figure 5.3 shows that there was a good relation between the bending rigidity and fabric weight. Hence, the heaviest fabric weight might also be attributed to the highest mean B value. It should be pointed out that Fabric Samples No. 1 and 3 had a comparatively high thickness and low B values which were considered to be relatively soft. It might appear from the fact that low twist Nu-Torque yarn structure and twistless yarn structure would provide space for the yarns to spread.

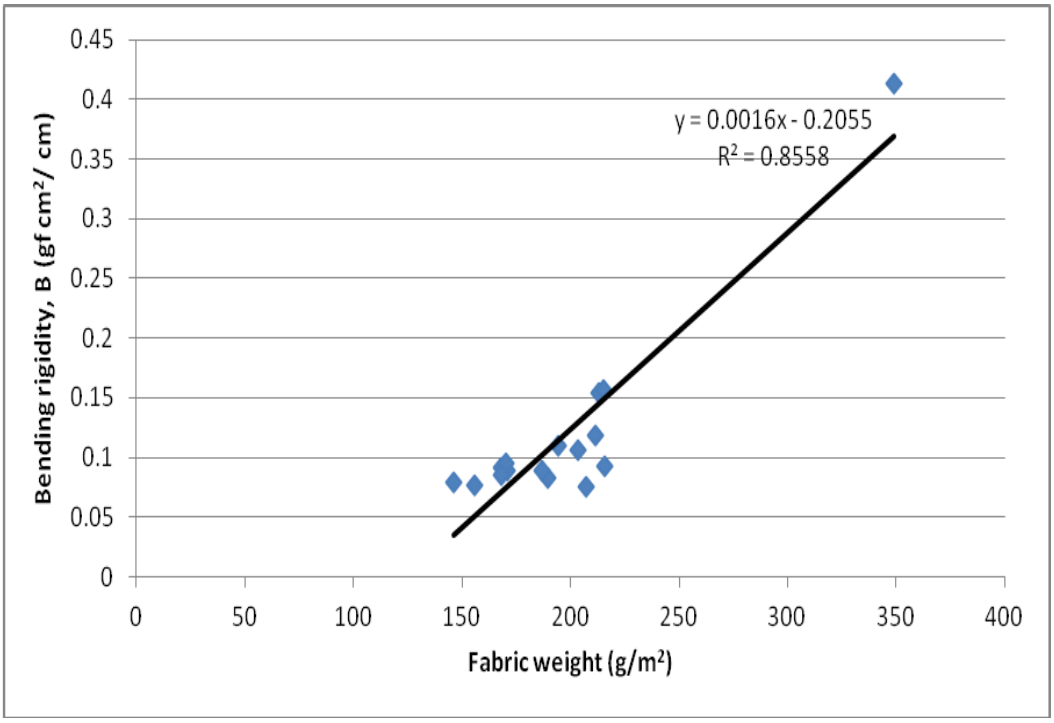


Figure 5.3 Relationship between bending rigidity and fabric weight

5.3.1.3 Surface test (KES-FB-4)

The surface properties of fabrics were evaluated by the Kawabata Evaluation System for Fabrics (KES-FB-4). The procedure of fabric pre-conditioning and conditioning was conducted based on the ASTM D 1776-08. The testing procedure followed the KES-F testing manual.

The results of the surface properties of the newly developed fabrics are indicated in Table 5.7. The surface properties include the coefficient of friction (MIU) and the geometrical roughness (SMD) of the fabric surface. The coefficient of friction reflects the surface friction while the geometrical roughness shows the evenness characteristics of the fabric surface. The surface properties influence not only the fabric handle but also the comfort properties of the patients' bedding and clothing. The patients' skins are very fragile and may get hurt during rubbing against their bedding or clothing materials, especially for those patients with spasticity. Hence, smooth fabrics used for the patients' bedding and clothing are preferable. On the other hand, the fabrics that can cause friction when wearing or lying in bed should be avoided as the patients spend much of their time in bed.

Table 5.7 Surface properties of fabric samples

	Coefficient of Friction, MIU			Geometrical Roughness, SMD (μm)		
Fabric Sample number	Warp	Weft	Mean	Warp	Weft	Mean
1	0.264	0.260	0.262	5.50	5.72	5.61
2	0.241	0.225	0.233	5.91	3.82	4.87
3	0.281	0.289	0.285	5.42	3.72	4.57
4	0.214	0.225	0.219	6.46	8.03	7.24
5	0.224	0.230	0.227	3.36	4.03	3.70
6	0.215	0.205	0.210	3.96	3.69	3.82
7	0.196	0.191	0.193	3.55	3.63	3.59
8	0.235	0.244	0.239	5.58	4.15	4.87
9	0.205	0.225	0.215	4.59	4.24	4.42
10	0.200	0.213	0.206	5.74	3.98	4.86
11	0.254	0.242	0.248	9.22	7.74	8.48
12	0.219	0.226	0.223	5.28	6.71	6.00
13	0.214	0.231	0.223	7.56	7.79	7.68
14	0.231	0.232	0.232	8.33	6.43	7.38
15	0.215	0.229	0.222	6.20	5.98	6.09
16	0.236	0.221	0.229	8.81	7.34	8.08

Table 5.7 reveals that the MIU values of all fabric samples did not vary significantly. The results of MIU values suggested that the fabrics shared a certain type of surface irregularity causing a similar resistance to sliding. This might be due to the interlacing structure combined with the same warp cotton yarns.

It was seen from Table 5.7 that Fabric Samples No. 5, 6 and 7 exhibited significantly low SMD values as they were considerably smooth among the sixteen different fabrics. The weft yarns of these fabrics composed of filament yarns, i.e. Coolmax yarns and Thermolite yarns while the other fabrics composed of spun weft yarns when compared with the fabrics in 2/2 twill weave. The protruding fibres in the spun yarns might increase the surface roughness. Therefore, the fabric samples with weft spun yarns had a generally high surface roughness. It was not surprising to see that the SMD value of Fabric Sample No. 11 was much larger than Fabric Sample No. 10 although their warp and weft yarns were the same. This could be due to the fact that the value of geometrical roughness also depended on the type of weave, i.e. Fabric Sample No. 11 was a 2/1 twill weft backed fabric but Fabric Sample No. 10 was a 2/2 twill fabric.

5.3.1.4 Shear test (KES-FB-1)

The Kawabata Evaluation System for Fabrics (KES-FB-1) was used to test the shear property of fabrics. The procedure of fabric preconditioning and conditioning was conducted according to the ASTM D 1776-08. The testing procedure followed the KES-F testing manual.

Shear deformation occurs when a fabric is bent in more than one direction, especially during wearing process when the fabric needs to conform to the body gesture by stretching. Shear property is highly related to the fabric bending property and thus indicates the ability of a fabric to drape. The shear property of various fabrics is shown in Table 5.8. Shear rigidity means the ability of a fabric to resist shear stress. Lower shear rigidity will lead to a better fabric handle.

Table 5.8 Shear property of fabric samples

Fabric Sample Number	Shear Rigidity, G (g/cm.deg)		
	Warp	Weft	Mean
1	1.40	1.41	1.40
2	1.06	1.00	1.03
3	0.85	0.83	0.84
4	1.16	3.36	2.26
5	1.00	1.03	1.01
6	0.95	0.96	0.95
7	1.25	1.30	1.27
8	1.98	1.97	1.98
9	2.21	2.18	2.20
10	0.87	0.90	0.88
11	0.66	0.60	0.63
12	1.15	1.12	1.13
13	1.29	1.29	1.29
14	1.56	1.59	1.58
15	1.25	1.21	1.23
16	1.44	1.46	1.45

Table 5.8 indicates that Fabric Sample No. 4 gave the highest G value of 2.26 g/cm.deg. The result implied that Fabric Sample No. 4 exhibited the worst fabric handle and drapebility. This might be due to the fact that Fabric No. 4 was the thickest fabric with the highest fabric density among all the fabric samples. In the case of 2/2 twill fabrics with twistless weft yarns, Fabric Samples No. 3 and 10 exhibited comparatively low shear rigidity. This might be explained in the light of the characteristics of constituent twistless yarns which resulted in higher inter-yarn spaces inside the fabrics after the removal of PVA filament when compared with the other fabrics. Hence, the higher mobility of cross threads inside the fabrics led to a lower fabric rigidity. The twistless yarn structure might be attributed to the lowest shear rigidity of Fabric Sample No. 11. However, the shear rigidity remained comparatively high for those fabric samples containing

the weft twistless yarns in plain weave. This might be due to the fact that the yarns were packing more compact in plain weave than the twill weave resulting in less inter-yarn spaces.

5.3.1.5 Thermal resistance test (ASTM D 1518-85 (2003))

The thermal resistance of fabrics was measured in terms of clo by the ASTM D 1518-85 (2003) using the SDL warmth retaining tester. The paraplegic and quadriplegic patients experience a lack of mobility which will decrease blood circulation causing a reduced sensation. They are unable to feel the cold and hence they must be warmly clothed. A higher thermal resistance of a fabric used for clothing is supposed to be better for keeping the patients warm.

The results of thermal resistance of fabric samples are shown in Figure 5.4. The clo values of all fabric samples were similar and higher than one clo. According to the literature review [16], one clo was the required insulation to keep a resting man comfortable. Therefore, fabrics with higher clo values would be more appropriate for making the patients' clothing. On the other hand, it is evident from Figure 5.4 that the fabric samples with plain weave, i.e. Fabric Samples No. 12 to 16 exhibited comparatively lower thermal resistance than the twill fabric samples, i.e. Fabric Samples No. 1 to 5, No. 7 and No. 9 to 11. However, the minimum thermal resistance of Fabric Sample No. 6 might be attributed to the smallest thickness value. Fabric Sample No. 7 showed the maximum value of thermal resistance. This might be due to the presence of Thermolite yarns in the weft working as insulating medium, and also the hollow fibres that entrapped the still air.

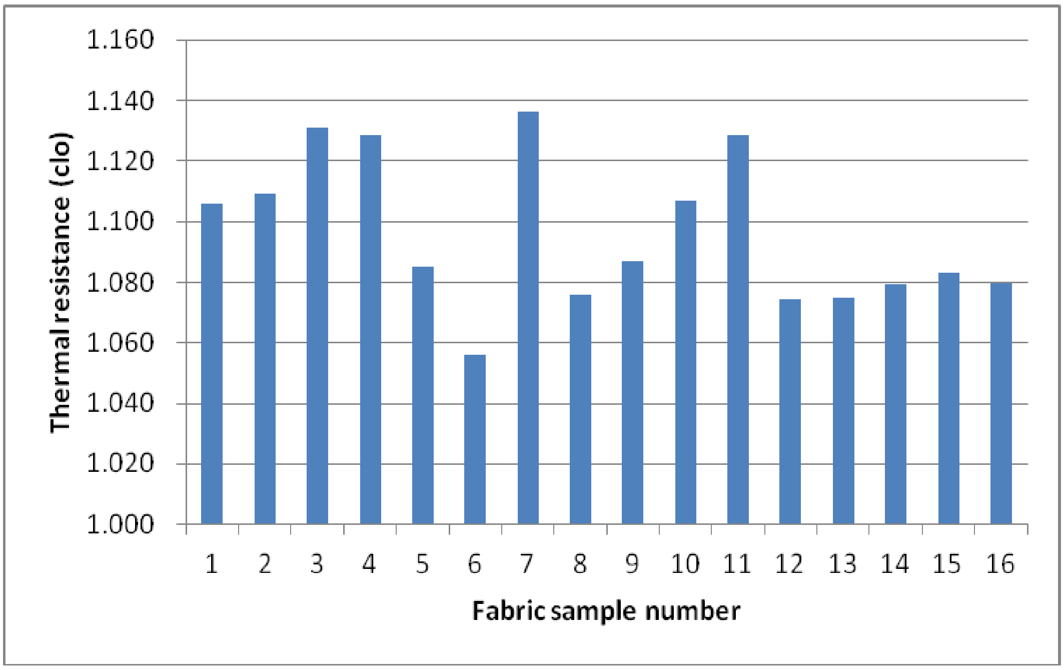


Figure 5.4 Thermal resistance of fabric samples

5.3.1.6 Air permeability test (ISO 9237:1995)

The air permeability of fabrics was evaluated by the ISO 9237:1995 using the SDL air permeability tester. The air permeability was measured with a pressure drop at 100 Pa and a test area of 5 cm^2.

Air permeability is an important parameter in evaluating the thermal comfort characteristic of a fabric. The patients' bedding and clothing used for paraplegic and quadriplegic patients must be breathable as their skin is very tender. Therefore good air permeability is preferable to allow for insensible perspiration.

The results of air permeability are demonstrated in Figure 5.5. It was seen that Fabric Sample No. 4 had the lowest air permeability among all the fabrics. This might be attributed to the fabric density. As the weft yarns used for Fabric Sample No. 4 contained Lycra, the number of ends per inch became the greatest (ends per cm: 44) after finishing. In addition, the heaviest fabric weight might also be attributed to the smallest value of air permeability.

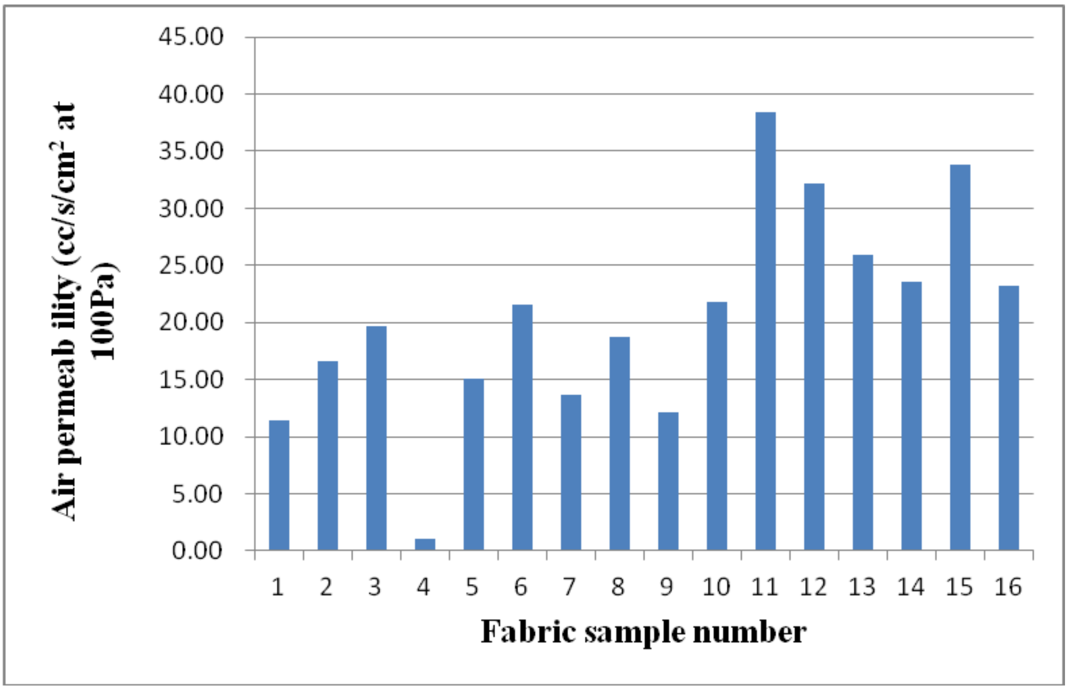


Figure 5.5 Air permeability of fabric samples

By using the bivariate correlation tool in SPSS 17.0, the correlation between the fabric weight and the test results of air permeability was determined. The results shown in Table 5.9 indicated that the fabric weight had a significant negative correlation with the air permeability property. This meant that a higher fabric weight might result in a lower air permeability value. In contrast, Fabric Sample No. 11 demonstrated the highest air permeability which could be due to the thinnest thickness. In general, the values of air permeability of fabrics with 2/2 twill weave, i.e. Fabric Samples No. 1 to 10, were smaller than those with plain weave, i.e. Fabric Samples No. 12 to 16.

Table 5.9 Correlation coefficient between fabric weight and air permeability

		Air permeability
Fabric Weight	Pearson Correlation	-.751**
	Sig. (2-tailed)	.001
	N	16

** Correlation is significant at the 0.01 level (2-tailed).

5.3.1.7 Water vapour permeability test (BS 7209:1990)

The water vapour permeability index of fabrics was determined by the BS 7209:1990 using the turntable. Good water vapour permeability of the patients' clothing and bedding is preferable. If the insensible perspiration cannot escape, a build-up of vapour will occur near the body, making the body feel clammy and uncomfortable.

The findings shown in Figure 5.6 illustrated the water vapour permeability index of fabrics. All fabrics demonstrated good water vapour permeability indices of higher than 95%.

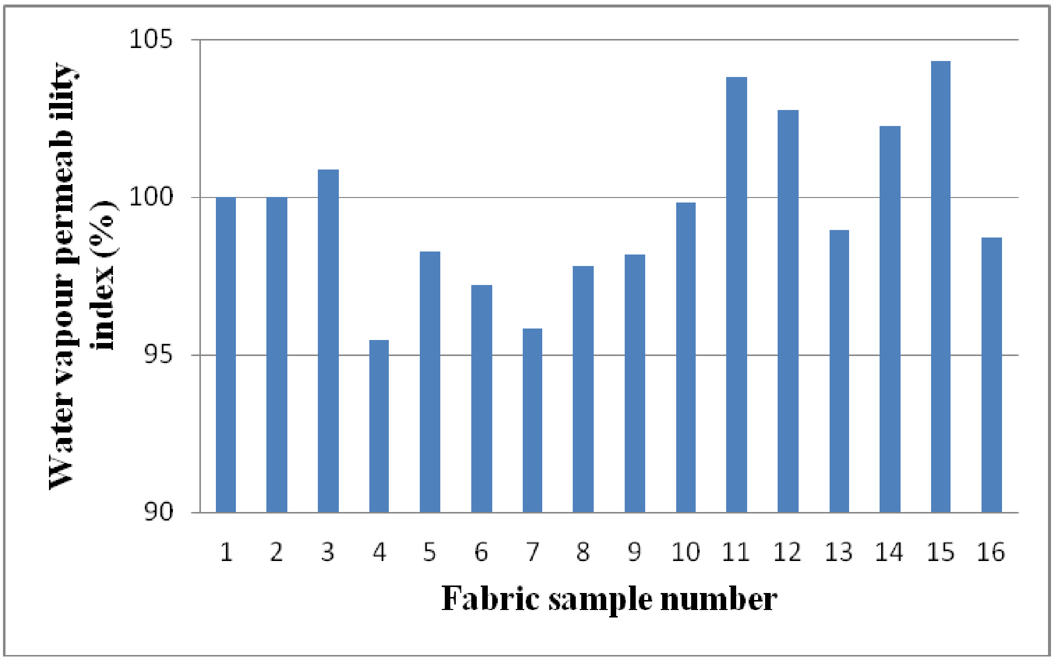


Figure 5.6 Water vapour permeability index of fabric samples

Figure 5.6 reveals that Fabric Sample No. 4 showed the lowest water vapour permeability index among all the fabric samples. This was probably due to the highest fabric density and heaviest fabric weight. In contrast, Fabric Sample No. 15 had the highest water vapour permeability index. The 100% cotton fabric samples with plain weave, i.e. Fabric Samples No. 12, 14 and 15 demonstrated higher water vapour permeability indices than the 2/2 twill fabrics, i.e. Fabric Samples No. 1 to 3 and No. 8 to 9, became open structure could allow more water vapour transmission. On the other hand, it must be noted that the fabric samples composed of synthetic fibres, i.e. Coolmax yarn, Thermolite yarn and Lycra yarn, had lower water vapour permeability indices than the fabrics made with cotton fibres, i.e. Nu-Torque yarn, MVS yarn and twistless cotton yarn. This might be due to the fact that synthetic fibres were hydrophobic whereas cotton fibres were hydrophilic.

Table 5.10 provides the correlation between the fabric weight, air permeability property and water permeability index. It was seen that the fabric weight and the air permeability property were significantly correlated to the water vapour permeability. The direction of the correlation was positive meaning that the fabric with a high air permeability would show a high water vapour permeability index. The negative correlation suggested that the heavier the fabric, the lower the water vapour permeability index would be.

Table 5.10 Correlation coefficient between fabric weight, air permeability and water vapour permeability

		Water Vapour Permeability Index
Fabric Weight	Pearson Correlation	-.676**
	Sig. (2-tailed)	.004
	N	16
Air Permeablity	Pearson Correlation	.803**
	Sig. (2-tailed)	.000
	N	16

** Correlation is significant at the 0.01 level (2-tailed).

5.3.1.8 Wickability test

The wickability of a fabric mainly depends on the fibre type, structure of yarn and fabric in general. Wicking occurs when a fabric is wetted by the liquid. The liquid is driven through the capillary spaces by means of capillary forces. Smaller pores are filled with the liquid first leading to the front movement of the liquid. The liquid then moves to the larger pores when the smaller pores are completely filled with the liquid. The inter-fibre spaces and pores are influenced by the size and spaces of fibres as well as their alignment. Hence, both the fibre surface and pore structure affect the wickability of fabric adversely.

Wickability of a fabric is of vital importance for clothing comfort. The fabric designed for the patients' clothing should absorb sweat quickly in order to prevent skin irritation caused by sweat which may result in discomfort. Wickability is also important to the patients' bedding. The patients usually wear diapers in the paediatric hospital and so they may suffer a great discomfort due to the urine leakage from diapers.

Figure 5.7 shows the apparatus of the wickability test. The longer the water distance, the better the capillary action of the fabric sample will be. The detailed test procedure is described in Appendix E [6].

Figure 5.7 Wicking test

Figures 5.8 and 5.9 show the wicking height of fabrics in the warp and weft directions for 1 minute, 3 minutes and 5 minutes respectively. The results of wickability in the warp direction were similar to those of the weft directions except Fabric Samples No. 5, 6 and 7. The wicking height of these fabric samples in the warp direction was about twofold of the weft direction. Since the warp yarns of these fabrics were belonged to the same cotton ring spun yarns, the structure of the weft yarns might affect this situation. The weft yarns of Fabric Samples No. 5 and 6 were Coolmax yarns composed of four-channeled fibres resulting in more capillaries for wicking. The weft yarns of Fabric Sample No. 7 were Thermolite yarns which were hollow fibres facilitating the fast liquid transport. On the other hand, Figure 5.9 shows that Fabric Sample No. 3 had the highest wicking height in the weft direction whereas Fabric Sample No. 2 demonstrated the lowest wicking height. The twistless weft yarns of Fabric Sample No. 3 were likely to be responsible for the highest wicking height. As the yarns were twistless, more parallel fibres would be generated in the fabric. The parallel channels and small pores would absorb more water with the aid of capillary pressure. However, the weft yarns of Fabric Sample No. 2 were ring spun yarns with their fibres being arranged in a helix causing the lowest wickability.

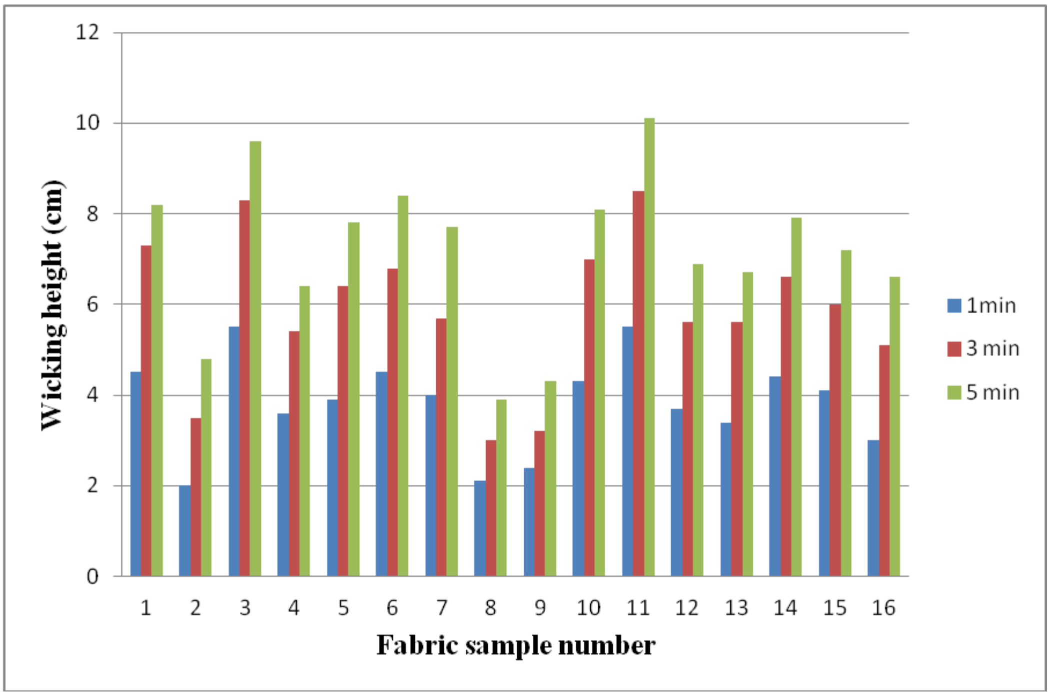


Figure 5.8 Wickability of warp direction of fabric samples

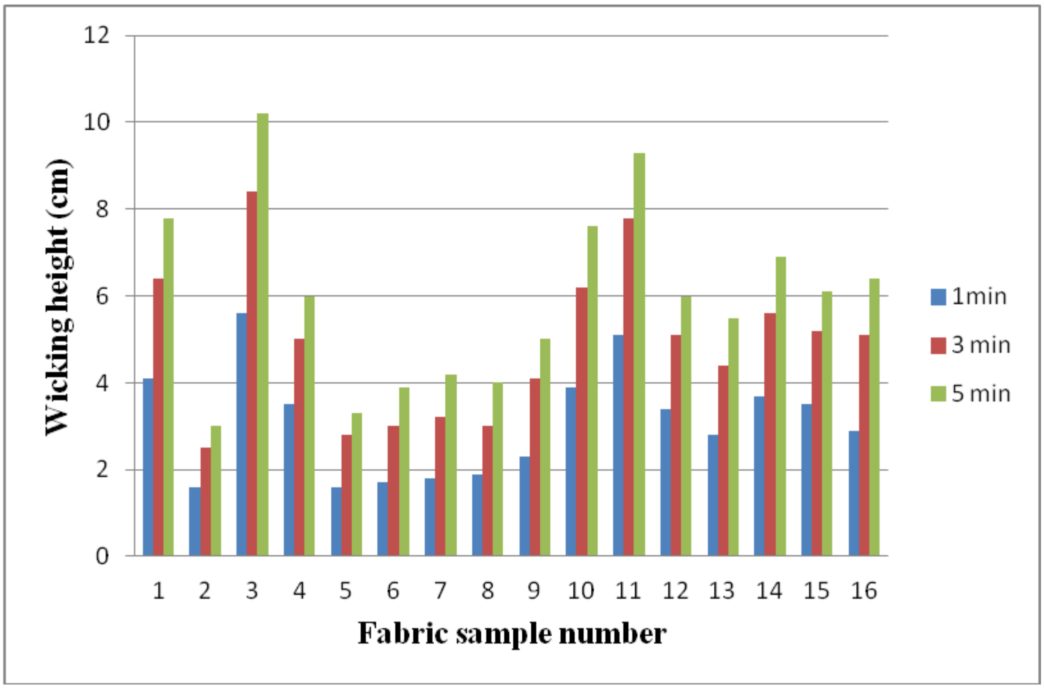


Figure 5.9 Wickability of weft direction of fabric samples

5.3.1.9 Absorbency test (AATCC TM 79-2007)

The water absorbency of fabrics was evaluated by the AATCC TM 79-2007 using the burette. During the test, a drop of water fell on the fabric and the time of absorbency was measured. The results of the absorbency of fabrics are summarized in Table 5.11.

Table 5.11 Absorbency of fabric samples

Fabric Sample Number	Wetting Time (s)
1	0.4
2	1.8
3	0
4	0
5	3.3
6	2.3
7	3.2
8	0
9	0
10	0
11	0
12	1.9
13	3
14	0
15	0
16	2.6

The absorbency value can indicate how fast the fabric absorbs sweat and urine. A faster wetting time is supposed to be better for clothing and bedding comfort. As shown in Table 5.11, the wetting time of the Fabric Samples No. 5, 6, 7, 13 and 16 with the presence of synthetic fibres such as Coolmax yarns and Thermolite yarns in the weft direction was comparatively long among all the fabric samples in general. This might be due to the fact that the moisture regain of polyester fibres was lower than cotton fibres. In addition, the weave structure and the fabric density could influence the open space within the fabric resulting in longer wetting time.

5.3.1.10 Flammability test (ASTM D 1230-94 (2001))

The flammability of fabrics was tested by the ASTM D 1230-94 (2001) using the SDL flammability tester. The fabric used for the young patients' bedding and clothing should not ignite immediately so as to avoid the young patients from being burnt. Therefore, the fabrics should meet the standard of the flammability test for safety consideration.

The flammability property of fabrics depends on the fibre composition, weave structure and fabric density. Cotton fibre is combustible while polyester fibre or Lycra fibre may be self-extinguishing or melt when subjected to a flame source. All the fabric samples did not ignite either before or after refurbishing states. Hence, they all fulfilled the standard of class 1 material. The reason of not burning was probably due to the fact that the fabrics were tightly woven. The flammability results are summarized in Table 5.12.

Table 5.12 Flammability of fabric samples

Fabric Sample Number	Classification
1	Class 1
2	Class 1
3	Class 1
4	Class 1
5	Class 1
6	Class 1
7	Class 1
8	Class 1
9	Class 1
10	Class 1
11	Class 1
12	Class 1
13	Class 1
14	Class 1
15	Class 1
16	Class 1

5.3.1.11 Pilling propensity tests (EN ISO 12945-1:2001 and EN ISO 12945-2:2001)

The pilling propensity of fabrics was determined by the ISO 12945-1 for 10 hours and ISO 12945-2 for 2000 revolutions using the ICI pilling tester and the SDL Martindale abrasion testing machine respectively. The tested fabric samples were laundered prior to the pilling tests in accordance with the AATCC TM 135-2004.

Pilling propensity is important to the patient's clothing and bedding because pill formation does affect the appearance adversely. When the fibres present on the fabric surface become entangled, pills are formed. This undesirable surface deterioration occurs during use, especially the action of rubbing between the materials of clothing and bedding. The pills usually occur in certain areas of a garment subjecting to rubbing such as (1) under the arm, (2) inside the collar, (3) knee, (4) elbow and (5) bottom. The frequent laundering in the hospital also deteriorates the formation of pills.

The results of pilling propensity tested by the pilling box and the modified Martindale are shown in Figures 5.10 and 5.11 respectively. The results showed that there were no correlations between these two test methods. Both Fabric Samples No. 8 and 9 achieved Grade 5 in the pilling tests, meaning that the surface of the fabrics had no change after the pilling tests. Pilling propensity of the fabrics was more adversely influenced by the spinning system than by the fibre type or yarn count. The best pilling resistance of Fabric Samples No. 8 and 9 constructed from the Murata vortex spun cotton yarns was probably attributed to the better binding of fibres to the uniform arrangement of wrapper fibres along the yarn length.

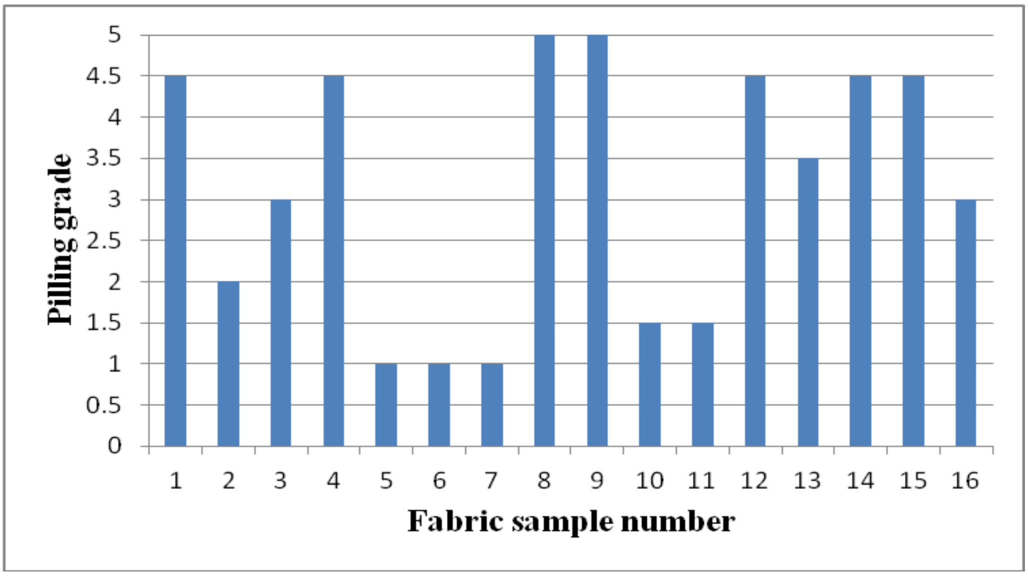


Figure 5.10 Pilling of fabric samples (ISO 12945-1)

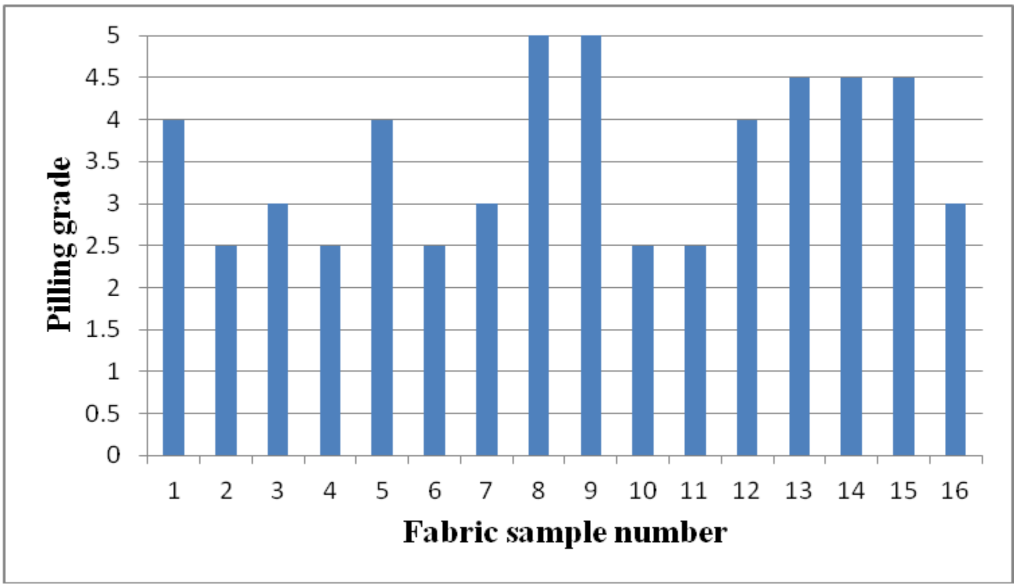


Figure 5.11 Pilling of fabric samples (ISO 12945-2)

5.3.1.12 Dimensional stability test (AATCC TM 135-2004)

The dimensional stability of fabrics was tested by the AATCC TM 135-2004 as a preliminary evaluation using the Whirlpool washing machine and the Whirlpool tumble dryer. Since the patients' bedding and clothing are washed and dried every day, the dimensional stability to washing and drying becomes important. Table 5.13 provides the dimensional stability in area of the fabric samples.

Table 5.13 Dimensional stability in area of fabric samples

Fabric Sample Number	Dimensional Stability (%)		
	Warp	Weft	Area
1	-2.7	-2.0	-4.6
2	-1.8	-1.8	-3.6
3	-3.8	-3.5	-7.2
4	-2.3	-0.7	-2.9
5	-1.9	-0.8	-2.6
6	-1.4	-0.7	-2.1
7	-2.3	-3.3	-5.5
8	-2.8	-3.1	-5.8
9	-2.1	-3.1	-5.1
10	-2.6	-1.8	-4.3
11	-4.0	-1.3	-5.3
12	-5.0	-4.1	-8.9
13	-4.0	-2.2	-6.1
14	-1.3	-3.9	-5.2
15	-4.5	-3.9	-8.3
16	-4.8	-1.2	-5.9

It was obvious that all the fabric samples showed a negative dimensional stability in area, i.e. shrinkage. The warp cotton yarns of the fabric samples might contribute to the shrinkage. Since cotton fibres are absorbent and swell significantly when wet, the fabrics made with cotton fibres would shrink after laundering and drying. More importantly, the agitation deteriorated the dimensional stability during laundering and drying. In contrast, polyester fibres and Lycra fibres have a low moisture regain and do not shrink when wet as compared to cotton fibres. Hence, the polyester fibres and Lycra fibres have a better dimensional stability. According to Table 5.13, the fabric samples such as Fabric Samples No. 1, 3, 8, 9, 12, 14 and 15 containing both warp and weft cotton yarns demonstrated a higher dimensional change in area among all the fabric samples. The effect was even more obvious for those fabric samples with the twistless cotton yarns in the weft direction and the twisted cotton yarns in the warp direction. When the fabric samples subjected to laundering and drying, the twisted warp yarns might intend to untwist causing shrinkage due to the yarn tension, the locking of the weave and the resistance to shrinkage afforded by the twistless yarns. It was seen that Fabric Sample No. 6 was the most dimensional stable one followed by Fabric Sample No. 5. The weft polyester yarns might contribute to the dimensional stability. The weft yarn in Fabric Sample No. 6 is 36.9 tex single yarn and in Fabric Sample No. 5 was 19.7 tex two ply yarn. It was believed that the count and ply of yarns might also deteriorate the dimensional stability.

5.3.1.13 Tearing strength test (ASTM D 1424-09)

The tearing strength of fabrics was tested by the ASTM D 1424-09 using the Elmatear, digital tear tester. Some young patients like tearing their clothes with their hands as observed during the hospital visits. Since the carers usually change the bedding by pulling, the bedding should withstand the pulling force. It will be dangerous for the child patients when the bedding or clothing snagged by a sharp object to form a small puncture which may be converted into a long rip. Therefore, the patients' bedding and clothing should withstand the tearing force exerted by the young patients as well as the carers.

Table 5.14 shows that Fabric Samples No. 5, 6, 7 and 11 could withstand the largest tearing force. Since the same cotton yarns were used as the warp yarns for all fabrics, higher tearing strength result might be mainly due to the weft yarns made of synthetic filaments which provided a better tearing strength than the natural staple yarns generally. In contrast, it was obvious that Fabric Sample No.

3 showed the weakest force in the weft direction among all the fabric samples. This was probably due to the fact that the staple fibres aligned parallel inside the twistless yarn might result in the smallest tearing strength. This was also considered as the main reason for the comparatively low tearing strength of the fabric samples with the weft twistless yarns.

Table 5.14 Tearing strength of fabric samples

Fabric Sample Number	Force (N)	
	Warp	Weft
1	40.0	26.9
2	39.7	30.5
3	19.9	8.8
4	37.9	37.4
5	64	64
6	64	64
7	64	64
8	19.3	31.7
9	28.3	34.1
10	39.9	63.4
11	64	64
12	25.8	16.1
13	29.4	60.2
14	27.0	18.5
15	24.3	14.6
16	30.8	62.1

5.3.1.14 Tensile strength test (EN ISO 13934-1:1999)

The tensile strength of fabrics was measured by the ISO 13934-1:1999 using the Instron Constant-rate-of-extension (CRE) machine. As stretching force is applied to the patients' clothing during dressing and undressing as well as the patients' bedding while changing, it is therefore important for the fabrics to pose sufficient strength in both the warp and weft directions.

According to Figure 5.12, the tensile strength Fabric Samples No. 5, 6 and 7 in the weft direction of was considerably larger than the warp direction This might be due to the use of synthetic filament for making the weft yarns of these fabrics. On the other hand, the warp densities of the fabrics were generally greater than the weft densities resulting in a better tensile strength.

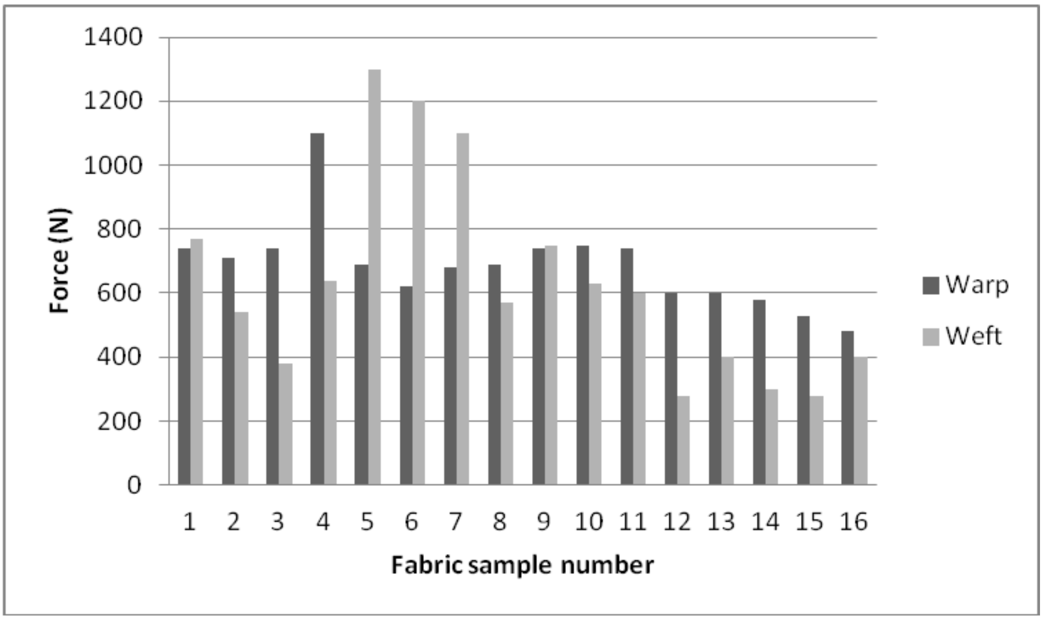


Figure 5.12 Tensile strength of fabric samples

5.3.1.15 Summary of objective experiments

The findings shown in Table 5.15 provided a summary of the objective results. These results were used together with a weighting obtained from the questionnaire survey shown in the following Section 5.3.2 to calculate the index of the performance evaluation. Higher the index implied that the fabrics were more suitable to meet the requirements of the paediatric paraplegic and quadriplegic patients' bedding and clothing as confirmed by both objective experiments and questionnaire results.

Table 5.15 A summary of results obtained from objective experiments

Fabric Sample Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Mean
Weight (g/m^2)	204	189	170	349	216	207	212	213	215	187	194	156	168	170	146	168	198
Compression WC (g.cm/cm^2) RC (%)	*WC:* 0.646 *RC:* 29.15	*WC:* 0.374 *RC:* 35.47	*WC:* 0.523 *RC:* 30.13	*WC:* 0.338 *RC:* 37.58	*WC:* 0.248 *RC:* 42.52	*WC:* 0.217 *RC:* 38.69	*WC:* 0.260 *RC:* 46.73	*WC:* 0.310 *RC:* 34.63	*WC:* 0.289 *RC:* 36.6	*WC:* 0.364 *RC:* 32.39	*WC:* 0.632 *RC:* 40.05	*WC:* 0.266 *RC:* 29.37	*WC:* 0.376 *RC:* 31.25	*WC:* 0.395 *RC:* 30.52	*WC:* 0.335 *RC:* 28.41	*WC:* 0.392 *RC:* 29.75	*WC:* 0.373 *RC:* 34.58
Thickness (mm)	1.527	1.157	1.450	1.440	1.012	0.890	0.942	1.167	1.107	1.290	0.893	0.975	1.293	1.197	1.193	1.133	1.167
Bending (gf.cm^2/ cm)	0.106	0.083	0.089	0.413	0.093	0.075	0.119	0.154	0.157	0.089	0.110	0.077	0.091	0.095	0.079	0.085	0.120
Surface MIU SMD (µm)	*MIU:* 0.262 *SMD:* 5.61	*MIU:* 0.233 *SMD:* 4.87	*MIU:* 0.285 *SMD:* 4.57	*MIU:* 0.219 *SMD:* 7.24	*MIU:* 0.227 *SMD:* 3.70	*MIU:* 0.21 *SMD:* 3.82	*MIU:* 0.193 *SMD:* 3.59	*MIU:* 0.239 *SMD:* 4.87	*MIU:* 0.215 *SMD:* 4.42	*MIU:* 0.206 *SMD:* 4.86	*MIU:* 0.248 *SMD:* 8.48	*MIU:* 0.223 *SMD:* 6.00	*MIU:* 0.223 *SMD:* 7.68	*MIU:* 0.232 *SMD:* 7.38	*MIU:* 0.222 *SMD:* 6.09	*MIU:* 0.229 *SMD:* 8.08	*MIU:* 0.229 *SMD:* 5.70
Shear (g/cm.deg)	1.40	1.03	0.84	2.26	1.01	0.95	1.27	1.98	2.20	0.88	0.63	1.13	1.29	1.58	1.23	1.45	1.32
Thermal Resistance (Clo)	1.106	1.109	1.131	1.129	1.085	1.056	1.136	1.076	1.087	1.107	1.129	1.074	1.075	1.079	1.083	1.080	1.096
Air Permeability (cc/s/cm^2 at 100Pa)	11.45	16.65	19.69	1.04	15.12	21.57	13.68	18.70	12.11	21.75	38.37	32.15	25.94	23.62	33.88	23.25	20.56
Water Vapour Permeability Index	100.02	100.02	100.87	95.48	98.25	97.20	95.84	97.79	98.19	99.82	103.81	102.75	98.97	102.23	104.30	98.75	99.64
Wickability (cm)	8.0	3.9	9.9	6.2	5.6	6.2	6.0	4.0	4.7	7.9	9.7	6.5	6.1	7.4	6.7	6.5	6.6

Table 5.15 A summary of results obtained from objective experiments (cont'd)

Fabric Sample Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Mean
Absorbency (s)	0.4	1.8	0	0	3.3	2.3	3.2	0	0	0	0	1.9	3.0	0	0	2.6	1.2
Flammability	Class1	Class1	Class1	Clas1	Class1	Class1	Class1	Class1	Class1	Class1	Class1	Class1	Class1	Class1	Class1	Class1	-------
Pilling Propensity	Part 1: 4.5 Part 2: 4	Part 1: 2 Part 2: 2.5	Part 1: 3 Part 2: 3	Part 1: 4.5 Part 2: 2.5	Part 1: 1 Part 2: 4	Part 1: 1 Part 2: 2.5	Part 1: 1 Part 2: 3	Part 1: 5 Part 2: 5	Part 1: 5 Part 2: 5	Part 1: 1.5 Part 2: 2.5	Part 1: 1.5 Part 2: 2.5	Part 1: 4.5 Part 2: 4	Part 1: 3.5 Part 2: 4.5	Part 1: 4.5 Part 2: 4.5	Part 1: 4.5 Part 2: 4.5	Part 1: 3 Part 2: 3	------- -------
Dimensional Stability (%)	-4.6	-3.6	-7.2	-2.9	-2.6	-2.1	-5.5	-5.8	-5.1	-4.3	-5.3	-8.9	-6.1	-5.2	-8.3	-5.9	-5.2
Tearing Strength (N)	33.5	35.1	14.4	37.7	64.0	64.0	64.0	25.5	31.2	51.7	64.0	21.0	44.8	22.8	19.5	46.5	40.0
Tensile Strength (N)	760	630	560	870	1000	910	890	630	750	690	670	440	500	440	410	440	660

5.3.2 Questionnaire about the importance and influence of the fabric attributes on the performance of the patients' bedding and clothing

A questionnaire survey was carried out with 85 medical personnel including 33 nurses and 52 nursing assistants aiming to rank the importance and influence of the fabric attributes on the performance of the patients' bedding and clothing as shown in Table 5.16.

Table 5.16 Fabric attributes for the patients' bedding and clothing

Fabric Attributes of the Patients' Bedding	Fabric Attributes of the Patients' Clothing
A] Handle e.g. comfort when lying in	A] Handle e.g. comfort when wearing
B] Breathability e.g. allow insensible perspiration	B] Breathability e.g. keep ventilation
C] Absorbency e.g. absorb sweat or urine	C] Absorbency e.g. absorb sweat or urine
D] Pilling Resistance e.g. not easy to form pills	D] Pilling Resistance e.g. not easy to form pills
E] Dimensional Stability e.g. durable after laundering	E] Dimensional Stability e.g. durable after laundering
F] Strength e.g. withstand pulling or tearing force	F] Strength e.g. withstand pulling or tearing force
G] Weight e.g. fabric weight	G] Weight e.g. fabric weight
H] Thickness e.g. fabric thickness	H] Thickness e.g. fabric thickness
	I] Warmth e.g. warmth-keeping

The fabric attributes were designed according to the requirements of the patients' bedding and clothing such as comfort, moisture management property and durability as shown in Section 4.4 of Chapter 4. On the other hand, the requirements of safety and anti-bacterial property were not included in the survey. The reason for not considering the safety criterion in the index rating was that the fabrics should pass the flammability standard before fabric selection. The anti-bacterial finishing was applied to the selected fabrics used for the patients' bedding and clothing. Moreover, the anti-bacterial finishing was evaluated by the standard tests before applying to the selected fabrics.

The questionnaire was divided into two parts. The first part concerned about the patients' bedding while the second part was about the patients' clothing. The respondents were asked to compare the fabric attributes in pairs first because it was easy to rate which attribute was more important. They were then asked to rank the importance among all the fabric attributes. The questionnaire was attached in Appendix B.

5.3.2.1 Results and discussion

The importance priority of the patients' bedding was F followed by A, G, C, E, B, D and H while the importance priority of the patients' clothing was A followed by I, F, C, B, G, E, H and D. The results showed that the importance priority of both patients' bedding and clothing obtained from pair comparison and ranking was consistent. Tables 5.17 and 5.18 indicate the ranking frequency of the importance of fabric attributes for the patients' bedding and clothing respectively. The respondents thought that the fabric handle and strength were very important to both patients' bedding and clothing. The results also suggested that the respondents emphasized strongly on the comfort and durability of fabric. In contrast, the thickness and pilling resistance of fabric were considered to be the least important for the patients' bedding and clothing respectively.

Table 5.17 Ranking frequency of the importance of fabric attributes for patients' bedding

Fabric Attributes	Frequency of Respondents								Total Score	Priority
	Rank 8	Rank 7	Rank 6	Rank 5	Rank 4	Rank 3	Rank 2	Rank 1		
A	21	17	14	12	13	3	4	1	501	2
B	8	7	6	12	14	15	9	14	342	6
C	9	12	12	16	15	16	5	0	426	4
D	1	2	5	5	14	15	21	22	242	7
E	6	11	7	11	13	17	15	5	360	5
F	23	19	12	17	5	3	4	2	513	1
G	14	13	22	9	8	8	6	5	453	3
H	3	4	7	3	3	8	21	36	223	8
								Total	3060	

Table 5.18 Ranking frequency of the importance of fabric attributes for patients' clothing

Fabric Attributes	Frequency of Respondents									Total Score	Priority
	Rank 9	Rank 8	Rank 7	Rank 6	Rank 5	Rank 4	Rank 3	Rank 2	Rank 1		
A	28	20	27	4	2	4	0	0	0	651	1
B	7	18	13	20	18	4	5	0	0	539	5
C	15	9	14	23	11	5	6	2	0	540	4
D	0	0	0	0	0	1	27	32	25	174	9
E	0	1	1	2	5	35	15	13	13	276	7
F	16	16	11	13	13	8	8	0	0	548	3
G	0	3	2	7	25	12	14	15	7	332	6
H	0	2	5	1	2	8	8	19	40	201	8
I	19	16	12	15	9	8	2	4	0	564	2
									Total	3825	

The score obtained from the ranking frequency was adopted to measure the the weighting of each fabric attribute according to the importance of the patients' bedding and clothing perceived from the professional medical personnel. The higher the weighting, the more important the fabric attribute would be. The weighting helped find out the most suitable fabrics used for the patients' bedding and clothing. The results of the weighting of the fabric attributes suitable for the patients' bedding and clothing are shown in Tables 5.19 and 5.20 respectively. The weighting of each fabric attribute was calculated by the following equation:

$$\textbf{Weighting of each fabric attribute} = \frac{\text{Total score of each fabric attribute}}{\text{Total score of all fabric attributes}} \times 100\%$$

Table 5.19 The weighting of each fabric attribute suitable for patients' bedding

Fabric Attributes	A	B	C	D	E	F	G	H
Weighting	16.37%	11.18%	13.92%	7.91%	11.76%	16.76%	14.80%	7.29%

Table 5.20 The weighting of each fabric attribute suitable for patients' clothing

Fabric Attributes	A	B	C	D	E	F	G	H	I
Weighting	17.02%	14.09%	14.12%	4.55%	7.22%	14.33%	8.68%	5.25%	14.75%

An indexing method was adopted to evaluate the suitability of the fabric samples by combining both objective and subjective measurements [18, 19]. The results of objective experiments were then weighted by the weighting of the fabric attributes obtained from the questionnaire results. The index of each fabric was measured using the following equation:

Index of each fabric =

$$\Sigma \left[(\text{Weighting of each fabric attribute} \times \text{experimental results of each fabric attribute}) / (\text{mean experimental results of each fabric attribute}) \right]$$

attributes is summarized in Table 5.21. According to Table 5.15, there was no numerical mean value for the test results of the pilling propensity. This was due to the fact that the results of the pilling propensity were expressed in grades. Therefore, their weighting was multiplied by one to calculate the index for the fabrics.

Table 5.21 Categorization of the objective measurement

	Patients' Bedding	Patients' Clothing
Fabric Attributes	Objective Measurement	
A] Handle	Compression Bending Surface	Compression Bending Surface Shear
B] Breathability	Air permeability Water vapour permeability	Air permeability Water vapour permeability
C] Absorbency	Wickability Absorbency	Wickability Absorbency
D] Pilling Resistance	Pilling propensity	Pilling propensity
E] Dimensional Stability	Dimensional stability	Dimensional stability
F] Strength	Tearing strength Tensile strength	Tearing strength Tensile strength
G] Weight	Weight	Weight
H] Thickness	Thickness	Thickness
I] Warmth	----------------	Thermal resistance

In general, higher values of the objective measurement would contribute to a higher suitability of the patients' bedding and clothing. However, the higher the values of the bending property, surface properties, shear property, absorbency time, dimensional stability, weight and thickness, the lower the suitability of the fabric would be.

For instance, the fabric with a high bending rigidity would be stiff. On the other hand, the fabric with large MIU and SMD values of surface property implied high surface roughness. The fabrics used for the patients' bedding and clothing should not be stiff or rough so as not to cause any skin irritation during abrasion. The fabric with a higher value of shear rigidity would make it harder to conform to the body while wearing. The longer absorbency time indicated that the sweat would stay on the skin for a longer time. The fabrics used for the patients' bedding and clothing should not be too heavy and thick, otherwise it would affect the ease of laundry processes and the transportation. Moreover, the light weight clothing was preferable as it would help reduce the pressure at the patients' skin. The results of the dimensional stability could be positive or negative because the fabrics might have shrinkage or growth after laundering. Higher magnitude generally indicated lower dimensional stability. The fabrics used for the patients' bedding and clothing should be dimensionally stable after laundering. Hence, negative signs were assigned to the results of the objective measurement such as the bending property, MIU and SMD values of surface property, shear property, absorbency time, dimensional stability, weight and thickness for the index measurements.

The following example shows the calculation of the index for the patients' bedding of Fabric Sample No. 1. The index was measured based on the weighting obtained from the ranking shown in Table 5.19 and the mean objective measurement as shown in Table 5.15.

Index for the patients' bedding of Fabric Sample No. 1

= (0.646/0.373 + 29.15/34.58 – 0.262/0.229 – 5.61/5.7-0.106/0.12) x 16.37% +

(11.45/20.56 + 100.02/99.64) x 11.18% +

(8/6.6 – 0.4/1.2) x 13.92% +

(4.5/1 + 4/1) x 7.91% +

- (-4.6/-5.2) x 11.76% +

(33.5/40 + 760/660) x 16.76% +

- (204/198) x 14.80% +

- (1.527/1.167) x 7.29%

= 0.880

The assessment results of the patients' bedding and clothing for all fabric samples are shown in Tables 5.22 and 5.23. The findings clearly indicated that Fabric Sample No. 1 demonstrated the highest index followed by Fabric Samples No. 11 and 9 for the patients' bedding. On the other hand, Fabric Sample No. 11 showed the highest index followed by Fabric Samples No. 1 and 10 for the patients' clothing. Therefore, Fabric Samples No. 1 and 11 were the most suitable fabric used for the patients' bedding and clothing based on the combination of the combination of the subjective and objective measurements.

Table 5.22 Index of the patients' bedding

Fabric Sample Number	Index
1	0.880
2	0.357
3	0.643
4	0.159
5	0.476
6	0.525
7	0.338
8	0.769
9	0.847
10	0.692
11	0.861
12	0.519
13	0.445
14	0.810
15	0.809
16	0.326

Table 5.23 Index of the patients' clothing

Fabric Sample Number	Index
1	0.839
2	0.453
3	0.779
4	0.479
5	0.530
6	0.612
7	0.460
8	0.686
9	0.719
10	0.838
11	1.095
12	0.522
13	0.421
14	0.730
15	0.791
16	0.333

5.4 Fabric selection

A meeting was held between the representatives from the DDU, Caritas Medical Centre who were professional medical personnel and the project team members from The Hong Kong Polytechnic University to discuss the fabric selection of the patients' bedding and clothing. The experimental test results of the sixteen fabric samples were shown and explained to the medical personnel in the aspects of performance and functions. The fabric swatches of all fabric samples were distributed to them for touching and feeling.

Finally, Fabric Samples No. 1 and 11 were selected for the patients' bedding and clothing respectively. However, the poor results of pilling propensity were the main concern of the professional medical personnel because the fabrics might form pills easily. The project team suggested using Nu-Torque cotton yarns to replace the twistless weft yarns of Fabric Sample No. 11 in order to solve the pilling problems. When comparing the test results, Fabric Sample No. 1 with Nu-Torque cotton yarn as weft demonstrated superior pilling grades to Fabric Sample No. 3 with twistless cotton yarn as weft. Regarding the durability, Fabric Sample No. 1 also performed better than Fabric Sample No. 3 in terms of dimensional stability, tearing strength and tensile strength based on the test results shown in Section 5.3.1. Hence, the project team and medical personnel agreed to use Nu-Torque cotton yarns to replace the twistless weft yarns.

In conclusion, 2/2 twill fabric with the weft Nu-Torque cotton yarns as well as 2/1 twill weft backed fabric with the weft Coolmax yarns and Nu-Torque cotton yarns were chosen for mass production of the patients' bedding and clothing fabric prototypes.

It should be noted that Fabric Samples No. 1 and 11 were suggested to be the most suitable fabric as assessed by the indexing method for the patients' bedding and clothing respectively. Like the highest index, the project team and professional medical personnel also chose the same fabrics for the patients' bedding and clothing. It might be due to the user-orientated approach for selecting the patients' bedding and clothing.

5.5 Anti-bacterial finishing methods

Based on the literature review, diseases and infections could be transmitted through the patients' bedding and clothing in hospitals. In order to achieve the anti-bacterial property, anti-bacterial finishing was applied by padding onto the fabric. The fibre composition of the fabric also influenced the anti-bacterial property. Since the professional medical personnel from the DDU had selected the suitable fabric for the patients' clothing, 2/1 twill weft backed fabrics with the weft Coolmax yarns and Nu-Torque cotton yarns (71.6% cotton and 28.4% polyester) were used in the following trials.

Triclosan and silver ion are widely used as anti-bacterial agents for textiles while chitosan is commonly applied in the bio-medical sectors. Hence, Microfresh Liquid Formulation 9200-200, Silpure FBR-5 and N-100 containing triclosan, silver ion and chitosan respectively were used in this study to obtain anti-bacterial property. Microfresh Liquid Formulation 9200-200 was obtained from the Dystar, Germany while Silpure FBR-5 was bought from the Huntsman, Germany. In addition, N-100 was developed and provided by Prof. John Xin's research team from the ITC, The Hong Kong Polytechnic University.

The anti-bacterial chemicals were padded onto the fabrics using the Rapid vertical padder with the pressure of 2.6 kg/m^2 and padding speed of 2.5 rpm to achieve the required pick-up weight. The fabric padded with Silpure FBR-5 was then dried and cured in the Mathis curing machine at the required temperature and duration while the fabric padded with Microfresh Liquid Formulation 9200-200 and N-100 was dried after padding. The amount of chemicals and finishing conditions were prepared in accordance with the requirements listed in Table 5.24.

The anti-bacterial finishing trials and also the fabric with weft blended cotton/chitosan yarns were evaluated by the anti-bacterial activity assessment of textile materials, i.e. parallel streak method and an assessment of anti-bacterial finishes on textile material.

Table 5.24 Experimental design of anti-bacterial finishing

Trials	Chemicals	Pick-up	Drying Temperature	Drying Duration	Curing Temperature	Curing Duration	Fabric	Number of Washing Cycles
Microfresh Liquid Formulation 9200-200								
Preliminary	Microfresh Liquid Formulation 9200-200: 2.5g/L Microban R10800-0: 5 g/L Acetic Acid: 0.9 ml/L	80%	--	--	145℃	120s	100% cotton plain weave	0
1	Microfresh Liquid Formulation 9200-200: 2.5g/L Microban R10800-0: 5 g/L Acetic Acid: 0.9 ml/L	80%	--	--	145℃	120s	71.6% cotton, 28.4% polyester 2/1 twill weft backed	50
2	Microfresh Liquid Formulation 9200-200: 3.75 g/L Microban R10800-0: 7.5 g/L Acetic Acid: 1 ml/L	80%	--	--	145℃	120s	71.6% cotton, 28.4% polyester 2/1 twill weft backed	50

Table 5.24 Experimental design of anti-bacterial finishing (cont'd)

Trials	Chemicals	Pick-up	Drying Temperature	Drying Duration	Curing Temperature	Curing Duration	Fabric	Number of Washing Cycles
Silpure FBR-5								
3	Silpure FBR-5: 30 g/L	80%	110℃	150s	165℃	60s	71.6% cotton, 28.4% polyester 2/1 twill weft backed	50
N-100								
4	N-100 : 80g/L	80%	--	--	165℃	90s	71.6% cotton, 28.4% polyester 2/1 twill weft backed	0
5	N-100 : 80g/L	80%	--	--	165℃	90s	71.6% cotton, 28.4% polyester 2/1 twill weft backed	30

Table 5.24 Experimental design of anti-bacterial finishing (cont'd)

Trials	Chemicals	Pick-up	Drying Temperature	Drying Duration	Curing Temperature	Curing Duration	Fabric	Number of Washing Cycles
N-100								
6	N-100 : 80g/L COT-B: 10g/L	80%	--	--	165℃	90s	71.6% cotton, 28.4% polyester 2/1 twill weft backed	50
7	N-100 : 100g /L	80%	--	--	165℃	90s	71.6% cotton, 28.4% polyester 2/1 twill weft backed	0
8	N-100 : 100g /L	80%	--	--	165℃	90s	71.6% cotton, 28.4% polyester 2/1 twill weft backed	50

5.5.1 Anti-bacterial property

The anti-bacterial property of fabrics was evaluated by the anti-bacterial activity assessment of textile materials, i.e. parallel streak method (AATCC TM 147: 2004) and assessment of anti-bacterial finishes on textile material (AATCC TM 100: 2004) conducted by the SGS Hong Kong Ltd. The AATCC TM 147 is a qualitative test while the AATCC TM 100 is a quantitative test. The results of the AATCC TM 147 showed the presence of clear zone and bacterial growth underneath the tested sample. However, the results of AATCC TM 100 showed the percentage reduction of bacterial growth. The anti-bacterial property of the fabrics could inhibit the bacterial growth which was important to the patients' bedding and clothing as far as the hospital environment was concerned.

Staphyloccocus aureus ATCC 6538 and *Klebsiella pneumonia* ATCC 4352 were selected as the bacterial test strain for both anti-bacterial tests according to the advice of the consultant paediatrician of the DDU. These bacteria are commonly found in the hospital environment.

5.5.2 Anti-bacterial activity assessment of textile materials: parallel streak method (AATCC TM 147: 2004)

Since the AATCC TM 147 is a qualitative test method, it is useful to act as a preliminary test for anti-bacterial property. In order to evaluate the anti-bacterial property of the blended cotton/chitosan yarn used in the weft assembly for Fabric Sample No. 2, a 100% blended cotton/chitosan yarn knitted fabric was tested by the AATCC TM 147. On the other hand, another preliminary test was conducted on the 100% cotton plain fabric padded with Microfresh Liquid Formulation 9200-200 to evaluate effect of the anti-bacterial property of this chemical on the cotton fabric. Table 5.25 summarizes the test results of the anti-bacterial property of the 100% blended cotton/chitosan yarn knitted fabric and the anti-bacterial finishing preliminary trial. It is clear that the 100% blended cotton/chitosan yarn knitted fabric did not render anti-bacterial property while the anti-bacterial finishing preliminary trial rendered the anti-bacterial property. The anti-bacterial test result of the 100% blended cotton/chitosan yarn knitted fabric suggested that Fabric Sample No. 2 would not render the anti-bacterial property as the anti-bacterial property depended mainly on the amount of chitin.

Table 5.25 Preliminary test results of anti-bacterial activity assessment of textile materials: parallel streak method

Fabrics	Bacterial Growth for *Staphylococcus aureus* (ATCC 6538)	Bacterial Growth for *Klebsiella pneumoniae* (ATCC 4352)
36.9 tex/1 100% blended cotton/chitosan yarn (88% cotton, 12 % chitin) knitted fabric	Yes	Yes
Anti-bacterial finishing preliminary trial	No	No

5.5.3 Assessment of anti-bacterial finishes on textile material (AATCC TM 100: 2004)

The AATCC TM 100 is a quantitative test method showing the level of bacterial reduction which helps design the anti-bacterial recipe. The durability of the anti-bacterial property should also be considered because the patients' bedding and clothing are laundered after use. The number of washing cycles was used to determine the level of suitability of the fabrics treated with the anti-bacterial finishing. The washing procedure was conducted according to the AATCC TM 61-2003 Test No. 2A before conducting the AATCC TM 100: 2004. The recipe and finishing conditions of the anti-bacterial trials were discussed in

Table 5.24 of Section 5.5.

As discussed in the previous sub-section, the anti-bacterial finishing preliminary trial did show the anti-bacterial property. Hence, the anti-bacterial finishing trial No. 1 was designed to examine the anti-bacterial property of Microfresh Liquid Formulation 9200-200 using the same finishing conditions and recipe but with different fabric content and weave structure. The anti-bacterial test results of the AATCC TM 100 are presented in Table 5.26.

Table 5.26 Test results of Assessment of anti-bacterial finishes on textile material

Anti-bacterial Finishing Trial Number	Number of Washing Cycles	Bacterial Reduction for *Staphylococcus aureus* (ATCC 6538)	Bacterial Reduction for *Klebsiella pneumonia* (ATCC 4352)
1	50	68.39%	89.12%
2	50	93.13%	74.33%
3	50	0%	0%
4	0	94.24%	97.27%
5	30	0%	0%
6	50	0%	0%
7	0	99.86%	99.41%
8	50	0%	0%

Table 5.26 indicates that the bacterial reduction of *Staphylococcus aureus* ATCC 6538 and *Klebsiella pneumonia* ATCC 4352 was 68.39% and 89.12% respectively after 50 washing cycles. The result suggested that the anti-bacterial finishing trial No. 1 could withstand 50 washing cycles. The concentrations of the Microfresh Liquid Formulation 9200-200, Microban R10800-0 and acetic acid were increased to formulate anti-bacterial finishing trial No. 2 in order to achieve a better bacterial reduction. The bacterial reduction of *Staphylococcus aureus* ATCC 6538 in the anti-bacterial finishing trial No. 2 was significantly

higher than trial No. 1 but the bacterial reduction of *Klebsiella pneumonia* ATCC 4352 was somewhat lower than trial No. 1.

The anti-bacterial finishing trial No. 3 was laundered for 50 washing cycles before undergoing the AATCC TM 100 as the durability of Silpure FBR-5 claimed to be 50 washing cycles. Hence, the anti-bacterial finishing trial No. 3 was conducted according to the recipe provided by the supplier. However, the fabric did not indicate the efficacy of anti-bacterial activity as the bacterial reduction of *Staphylococcus aureus* ATCC 6538 and *Klebsiella pneumonia* ATCC 4352 was 0%.

The results of the bacterial reduction of *Staphylococcus aureus* ATCC 6538 and *Klebsiella pneumonia* ATCC 4352 were 94.24% and 97.27% which showed the efficacy of anti-bacterial activity when the anti-bacterial finishing trial No. 4 was tested without laundering. The anti-bacterial finishing trial No. 5 was tested after 30 washing cycles to determine its durability for laundering. However, the results showed 0% bacterial reduction for both types of bacteria and did not indicate any anti-bacterial property. The recipe of the anti-bacterial finishing trial No. 6 was then adjusted based on the recipe of the anti-bacterial finishing No. 4. The findings of the bacterial reduction after 50 washing cycles for both types of bacteria were 0% even though there was a binder COT-B in the trial No. 6. It seemed that the binder did not enhance the durability of the anti-bacterial property of N-100. The concentration of N-100 was then increased in the trial No. 7 when compared with the concentration of the trial No. 4. Obviously, the bacterial reduction of *Staphylococcus aureus* ATCC 6538 and *Klebsiella pneumonia* ATCC 4352 in the trial No. 7 rose gradually to 99.86% and 99.41% respectively when the fabric was not laundered. The trial No. 8 was washed after 50 washing cycles and then tested by the AATCC TM 100 again. However, the findings indicated that the fabric did not render any anti-bacterial property.

It was found that the anti-bacterial finishing trial No. 2 demonstrated the best anti-bacterial property among all the trials after subjecting to 50 washing cycles. Hence, the anti-bacterial trial No. 2 was adopted as the application of the anti-bacterial finishing method for the selected fabrics used for the patients' bedding and clothing.

5.6 Conclusion

The stages covering the "Development of ideas and technical solution" and "Evaluation, modification and selection of prototype" of the product development process were employed for the fabric development and evaluation. Sixteen different woven fabrics were produced by different combinations of weft yarns such as Coolmax yarn, Thermolite yarn, Nu-Torque cotton yarn, Murata vortex spun cotton yarn, twistless cotton yarn, Lycra yarn and blended cotton/chitosan yarn with different weave structures namely 2/2 twill, plain and 2/1 twill weft backed fabrics. The objective measurement was designed based on the requirements of the patients' bedding and clothing including comfort, moisture management property, safety, durability and anti-bacterial property. The questionnaire survey was contributed to the professional medical personnel to study the importance and influence of the fabric attributes on the performance of the patients' bedding and clothing. The weighting of each fabric attribute was calculated based on the survey results. It was found that the fabric attributes with the highest weighting were fabric strength and handle of the bedding and clothing respectively. The indexing method was adopted to evaluate the most suitable fabrics used for the patients' bedding and clothing by combining both the objective and subjective measurements. The results showed that Fabric Samples No. 1 and 11 were the most suitable fabrics used for the bedding and clothing respectively. Finally, the professional medical personnel selected the 2/2 twill fabric with the weft Nu-Torque cotton yarns and 2/1 twill weft backed fabric with the weft Coolmax yarns and Nu-Torque cotton yarns for the mass production of the patients' bedding and clothing fabric prototypes. The anti-bacterial finishing trials using triclosan, chitosan and silver ion were evaluated by the anti-bacterial tests and then modified to achieve the anti-bacterial property. The anti-bacterial finishing trial No. 2 was chosen and applied to the selected fabrics for the mass production of the patients' bedding and clothing.

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Chapter 6 Evaluation of the Performance of the Newly Developed Functional Fabrics for Patients' Bedding and Clothing

6.1 Introduction

The fabric materials suitable for making the child patients' bedding and clothing in terms of comfort, moisture management property, safety, durability and anti-bacterial property were selected and discussed in Chapter 5. The prototype fabrics used for making the patients' bedding and clothing were initially developed for mass production, and then evaluated and compared with the current hospital patients' bedding and clothing in this chapter. The laboratory tests and user trial as well as skin temperature measurements and a set of questionnaire survey in the Developmental Disabilities Unit (DDU) of Caritas Medical Centre were conducted to evaluate the performance of the new fabrics by comparing with the current ones. These newly developed prototypes used for making the patients' bedding and clothing were evaluated objectively and subjectively to achieve the final stage, i.e. "Evaluation of the final solution in relation to the objectives", of the product development process as shown in Figure 6.1.

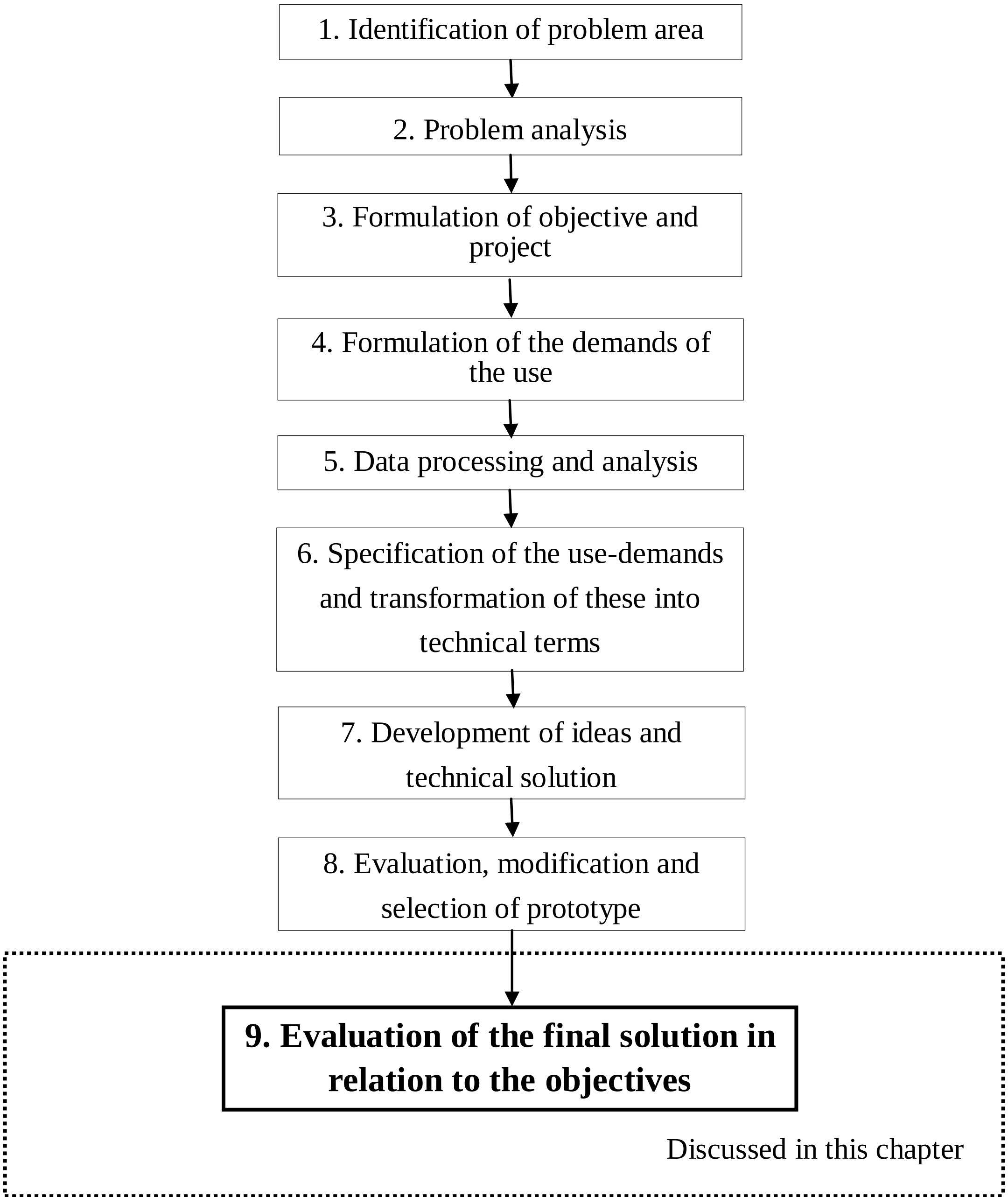

Figure 6.1 Stage 9 of the product development process

6.2 Prototypes of new patients' bedding and clothing

The fabrics suitable for making the child patients' bedding and clothing were selected by the professional medical personnel of hospital and the project team from the sixteen different fabric samples as described previously in Chapter

5. The anti-bacterial finishing method was applied to the new patients' bedding and clothing based on the selected recipe of Microfresh Liquid Formulation 9200-200. A fabric manufacturer was appointed for fabric production and a garment manufacturer was chosen for garment and bedding making-up so as to assure the industrial quality of production. The specifications of the selected fabrics produced and used for the new patients' bedding and clothing are illustrated in Table 6.1.

Table 6.1 Specifications of the new patients' bedding and clothing

	New Patients' Bedding Fabric	New Patients' Clothing Fabric
Fibre Content	100% cotton	71.6% cotton, 28.4% polyester
Fabric Weight	193.7 g/m^2	194.5 g/m^2
Weave Structure	2/2 twill	2/1 twill weft backed
Thread Density	26 ends/ cm 24 picks/ cm	29 ends/ cm 27 picks/ cm

The thread density and the fabric weight of the new patients' bedding are different from the selected fabric for the patients' bedding with a weight 204 g/m^2 and a thread density of 29 ends/ cm and 26 picks/ cm. This might be due to the variation of machines in mass production for finishing processes such as bleaching and scouring.

The style of the newly developed patients' bedding and clothing prototypes was the same as the current hospital patients' bedding and clothing. However, the pattern of the garment was re-engineered, so that the seams would be placed from the underside of the body of the patients so as not to abrade the patient's skin as they laid almost permanently in bed. The current hospital patients' clothing consisted of top and pants. Sixteen pieces of bedding and clothing were produced for the user trial in the DDU, Caritas Medical Centre. The size of the clothing included S, M and L according to the sizing system of the current hospital patients' clothing. The measurement charts of the size of the clothing are attached in Appendix F. The fabric of the new patients' bedding and the newly developed patients' clothing are shown in Figures 6.2 and 6.3 respectively. The fabric swatches of the new patients' bedding and clothing are attached in Appendix D.

Figure 6.2 Fabric of the new patients' bedding

Figure 6.3 Prototype of the newly developed patients' clothing

6.3 Comparison of experimental test results

As discussed in Chapter 4, the fabrics used for the patients' bedding and clothing should be comfortable, durable and safe with a good moisture management property and anti-bacterial property. A specification of standard requirements used for the child patients' bedding was generated with reference to (1) DD ENV 14237:2002 "textiles in healthcare system", (2) ASTM D 4037-02 (2008) "standard performance specification for woven, knitted or flocked bedspread fabrics", and (3) ASTM D 5431-08 "standard performance specification for woven and knitted sheeting products for institutional and household use". A specification of standard requirements used for the child patients' clothing was generated with reference to (1) DD ENV 14237:2002 "textiles in healthcare system" and (2) ASTM D 3819-02 "standard performance specification for men's and boys' woven pyjama fabrics". Tables 6.2 and 6.3 show the standard requirements and test methods of the International, European and US Standards for the patients' bedding and clothing.

Table 6.2 Specification of standard requirements for patients' bedding

Properties	Requirements	International Standards	Standard Test Methods
Tearing Strength	6.7 N minimum	ASTM D 4037-02 (2008)	ASTM D 1424-09
Tensile Strength	Warp: $\geq$ 400 N Weft: $\geq$ 400 N	DD ENV 14237:2002	EN ISO 13934-1:1999
Flammability	Class 1	ASTM D 5431-08	ASTM D 1230-94 (2001)
Dimensional Stability	Warp: $\pm$ 5 % Weft: $\pm$ 5 %	DD ENV 14237:2002	EN 25077:1994

Table 6.3 Specification of standard requirement for patients' clothing

Properties	Requirements	International Standards	Standard Test Methods
Tearing Strength	6.7 N minimum	ASTM D 3819-02	ASTM D 1424-09
Tensile Strength	Warp: ≥ 350 N Weft: ≥ 350 N	DD ENV 14237:2002	EN ISO 13934-1:1999
Flammability	Class 1	ASTM D 3819-02	ASTM D 1230-94 (2001)
Dimensional Stability	Warp: ± 3 % Weft: ± 3 %	DD ENV 14237:2002	EN 25077:1994

In order to confirm the suitability of the fabrics used for making the new patients' bedding and clothing objectively, an extensive series of experimental tests were conducted. Their properties were compared with the current hospital patients' bedding and clothing based on specifications of standard requirement mentioned in Tables 6.2 and 6.3 as well as Table 5.4 Categorization of objective experiments for assessment of the patients' bedding and clothing was mentioned in Section 5.3.1 of Chapter 5. The experimental tests required for the new and current patients' bedding and clothing are illustrated in Table 6.4.

Table 6.4 Experimental tests required for the new and current hospital patients' bedding and clothing

	Patients' Bedding	Patients' Clothing
(1) Comfort	● Compression test (KES-FB-3) ● Bending test (KES-FB-2) ● Surface test (KES-FB-4) ● Air permeability (ISO 9237:1995)	● Compression test (KES-FB-3) ● Bending test (KES-FB-2) ● Surface test (KES-FB-4) ● Shear test (KES-FB-1) ● Thermal resistance (ASTM D 1518-85 (2003)) ● Air permeability (ISO 9237:1995)
(2) Moisture Management Property	● Water vapour permeability test (BS 7209:1990) ● Wickability test ● Absorbency test (AATCC TM 79-2007)	● Water vapour permeability test (BS 7209:1990) ● Wickability test ● Absorbency test (AATCC TM 79-2007)
(3) Safety	● Flammability test (ASTM D 1230-94 (2001))	● Flammability test (ASTM D 1230-94 (2001))
(4) Durability	● Abrasion resistance test (ASTM D 4966-98 (2007)) ● Dimensional stability test (EN 25077:1994) ● Tearing strength test (ASTM D1424-09) ● Tensile strength test (EN ISO 13934-1)	● Abrasion resistance test (ASTM D 4966-98 (2007)) ● Dimensional stability test (EN 25077:1994) ● Tearing strength test (ASTM D1424-09) ● Tensile strength test (EN ISO 13934-1)

The pilling propensity test was replaced by the abrasion resistance test as required by the consultant paediatrician of the DDU. The reason of selecting the abrasion resistance test was due to the fact that the medical staff discarded the hospital patients' bedding and clothing when the fabrics were ruptured. Hence, the end point method was adopted for evaluation. The number of movements required to break two or more yarns in the fabrics were recorded for the comparison purpose. The fabric samples were washed at 40 ℃ according to the AATCC TM 135 as the preliminary dimensional stability test for the fabric selection. It was observed that the laundry section of CMC used the European washing machines at 70 ℃ for washing. After a careful consideration, 90 ℃ washing temperature and European standard (EN 25077) was finally selected for laundering. The dimensional stability test of EN 25077:1994 was conducted by the SGS Hong Kong Ltd due to the extremely high temperature washing.

6.3.1Comparison of compression test (KES-FB-3) of patients' bedding and clothing

As discussed in Section 5.3.1.1 of Chapter 5, the Kawabata Evaluation System for Fabrics (KES-FB-3) was used to measure the compression property. The results of compression property of the new patients' bedding and clothing as well as the current ones are presented in Table 6.5.

Table 6.5 Compression property of patients' bedding and clothing

Patients' Bedding		
Compression Property	New Patients' Bedding	Current Patients' Bedding
Compressional Energy, WC (g.cm /cm^2)	0.200	0.160
Compressional Resilience, RC (%)	42.80	38.61
Thickness (mm)	0.618	0.414
Patients' Clothing		
Compression Property	New Patients' Clothing	Current Patients' Clothing
Compressional Energy, WC (g.cm /cm^2)	0.237	0.193
Compressional Resilience, RC (%)	40.78	39.29
Thickness (mm)	0.463	0.918

The compression energy and the compression resilience of both the new patients' bedding and the new patients' clothing were higher than the current ones. This meant that the patients would feel more comfortable when they wore the new patients' clothing and lying in the new patients' bedding because of the improved softness. The new patients' bedding was thicker than the current patients' bedding but the new patients' clothing was thinner than the current patients' clothing. The thickness was important to the end use of the patients' bedding and clothing because it might influence the handle, thermal resistance, air permeability, water vapour permeability and strength. Furthermore, the fabric thickness might also affect the ease of handling such as the laundering and drying processes as well as the transportation. Thin fabrics would be preferable for handling issues.

6.3.2 Comparison of bending test (KES-FB-2) of patients' bedding and clothing

The bending property of the fabric was tested by using the Kawabata Evaluation System for Fabrics (KES-FB-2). Table 6.6 illustrates the bending rigidity of the new patients' bedding and the new patients' clothing as well as the current ones. It was obvious that the values of bending rigidity of the new patients' bedding and clothing were higher than the current ones.

Table 6.6 Bending property of patients' bedding and clothing

Patients' Bedding		
Bending Rigidity, B (gf cm^2/ cm)	New Patients' Bedding	Current Patients' Bedding
Warp	0.126	0.064
Weft	0.075	0.039
Mean	0.101	0.052
Patients' Clothing		
Bending Rigidity, B (gf cm^2/ cm)	New Patients' Clothing	Current Patients' Clothing
Warp	0.152	0.080
Weft	0.076	0.058
Mean	0.114	0.069

6.3.3 Comparison of surface test (KES-FB-4) of patients' bedding and clothing

The surface test was performed by using the KES-FB-4 surface tester. The values of coefficient of friction (MIU) and geometrical roughness (SMD) are shown in Table 6.7. The MIU values of the new patients' bedding and clothing were almost similar to the current fabrics. However, the values of SMD of the new patients' bedding and clothing were much lower than the current ones. This confirmed that the fabrics used for the new patients' bedding and clothing were smoother than the current fabrics. In the case of patients' clothing, the smooth surface of the clothing fabric was preferred because the tender skin of patients might get hurt when rubbing with the clothing, especially those patients with spasticity. On the other hand, their limbs might also rub with the fabric of bedding. Therefore, the bedding with a smooth surface was more desirable and suitable for the patients.

Table 6.7 Surface property of patients' bedding and clothing

Patients' Bedding			
Surface Property		New Patients' Bedding	Current Patients' Bedding
Coefficient of Friction, MIU	Warp	0.189	0.169
	Weft	0.188	0.176
	Mean	0.188	0.173
Geometrical Roughness, SMD (μm)	Warp	3.27	5.73
	Weft	3.85	2.74
	Mean	3.56	4.24
Patients' Clothing			
Surface Property		New Patients' Clothing	Current Patients' Clothing
Coefficient of Friction, MIU	Warp	0.190	0.189
	Weft	0.179	0.204
	Mean	0.184	0.196
Geometrical Roughness, SMD (μm)	Warp	4.62	2.44
	Weft	2.65	5.79
	Mean	3.63	4.11

6.3.4 Comparison of shear test (KES-FB-1) of patients' clothing

The KES-FB-1 shear tester was used for measuring the shear rigidity of the fabrics. Table 6.8 summarizes the shear rigidity values of the new patients' clothing and the current patients' clothing. The fabrics with firm handle might be due to high shear rigidity but the fabrics with low shear rigidity would result in good draping characteristics and the ease of movement for clothing. The new patients' clothing exhibited a slightly higher shear rigidity than the current patients' clothing. However, the matter of draping and difficulties in movement were not seen as the main problem for the new patients' clothing prototype during the user trial.

Table 6.8 Shear property of patients' clothing

Patients' clothing		
Shear Rigidity, G (g/cm.deg)	New Patients' Clothing	Current Patients' Clothing
Warp	1.01	0.76
Weft	0.84	0.79
Mean	0.92	0.77

6.3.5 Comparison of thermal resistance test (ASTM D 1518-85 (2003)) of patients' clothing

The thermal resistance of the patients' clothing was measured by the SDL warmth retaining tester. The function of the clothing is to keep the body warm. Hence, the thermal resistance is an important property to indicate the warmth keeping capacity. Furthermore, the paraplegic and quadriplegic patients with a limited mobility usually spend much of their time in bed. Hence, their clothing should provide a better thermal insulation. Table 6.9 reveals that the clo values of both the new and the current patients' clothing were almost the same and slightly higher than 1 clo. The new patients' clothing was considered to be suitable and satisfactory based on the measurement results [1, 2].

Table 6.9 Thermal resistance of patients' clothing

Patients' clothing		
	New Patients' Clothing	Current Patients' Clothing
Thermal Resistance (clo)	1.085	1.108

6.3.6 Comparison of air permeability test (ISO 9237:1995) of patients' bedding and clothing

The SDL air permeability tester was used to measure the air permeability of fabrics. Air permeability is a critical property of the clothing because the fabrics with a high air permeability will allow the insensible perspiration to pass through the fabrics from the body. In contrast, the fabrics with low air permeability can minimize the heat loss of the patients caused by convection. The air-conditioned hospital environment may produce a lot of air currents. On the other hand, the insensible perspiration may happen at the patients' limbs when they lie in bed. Hence, the fabrics with some air permeability are preferred to use for making the patients' clothing and bedding so as to allow the insensible perspiration.

The results shown in Table 6.10 indicated that the air permeability of the current patients' bedding was considerably higher than the new bedding due to thinner and looser weave structure. However, there was a deterioration of the abrasion resistance, dimensional stability, tearing strength and tensile strength of the current patients' bedding. Furthermore, the requirement of dramatically high air permeability of the bedding was less critical for the ease of the removal insensible perspiration. The new bedding was considered to be suitable for the patients. Since the air permeability of the new patients' clothing was slightly higher than the current one, the new clothing was confirmed to be suitable for the patients.

Table 6.10 Air permeability of patients' bedding and clothing

Patients' Bedding		
	New Patients' Bedding	Current Patients' Bedding
Air Permeability ($cc/s/cm^2$ at 100Pa)	32.66	51.20
Patients' Clothing		
	New Patients' Clothing	Current Patients' Clothing
Air Permeability ($cc/s/cm^2$ at 100Pa)	22.52	21.94

6.3.7 Comparison of water vapour permeability test (BS 7209:1990) of patients' bedding and clothing

The turntable was used to determine the water vapour permeability index. The water vapour permeability property is critical to the paraplegic and quadriplegic patients because they may sweat heavily. A fabric used for the patients' bedding or clothing with a high water vapour permeability index can allow water vapour to pass through it easily. Therefore, the patients' body or limbs will not feel uncomfortable.

According to Table 6.11, the new patients' bedding and clothing were considered to be suitable for the patients as they both demonstrated an index of greater than 100% when compared with the dish covered with the standard fabric. The water vapour permeability property of the new patients' clothing was also improved when compared with the current patients' clothing.

Table 6.11 Water vapour permeability index of patients' bedding and clothing

Patients' Bedding		
	New Patients' Bedding	Current Patients' Bedding
Water Vapour Permeability Index (%)	100.16	102.14
Patients' Clothing		
	New Patients' Clothing	Current Patients' Clothing
Water Vapour Permeability Index (%)	101.26	99.93

6.3.8 Comparison of wickability test of patients' bedding and clothing

The test method of wickability was described in Section 5.3.1.8 of Chapter 5. The fabrics were tested in the initial stage without washing. Since the current patients' clothing did not absorb water in the initial stage, one washing cycle was conducted to eliminate the effects of impurities or residue of finishing chemicals. The washing cycle was conducted in accordance with the AATCC TM 135-2004 by using the Whirlpool washing machine and the Whirlpool tumble dryer.

The findings shown in Table 6.12 summarize the wickability of fabrics. It should be noted that the current patients' clothing did not absorb water unless it was washed. This might be due to the impurities or residue of chemicals generated from the finishing processes. The results of after-wash wickability of all fabrics were improved when compared with those in the initial stage. Both the new patients' bedding and clothing demonstrated almost twofold wicking height than the current ones. In general, the patients may sweat heavily and also wear napkins in ward. The clothing and the bedding fabrics commonly used can absorb sweat and urine quickly in case of urine leakage in order to prevent skin irritation if the fabrics demonstrate good wickability. Based on these conditions, the fabrics with good wickability are desirable for the paraplegic and quadriplegic patients' bedding and clothing. Therefore, both the new patients' bedding and clothing were considered to be more suitable for the patients according to above-mentioned end uses.

Table 6.12 Wickability of patients' bedding and clothing

Patients' Bedding			
In the Initial Stage		New Patients' Bedding	Current Patients' Bedding
Wicking Height in Warp (cm)	1min	4.4	1.9
	3 min	7.3	3.2
	5 min	9.1	4.2
Wicking Height in Weft (cm)	1min	4.3	1.9
	3 min	7.3	3.1
	5 min	9.1	3.9
After 1 Washing Cycle		New Patients' Bedding	Current Patients' Bedding
Wicking Height in Warp (cm)	1min	4.1	2.1
	3 min	6.9	3.0
	5 min	8.5	4.1
Wicking Height in Weft (cm)	1min	4.9	2.2
	3 min	8.0	3.3
	5 min	10.1	4.3
Patients' Clothing			
In the Initial Stage		New Patients' Clothing	Current Patients' Clothing
Wicking Height in Warp (cm)	1min	4.0	0
	3 min	6.6	0
	5 min	8.3	0
Wicking Height in Weft (cm)	1min	4.1	0
	3 min	6.5	0
	5 min	8.2	0
After 1 Washing Cycle		New Patients' Clothing	Current Patients' Clothing
Wicking Height in Warp (cm)	1min	4.9	2.3
	3 min	7.7	4.7
	5 min	9.8	6.4
Wicking Height in Weft (cm)	1min	5.0	1.7
	3 min	8.3	3.2
	5 min	10.2	5.1

6.3.9 Comparison of absorbency test (AATCC TM 79-2007) of patients' bedding and clothing

A burette was used to measure the water absorbency of fabrics. The shorter the wetting time, the quicker the water absorbed by the fabric will be. The wetting time is denoted with 60+ seconds when the wetting time is longer than sixty seconds. The fabrics were tested in the initial stage without washing according to the AATCC TM 79-2007. All the fabrics were tested again after wash to minimize the effects caused by the impurities or residue of chemicals generated from the finishing processes because the wetting time of the current patients' clothing was more than sixty seconds which was extremely long. The washing cycle was conducted in accordance with the AATCC TM 135-2004.

Table 6.13 provides a summary of the absorbency test results. The new patients' bedding and clothing absorbed water immediately with the wetting time of 4.2 seconds and 9.9 seconds for the patients' current bedding and clothing after wash. It was obvious that the absorbency of the new fabrics used for making the patients' bedding and clothing had been improved when compared with the current ones. A fabric with a faster wetting time should be more suitable for absorbing sweat or urine in order to achieve comfort.

Table 6.13 Absorbency of patients' bedding and clothing

Patients' Bedding		
Absorbency (s)	New Patients' Bedding	Current Patients' Bedding
In the Initial Stage	0.3	4.9
After 1 Washing Cycle	0	4.2
Patients' Clothing		
Absorbency (s)	New Patients' Clothing	Current Patients' Clothing
In the Initial Stage	0.4	60+
After 1 Washing Cycle	0	9.9

6.3.10 Comparison of flammability test (ASTM D 1230-94 (2001)) of patients' bedding and clothing

The flammability test was conducted by using the SDL flammability tester. It was essential to test the flammability before conducting the user trial because the fabrics used for the young patients' bedding and clothing should not ignite immediately for the sake of safety consideration. Both the new and the current patients' bedding and clothing did not ignite during the flammability test. They were classified as Class 1 materials as shown in Table 6.14. Therefore, all the fabrics being studied could fulfill the standard of the flammability test and were considered to be suitable for the patients' bedding and clothing.

Table 6.14 Flammability of patients' bedding and clothing

Patients' Bedding			
	New Patients' Bedding	Current Patients' Bedding	Requirement
Flammability	Class 1	Class 1	Class 1
Patients' Clothing			
	New Patients' Clothing	Current Patients' Clothing	Requirement
Flammability	Class 1	Class 1	Class 1

6.3.11 Comparison of abrasion resistance test (ASTM D 4966-98 (2007)) of patients' bedding and clothing

The SDL Martindale abrasion testing machine was used to determine the abrasion resistance of fabrics. The end point was recorded when two or more yarns of the tested fabric were broken. Abrasion resistance was an important characteristic of the patients' bedding and clothing because the bedding and clothing would only be replaced when they were broken. Table 6.15 shows that the number of movements of the new patients' bedding was significantly higher than the current patients' bedding. On the other hand, the number of movements of the new patients' clothing was also higher than the current patients' clothing. This meant that the new patients' bedding and clothing would be more durable during wear and were more suitable than the current ones.

Table 6.15 Abrasion resistance of patients' bedding and clothing

Patients' Bedding		
Abrasion Resistance	New Patients' Bedding	Current Patients' Bedding
Number of Movements	33500	13080
Patients' Clothing		
Abrasion Resistance	New Patients' Clothing	Current Patients' Clothing
Number of Movements	29000	27000

6.3.12 Comparison of dimensional stability test (EN 25077:1994) of patients' bedding and clothing

The dimensional stability of fabrics was evaluated by the EN 25077: 1994 Prior washing with three washing cycles according to programme 1A using the James H. Heal & Co. Ltd. washing machine. The drying process E was conducted by ISO 6330: 2000 using the Whirlpool tumble dryer. The aim of this test was to confirm whether the fabric concerned could withstand the laundering programme. The dimensional stability of the fabrics is shown in Table 6.16. The new patients' bedding demonstrated 0.4% growth in the warp direction but 3.6% shrinkage in the weft direction. On the other hand, the current patients' bedding exhibited 10.7% and 4.7% shrinkage in the warp and the weft directions respectively. The new patients' bedding fulfilled the requirement of the standard while the current patients' bedding failed to meet the requirement. Hence, the dimensional stability of the new patients' bedding was considered to be acceptable. The new patients' clothing exhibited 2.9% and 0.4% shrinkage in the warp and the weft directions. Similarly, the current patients' bedding had 5.1% shrinkage in the wrap direction but 0.1% growth in the weft direction. According to the standard requirement of the patients' clothing, the new patients' clothing fulfilled the requirement but the current patients' clothing failed to meet the requirement. Therefore, the dimensional stability of the new patients' clothing was considered to be acceptable.

Table 6.16 Dimensional stability of patients' bedding and clothing

Patients' Bedding			
Dimensional Stability	New Patients' Bedding	Current Patients' Bedding	Requirement
Warp	+0.4%	-10.7%	± 5 %
Weft	-3.6%	-4.7%	± 5 %
Patients' Clothing			
Dimensional Stability	New Patients' Clothing	Current Patients' Clothing	Requirement
Warp	-2.9%	-5.1%	± 3 %
Weft	-0.4%	+0.1%	± 3 %

6.3.13 Comparison of tearing strength test (ASTM D 1424-09) of patients' bedding and clothing

The tearing strength was evaluated by using the Elmatear, digital tear tester. The aim of the tearing test is to confirm the fabrics can withstand the tearing force during handle and use. It is necessary to conduct the tearing strength test before the user trial. If the tearing strength is low, the young patients can tear their bedding or clothing easily. Moreover, accidents may happen when they are wearing their clothing or lying in bed. High tearing strength is preferred to prevent this kind of accidents.

As shown in Table 6.17, the tearing strength of the new patients' bedding is almost threefold of the current patients' bedding. On the other hand, the new patients' clothing is also stronger than the current patients' clothing. Both of the new patients bedding and clothing not only meet the standard requirement but also improve the tearing strength compared with the current ones. Therefore, the new patients' bedding and clothing are considered to be suitable from the aspect of tearing strength.

Table 6.17 Tearing strength of patients' bedding and clothing

Patients' Bedding			
Tearing Strength	New Patients' Bedding	Current Patients' Bedding	Requirement
Warp (N)	34.3	9.1	$\geq$ 6.7
Weft (N)	25.8	8.5	$\geq$ 6.7
Patients' Clothing			
Tearing Strength	New Patients' Clothing	Current Patients' Clothing	Requirement
Warp (N)	57.8	48.7	$\geq$ 6.7
Weft (N)	60.7	34.9	$\geq$ 6.7

6.3.14 Comparison of tensile strength test (EN ISO 13934-1:1999) of patients' bedding and clothing

The Instron CRE machine was used to measure the tensile strength of fabrics. It was vital to confirm whether the fabric could withstand the stretching force before the user trial as the stretching force might be applied to the patients' clothing during dressing or undressing and also the bedding while changing. Furthermore, the patients might get hurt during dressing and undressing if the patients' clothing could not withstand sufficient strength. The results of the tensile strength are illustrated in Table 6.18. It was obvious that both the new patients' bedding and clothing met the standard requirement and were acceptable for their end use. They also had a better tensile strength when compared with the current ones. However, the current patients' bedding failed to meet the standard requirement.

Table 6.18 Tensile strength of patients' bedding and clothing

Patients' Bedding			
Tensile Strength	New Patients' Bedding	Current Patients' Bedding	Requirement
Warp (N)	600	330	≥ 400
Weft (N)	510	280	≥ 400
Patients' Clothing			
Tensile Strength	New Patients' Clothing	Current Patients' Clothing	Requirement
Warp (N)	760	740	≥ 350
Weft (N)	560	440	≥ 350

6.3.15 Summary of experimental test results

The experimental test results of the newly developed and the current patients' bedding and clothing are summarized in Tables 6.19 and 6.20 respectively. The results showed that the properties of the newly developed bedding fabric were improved in terms of compression properties, surface properties, wickability, absorbency, abrasion resistance, dimensional stability, tearing strength and tensile strength when compared with the current hospital patients' bedding.

On the other hand, the properties of the newly developed clothing fabric were also improved in terms of compression properties, surface properties, air permeability, water vapour permeability, wickability, absorbency, abrasion resistance, dimensional stability, tearing strength and tensile strength.

Table 6.19 Comparison of the new and current patients' bedding

Tests	New Patients' Bedding	Current Patients' Bedding	Standard Requirements / Remarks
Compression *WC (g.cm /cm^2)* *RC (%)*	*WC:* 0.200 *RC:* 42.80	*WC:* 0.160 *RC:* 38.61	The newly developed fabric improves softness The newly developed fabric improves softness
Thickness (mm)	0.618	0.414	The newly developed fabric is thicker but with better abrasion resistance, tearing strength and tensile strength
Bending (gf.cm^2/ cm)	0.101	0.052	The newly developed fabric has a higher rigidity as well as better tearing strength and tensile strength
Surface MIU SMD (μm)	*MIU:* 0.188 *SMD:* 3.56	*MIU:* 0.173 *SMD:* 4.24	The coefficient of friction of the newly developed fabric is almost the same as the current one The newly developed fabric has a smoother surface
Air Permeability (cc/s/cm^2 at 100Pa)	32.66	51.20	The newly developed fabric has a lower air permeability but with a better abrasion resistance, dimensional stability, tearing strength and tensile strength
Water Vapour Permeability Index (%)	100.16	102.14	Both the newly developed and current bedding fabric are higher than 100%
Wickability (cm)	*In the initial stage without washing:* 9.1 *After 1 washing cycle:* 9.3	*In the initial stage without washing:* 4.1 *After 1 washing cycle:* 4.2	The newly developed fabric absorbs sweat and urine more quickly Both fabrics improve wickability after washing. The newly developed fabric absorbs sweat and urine more quickly

Table 6.19 Comparison of the new and current patients' bedding (cont'd)

Tests	New Patients' Bedding		Current Patients' Bedding		Standard Requirements / Remarks	
Absorbency (s)	*In the initial stage without washing:* 0.3 *After 1 washing cycle:* 0		*In the initial stage without washing::* 4.9 *After 1 washing cycle:* 4.2		The wetting time of the newly developed fabric is faster. The new patients' bedding should be more suitable for sweat or urine absorption in order to achieve comfort Both fabrics improve the wetting time after washing. The wetting time of the newly developed fabric is faster. The new patients' bedding should be more suitable for sweat or urine absorption in order to achieve comfort	
Flammability	Class 1		Class 1		Standard requirement: Class 1	
Abrasion Resistance (Number of Movements)	33500		13080		The newly developed fabric is more abrasion resistant	
Dimensional Stability (%)	Warp	+0.4%	Warp	-10.7	Standard requirement: warp	± 5
	Weft	-3.6%	Weft	-4.7	Standard requirement: weft	± 5
Tearing Strength (N)	Warp	34.3	Warp	9.1	Standard requirement: warp	≥ 6.7
	Weft	25.8	Weft	8.5	Standard requirement: weft	≥ 6.7
Tensile Strength(N)	Warp	600	Warp	330	Standard requirement: warp	≥ 400
	Weft	510	Weft	280	Standard requirement: weft	≥ 400

Table 6.20 Comparison of the new and current patients' clothing

Tests	New Patients' Clothing	Current Patients' Clothing	Standard Requirements/ Remarks
Compression *WC (g.cm /cm^2)* *RC (%)*	<u>*WC:*</u> 0.237 <u>*RC:*</u> 40.78	<u>*WC:*</u> 0.193 <u>*RC:*</u> 39.29	The newly developed fabric improves softness The newly developed fabric improves softness
Thickness (mm)	0.463	0.918	The newly developed fabric is thinner resulting in the ease of handling such as the laundering and drying processes as well as the transportation
Bending (gf.cm^2/ cm)	0.114	0.069	The newly developed fabric has a higher rigidity as well as better tearing strength and tensile strength
Shear (g/cm.deg)	0.92	0.77	The shear rigidity of the newly developed fabric is higher but there is no problem of draping and difficulties in the movement of the wearers
Thermal Resistance (Clo)	1.085	1.108	The thermal resistance of the newly developed fabric is almost the same as the current one
Surface MIU SMD (μm)	<u>*MIU:*</u> 0.184 <u>*SMD:*</u> 3.63	<u>*MIU:*</u> 0.196 <u>*SMD:*</u> 4.11	The coefficient of friction of the newly developed fabric is almost the same as the current one The newly developed fabric has a smoother surface

Table 6.20 Comparison of the new and current patients' clothing (cont'd)

Tests	New Patients' Clothing	Current Patients' Clothing	Standard Requirements/ Remarks
Air Permeability ($cc/s/cm^2$ at 100Pa)	22.52	21.94	The newly developed fabric is more breathable
Water Vapour Permeability Index (%)	101.26	99.93	Both the newly developed and current bedding fabrics are higher than 100%
Wickability (cm)	*In the initial stage without washing:* 8.3 *After 1 washing cycle:* 10	*In the initial stage without washing:* 0 *After 1 washing cycle:* 5.8	The current fabric does not absorb water but the newly developed fabric absorbs water quickly The current fabric absorbs water after washing but slower than the newly developed fabric
Absorbency (s)	*In the initial stage without washing:* 0.4 *After 1 washing cycle:* 0	*In the initial stage without washing:* 60+ *After 1 washing cycle:* 9.9	The wetting time of the current fabric is longer than 60 seconds but the newly developed fabric absorbs water quickly The current fabric absorbs water after washing but the newly developed fabric absorbs water immediately
Flammability	Class 1	Class 1	Standard requirement: Class 1
Abrasion Resistance (Number of Movements)	29000	27000	The newly developed fabric is more abrasion- resistant

Table 6.20 Comparison of the new and current patients' clothing (cont'd)

Tests	New Patients' Clothing		Current Patients' Clothing		Standard Requirements/ Remarks	
Dimensional Stability (%)	Warp	-2.9	Warp	-5.1	Standard requirement: warp	± 3
	Weft	-0.4	Weft	+0.1	Standard requirement: weft	± 3
Tearing Strength (N)	Warp	57.8	Warp	48.7	Standard requirement: warp	≥ 6.7
	Weft	60.7	Weft	34.9	Standard requirement: weft	≥ 6.7
Tensile Strength(N)	Warp	760	Warp	740	Standard requirement: warp	≥ 350
	Weft	560	Weft	440	Standard requirement: weft	≥ 350

6.4 User trial in hospital

The newly developed patients' bedding and clothing prototypes were laundered in the laundering section of Caritas Medical Centre and then sent to the DDU of CMC, Hong Kong for the user trial with full support obtained from the professional medical personnel of the hospital and the consent of CMC and the Kowloon West Cluster Clinical Research Ethics Committee, HA. A total of eight child patients aged between 7 and 14 years old in the hospital ward were selected by the ward manager for the user trial with the consent of their guardians. The user trial was conducted using with the newly developed patients' bedding and clothing prototypes; and compared with the current hospital patients' bedding and clothing of the same patient on the alternate day.

6.4.1 Procedures of user trial

The procedures of the user trial of the newly developed prototypes of the patients' bedding and clothing were performed as follows:

1. A patient was dressed with a set of the newly developed patients' clothing prototype after bathing by the medical staff in the morning. The correct size of clothing worn by the patient was selected according to the actual size of the current hospital patients' clothing.
2. The patient's bedding was changed to the newly developed patients' bedding prototype. The patient was put on bed with the assistance of the medical staff. The user trial was lasted for 24 hours with two feeding intervals. The patient was evaluated and observed by two medical staff in order to ensure the safety during the user trial. Furthermore, the skin temperature of the patient was

measured by the medical staff using an infrared thermometer every hour. The humidity and room temperature were also recorded during the user trial.

3. The newly developed patients' bedding and clothing were taken off by the medical staff after the user trial.
4. The user trial was repeated by using the current hospital patients' bedding and clothing on the alternate day.

Figures 6.4 and 6.5 show the user trial of the current hospital patients' bedding and clothing, and the newly developed patients' bedding and clothing prototypes.

Figure 6.4 User trial of the current hospital patients' bedding and clothing

Figure 6.5 User trial of the newly developed patients' bedding and clothing prototypes

6.4.2 Evaluation of the newly developed patients' bedding and clothing prototypes

The skin temperature of each patient was measured during the user trial to evaluate the thermal insulation of the newly developed patients' bedding and clothing prototypes as well as the current ones objectively. Furthermore, a set of questionnaire was designed and distributed to the medical personnel in the DDU after the user trial aiming to evaluate and compare the performance and effectiveness of the newly developed patients' bedding and clothing prototypes with those of the current hospital patients' bedding and clothing.

Questionnaire about the comparison between the new prototypes and the current ones

The aim of the questionnaire was to evaluate and compare the performance of the newly developed patients' bedding and clothing prototypes with those of the current hospital patients' bedding and clothing in terms of comfort sensation and overall performance. The comfort sensation used for comparison included the quick dry property, breathability, improvement of prickliness, fineness, comfort, smoothness and softness. The overall performance was evaluated in the conclusion part. All the items evaluated in both the comfort sensation and the conclusion part were similar for both the patients' bedding and clothing except one item, i.e. the patients' clothing was assessed by the additional improvement of stickiness in the comfort sensation.

An 11-point scale was adopted for the questionnaire. The score assignment was designed from 5 to -5 where 0 represented the performance of the current patients' bedding or clothing. A positive score implied that the new prototype had improvement in a particular performance. The larger the positive score, the better the performance of the new prototype would be. In contrast, the negative scores implied that the new prototype was worse in a particular performance. The larger magnitude the negative score, the worse the performance of the new prototype would be. A total of thirty-seven medical personnel who had been involved in the user trial took part in the questionnaire survey. The questionnaire is attached in Appendix C.

Skin temperature measurements

The skin temperature was measured for each patient during the user trial according to the ISO 9886: 2004. Figure 6.6 shows the measuring points.

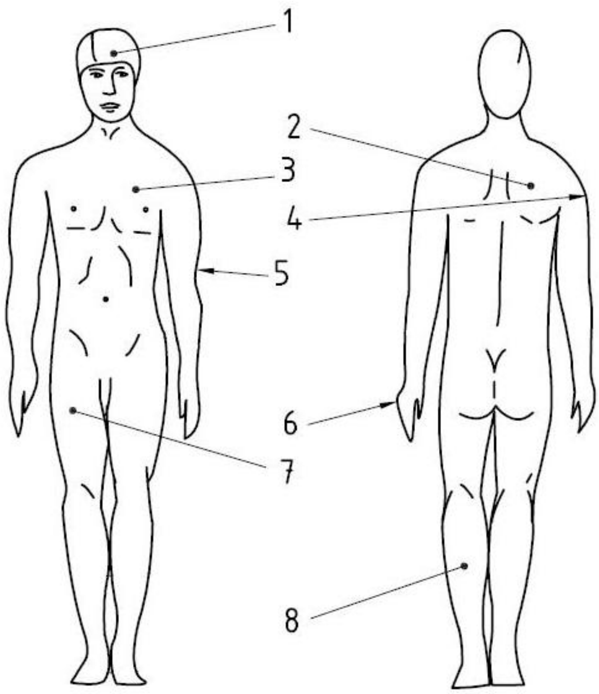

Figure 6.6 Measuring points for user trial
Source: ISO 9886: 2004

The skin temperature (t_{sk}) was calculated according to the following equation in accordance with the ISO 9886: 2004 :

$$t_{sk}=0.07t_1 + 0.175\,t_2 + 0.175\,t_3 + 0.07\,t_4 + 0.07\,t_5 + 0.05\,t_6 + 0.19\,t_7 + 0.2\,t_8 \quad (6.1)$$

Where t_{sk} is the skin temperature;

t_1 is the temperature at forehead;

t_2 is the temperature at right scapula;

t_3 is the temperature at left upper chest;

t_4 is the temperature at right arm in upper location;

t_5 is the temperature at left arm in lower location;

t_6 is the temperature at left hand;

t_7 is the temperature at right anterior thigh;

t_8 is the temperature at left calf.

6.4.2.1 Results and discussion

Questionnaire about the comparison between the new prototypes and the current ones

The questionnaire results of the comparison between the newly developed patients' bedding prototype and the current hospital patients' bedding are summarized in Figure 6.7. In addition, the questionnaire results of the comparison between the newly developed patients' clothing prototype and the current hospital patients' clothing are shown in Figure 6.8.

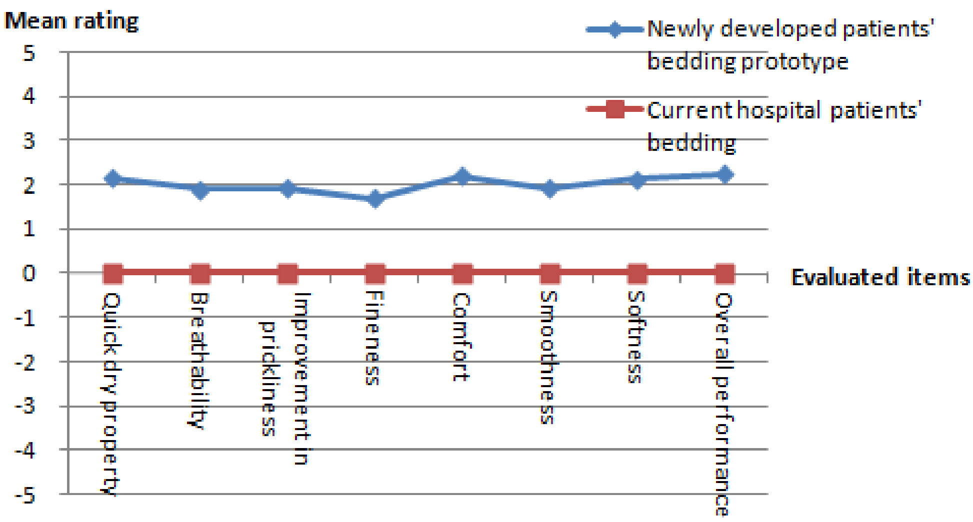

Figure 6.7 Questionnaire results of comparison between the newly developed patients' bedding prototyope and the current hosptital patients' bedding

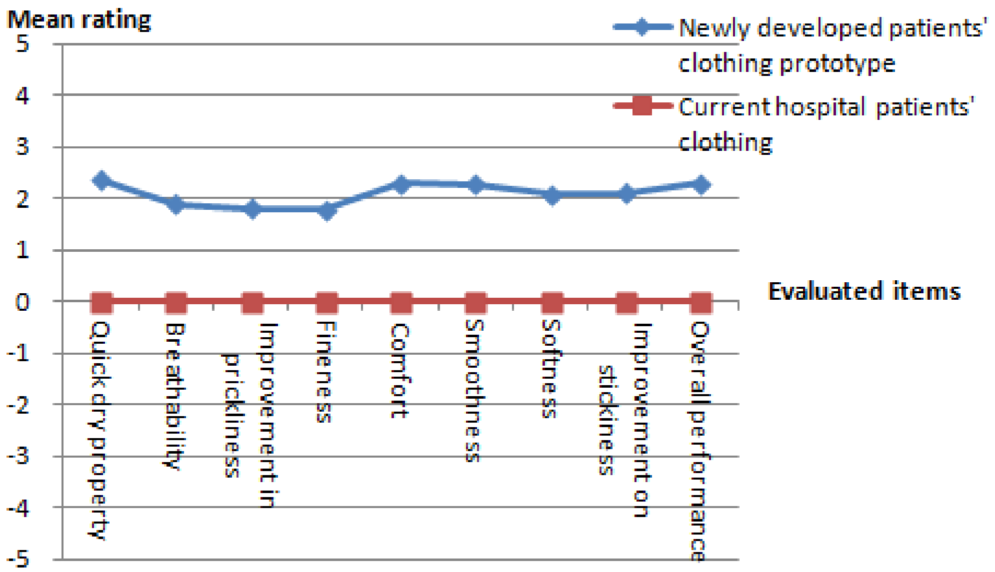

Figure 6.8 Questionnaire results of comparison between the newly developed patients' clothing prototype and the current hospital patients' clothing

In summary, the positive mean ratings of the newly developed patients' bedding prototype were not only obtained from the comfort sensation part such as the quick dry property with a mean score of 2.16, breathability with a mean score of 1.89, improvement in prickliness with a mean score of 1.92, fineness with a mean score of 1.70, comfort with a mean score of 2.19, smoothness with a mean score of 1.92 and softness with a mean score of 2.14 but also from the conclusion part in terms of overall performance with a mean score of 2.24.

Similar to the performance of the newly developed patients' bedding prototype, the positive mean ratings of the newly developed patients' clothing prototype were also obtained from both the comfort sensation and conclusion part in terms of the quick dry property with a mean score of 2.35, breathability with a mean score of 1.89, improvement on prickliness with a mean score of 1.81, fineness with a mean score of 1.78, comfort with a mean score of 2.30, smoothness with a mean score of 2.27, softness with a mean score of 2.08, improvement in stickiness with a mean score of 2.11 and the overall performance with a mean score of 2.30.

It was concluded that that the performance of both the newly developed patients' bedding and clothing prototypes were improved when compared with the current ones. The newly developed patients' bedding had improvement in the quick dry property, breathability, prickliness, fineness, comfort, smoothness, softness and the overall performance. On the other hand, the newly developed clothing prototype had improvement in the quick dry property, breathability, prickliness, fineness, comfort, smoothness, softness, stickiness and the overall performance.

Skin temperature measurements

The measurements of the skin temperature of eight patients during the user trial are listed in Table 6.21. Since the hospital environment was air-conditioned, the humidity and room temperature were recorded during the user trial. The average humidity and room temperature of the newly developed patients' bedding and clothing prototypes as well as the current hospital patients' bedding and clothing recorded were 35.89% RH (± 1.12%) and 21.88℃ (± 0.22℃), 35.97% RH (± 1.19%) and 21.80℃ (± 0.39℃) respectively. The details of the humidity and room temperature are shown in Appendix G. The average skin temperature of the eight patients using the newly developed patients' bedding and clothing prototypes and the current ones was virtually the same, i.e. 32.89℃. The skin temperature of each measuring point is demonstrated in Appendix H. Since 33℃ was the normal human skin temperature [3-5], both the newly developed patients' bedding and clothing prototypes as well as the current ones could be regarded as thermal comfortable to the patients. However, the standard deviation of the current hospital patients' bedding and clothing was almost twofold of the newly developed patients' bedding and clothing prototypes. This meant that the skin temperature of the patients using the newly developed patients' bedding and clothing prototypes was more consistent resulting in more comfort. In general, it is vital to keep the skin temperature consistent as the paraplegic and quadriplegic patients' skin is very tender.

Table 6.21 Measurements of skin temperature

	Skin Temperature (Mean ± SD, ℃)								
	Forehead	Right Scapula	Left Upper Chest	Right Arm in Upper Location	Left Arm in Lower Location	Left Hand	Right Anterior Thigh	Left Calf	Average
Newly Developed Patients' Bedding and Clothing Prototypes	33.39 ±0.37	34.89 ±0.39	33.99 ±0.28	33.08 ±0.42	32.59 ±0.56	32.39 ±0.77	31.88 ±0.47	31.14 ±0.61	32.89 ±0.31
Current Hospital Patients' Bedding and Clothing	33.11 ±0.36	34.59 ±0.38	33.88 ±0.31	33.00 ±0.64	32.49 ±0.67	31.50 ±1.23	31.88 ±0.65	31.85 ±1.18	32.89 ±0.58

6.5 Conclusion

The final stage of "Evaluation of the final solution in relation to the objectives" of the product development process was completed with the majority of acceptance of the performance of the newly developed bedding and clothing prototypes. The user trial of the newly developed patients' bedding and clothing prototypes were conducted in the DDU of CMC and their results obtained were compared with the current hospital patients' bedding and clothing. Before the user trial, both the newly developed patients' bedding and clothing fabrics and the current ones were evaluated by a series of experimental tests including the requirements of comfort, moisture management property, safety and durability for comparison. The experimental results indicated that the newly developed patients' bedding and clothing fabrics performed better than the current ones. According to the questionnaire survey, there was improvement of the newly developed patients' bedding and clothing prototypes when compared with the current ones. The skin temperature of the patients using the newly developed bedding and clothing prototypes in the user trial was more consistent than the current ones.

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Chapter 7 Conclusions and Suggestions for Future Research

7.1 Summary

The present study was conducted in a user-oriented approach in accordance with the product development process. The aim was to develop new textile materials such as the bedding and clothing for a specialized group of hospital patients who were paraplegic and quadriplegic patients in the paediatric hospital.

At the beginning of the research, literature studies about the care of the paraplegic and quadriplegic patients as well as comfort, anti-bacterial property and the recent development of functional yarns were reviewed in Chapter 2. All the information obtained was related to the latest development process of the child patients' bedding and clothing. Special care of the paraplegic and quadriplegic patients was studied comprehensively in order to understand more about the environments of rehabilitation as well as their special needs based on their physical conditions. This information could help formulate the requirements of the patients' bedding and clothing. Based on the preliminary investigation of the paraplegic and quadriplegic patients, some ideas and technical solutions were developed through the literature review of comfort, anti-bacterial property and the recent development of functional yarns.

The first step of the research was to establish the requirements of the patients' bedding and clothing. Some important factors such as the paediatric ward environment, the current hospital patients' bedding and clothing, the handling practice of the bedding and clothing, the child patients' characteristics and their daily activities were studied in details and observed through the hospital visits. These studies were fully supported by the professional medical personnel of the the Developmental Disabilities Unit (DDU) of Caritas Medical Centre (CMC). Questionnaire surveys were conducted to obtain the information of the importance of the child patients' characteristics on the desire of the bedding and clothing and the problems of the current hospital patients' bedding and clothing.

The next stage of the research concerned the design and development of new fabrics for the child patients' bedding and clothing. Totally sixteen different fabrics were developed through different yarn combinations and weave structures based on the beneficial functions of the yarns to meet the established requirements of the patients' bedding and clothing.

The next task of the research was to evaluate the performance of new fabrics by means of a series of experimental tests objectively. The experimental tests were designed based on the established requirements of the patients' bedding and clothing. The importance and influence of fabric attributes on the performance of the patients' bedding and clothing were highlighted by questionnaires. An indexing method was adopted by combining both objective and subjective measurements in order to examine the suitability of the new fabrics used for making the patients' bedding and clothing. Finally, the fabrics used for the patients' bedding and clothing were selected by the medical and nursing personnel of the DDU of CMC as well as the project team members. The newly developed prototypes of the patients' bedding and clothing were produced in accordance with the selected fabrics.

The next phase of the research was to achieve the anti-bacterial property by using the blended cotton/chitosan yarn and the application of anti-bacterial finishing. Firstly, some preliminary tests were conducted to examine the anti-bacterial property of the fabric made by the blended cotton/chitosan yarns and the efficacy of the anti-bacterial chemicals. The anti-bacterial chemicals were then padded onto the selected clothing material for the study of anti-bacterial property. A total of eight trials using different concentrations of anti-bacterial chemicals or binders were examined by the anti-bacterial tests. Some of the fabric samples underwent different washing cycles while the other fabric samples were not subjected to any washing cycles. The chemicals with the best anti-bacterial performance was selected and applied to the newly developed prototypes of the patients' bedding and clothing.

The final stage of the project was to evaluate the newly developed prototypes of the patients' bedding and clothing objectively and subjectively. The performance of the newly developed prototypes of the patients' bedding and clothing and the current ones was evaluated by the experimental tests, user trial as well as skin temperature measurements. The experimental tests were designed according to the established requirements of the patients' bedding and clothing. Questionnaire surveys used to evaluate the performance improvement of the newly developed prototypes were distributed to the medical personnel after the user trial.

7.2 Conclusions

In conclusion, the newly developed prototypes of the patients' bedding and clothing are able to satisfy the needs of the patients in terms of comfort, good moisture management property, anti-bacterial property, safety and durability to the paraplegic and quadriplegic patients in the paediatric hospital. Furthermore, the newly developed prototypes have been proved to have an overall improved performance as compared to the current hospital patients' bedding and clothing.

The conclusions based on the results generated from the research are summarized as follows;

1. Sweating, spasticity, eczema, tracheostomy, fragile skin and serious saliva are the patients' characteristics affecting the desire of the patients' bedding and clothing. The problems of the current patients' bedding are identified as quick dry property, breathability, un-prickle, fineness, comfort, smoothness, softness, launderability, abrasion resistance, strength and weight. On the other hand, the weaknesses of the current patients' clothing are non-stickiness, quick dry property, breathability, un-prickle, fineness, comfort, smoothness, softness, launderability, abrasion resistance, strength and weight. The results obtained from the present study are strongly useful for the development of patients' bedding and clothing in order to improve their performance.
2. The requirements of the development of the patients' bedding and clothing had been formulated including comfort, good moisture management property, anti-bacterial property, safety and durability.
3. Sixteen different fabrics had been designed and developed based on the established requirements of the patients' bedding and clothing. The results of questionnaire about the importance and influence of the fabric attributes on the performance of the patients' bedding and clothing indicated that the strength and handle of fabrics were the most important attributes of the patients' bedding and clothing respectively. More importantly, the 2/2 twill

fabric with the weft Nu-Torque cotton yarns was selected for the patients' bedding whereas the 2/1 twill weft backed fabric with the weft Coolmax yarns and Nu-Torque cotton yarns was selected for the patients' clothing by the professional medical personnel of the DDU of CMC and the project team members.

4. The triclosan based anti-bacterial chemical was proven to render the anti-bacterial property and finally selected to apply onto the newly developed prototypes of the patients' bedding and clothing for the user trial.
5. The experimental results showed that the performance of the newly developed prototypes was improved in terms of the requirements of comfort, moisture management property, safety and durability when compared with the current hospital patients' bedding and clothing. On the other hand, it was also found that there was an improvement of the performance of the newly developed prototypes of the patients' bedding and clothing according to the questionnaire surveys. Comparison between the newly developed prototypes and the current ones was also conducted by the user trial via the nursing staff.
6. The measured skin temperature of the patients using the newly developed bedding and clothing prototypes during the user trial was more consistent than the current ones.

7.3 Limitations

Limitations in this study are found in the following areas:

1. Cognitive ability of child patients

Since the child patients in the DDU of CMC are mentally handicapped with a profound disability, the child patients cannot be interviewed. The medical personnel have to take care of their daily life during hospitalization. Only their parents or guardians as well as the medical personnel understand their needs. As a result, such medical personnel, patients' parents or patients' guardians were interviewed instead of the child patients in the present study.

2. Sample size of questionnaire and user trial

All the questionnaire surveys and user trial were conducted in the DDU of CMC. The sample size of each questionnaire was different due to the shifts of nursing duties and the limited visiting time of parents and guardians. Convenience sampling method was adopted for the questionnaire surveys. Since the physical and medical conditions of the child patients varied extremely, the sample size of the patients for the user trial was limited. Furthermore, some patients were the abandoned children and therefore it was difficult to seek the consent of the patients' parents or guardians. Medical personnel only recommended these eight patients whose health conditions were suitable for the user trial.

7.4 Suggestions for future research

All the objectives have been achieved in the present study. However, future investigations in four aspects including end-users, design of clothing, commercialization as well as textiles used in medical field are recommended.

1. End-users

The present study is focused on the child paraplegic and quadriplegic patients who are mentally handicapped in the DDU. Further research conducted on the paraplegic and quadriplegic patients in other hospitals is highly recommended. For example, blind tests used for the user trial can be conducted and the users' feedback can be collected from the other patients who are able to feedback themselves. This can help understand the real features of the patients' bedding and clothing in order to ascertain the satisfactory performance obtained so far. Besides, increasing the number of patients in the user trial is also recommended in order to improve the accuracy of the user trial results.

2. Design of clothing

The design of the clothing has been slightly changed in terms of pattern engineering in this research. The performance of the patients' clothing can be further improved by varying their design. For example, the position, size or types of closure can be varied for typical style of the clothing in order to improve comfort. Furthermore, clothing comfort can also be improved by the design of garment fit.

3. Commercialization

Cost is the main concern of the patients' bedding and clothing procurement handled by the Hospital Authority. Hence, future study to achieve a cost effective purpose such as marker planning, fabric design and the CAD/CAM technology application in the manufacturing processes is highly recommended. This will lead to a viable mass production of the patients' bedding and clothing for the hospitals in Hong Kong.

4. Textiles used in medical field

Ideas for the development of other textiles in medical field have been generated through the hospital visits and the meeting with the medical personnel. For example, the modification of the cover of bathing chair and sofa, curtains, bibs and towels can benefit the patients in ward. This may result in enhancing the future research venture of this virtual unexplored area in Hong Kong hospitals.

Appendices

Appendix A: Questionnaire about the current patients' bedding and clothing

<u>Questionnaire about the current patients' bedding and clothing</u>

Textiles Needs of Paraplegic and Quadriplegic Patients in Paediatric Hospitals
- By Institute of Textiles and Clothing, The Hong Kong Polytechnic University
Targets: Medical Personnel / Patients' guardians

Questionnaire:
The data collected from the questionnaire will be used for a research about the textiles needs of paraplegic and quadriplegic patients in paediatric hospitals.
The research is aimed to develop innovative and technological textile materials which benefit child patients and medical personnel in paediatric hospital.
The questionnaire is divided in two parts to collect:

1. Comments on how does children's characteristic affect the desire on textile products (bedding and clothing) using in the hospital.
2. Comments on current hospital textile products (bedding and clothing).

PART A: How do children's characteristics affect the desire on textile products (bedding and clothing) using in the hospital?

Please circle the most suitable importance for how children's characteristic affect the desire on textile products (bedding and clothing) using in the hospital:

1 – Less important
2 – Unimportant
3 – Neutral
4 – Important
5 – Most Important

Characteristics of Child Patients	Please Circle one option				
Sweating	1	2	3	4	5
Spasticity	1	2	3	4	5
Eczema	1	2	3	4	5
Tracheostomy	1	2	3	4	5
Fragile skin	1	2	3	4	5
Serious saliva	1	2	3	4	5

Part B: Comments on the current hospital textile products (bedding and clothing)

I: Bedding

Patients' bedding provided by Hospital Authority

A. Comfort Sensation

Please circle the rating in the middle of below:

Ratings	Very bad	Bad	Fair	Good	Very good
Quick dry property	1	2	3	4	5
Breathablility	1	2	3	4	5
Un-prickle	1	2	3	4	5
Fineness	1	2	3	4	5
Comfort	1	2	3	4	5
Smoothness	1	2	3	4	5
Softness	1	2	3	4	5

B. Handling Issues

Please circle the rating in the middle of below:

Ratings	Very bad	Bad	Fair	Good	Very good
Launderability	1	2	3	4	5
Abrasion resistance	1	2	3	4	5
Strength	1	2	3	4	5
Weight	1	2	3	4	5

COMMENTS

1. Do you have any other comments on the current bedding?

___

2. Do you have recommendation for the new development of the bedding?

___

II: Clothing

Patients' clothing provided by Hospital Authority

A. Comfort Sensation

Please circle the rating in the middle of below:

Ratings	Very bad	Bad	Fair	Good	Very good
Non-stickiness	1	2	3	4	5
Thermal insulation	1	2	3	4	5
Quick dry property	1	2	3	4	5
Breathablility	1	2	3	4	5
Un-prickle	1	2	3	4	5
Fineness	1	2	3	4	5
Comfort	1	2	3	4	5
Smoothness	1	2	3	4	5
Softness	1	2	3	4	5

B. Handling Issues

Please circle the rating in the middle of below:

Ratings	Very bad	Bad	Fair	Good	Very good
Launderability	1	2	3	4	5
Abrasion resistance	1	2	3	4	5
Strength	1	2	3	4	5
Weight	1	2	3	4	5

COMMENTS

1. Do you have any other comments on the current clothing?

____

2. Do you have recommendation for the new development of the clothing?

____

PART C: Personal Information

Please circle one option.

1. Occupation :
   A. Nurse
   B. Nursing assistant
   C. Patients' guardian
   D. Others :____________
2. Age :
   A. Below 25
   B. 26-35
   C. 36 or above
3. Gender :
   A. Male
   B. Female
4. How many years have you served / experienced in the hospital?
   A. 1-5
   B. 6-10
   C. Above 10
   D. Not applicable

OTHER RECOMMENDATION

What are the properties you think are important for the development of new textiles materials for the patients based on above queries.

____

____

THANK YOU VERY MUCH FOR YOUR COORERATION

Appendix B: Questionnaire about the importance and influence of the fabric attributes on the performance of the patients' bedding and clothing

Questionnaire about the importance and influence of the fabric attributes on the performance of the patients' bedding and clothing

We are the research staff working on behalf of the Institute of Textiles and Clothing at The Hong Kong Polytechnic University. We are conducting a research project named as 'Textiles Needs of Paraplegic and Quadriplegic Patients in Paediatric Hospitals'. This survey aims at developing innovative and functional textiles materials which benefit child patients and medical personnel in paediatric hospitals. The questionnaire is about the importance and influence of fabric attributes on the performance of the patients' bedding and clothing. The information you provided should be kept confidential and used for research purpose only.

I. Personal Information

Please circle one answer only.

1. Occupation:
a) Nurses
b) Nursing assistant
c) Patients' guardian
d) Others: ____________

2. Age:
a) 25 or below 25
b) 26-35
c) 36 or above 36

3. Gender:
a) Male
b) Female

4. How many years have you served / experienced in the hospital?
a) 1-5
b) 6-10
c) Above 10
d) Not applicable

II. The importance and influence of the fabric attributes on the overall performance of the patients' bedding and clothing used in the paediatric hospital.

Example:

(1) Please advise 11 points in total for each pair of statements depending on how important each fabric attribute. For example, you can rate the total points as below (***11:0*** , ***10:1*** , ***9:2*** , ***8:3*** or ***7:4)*** if the strength of the fabric is more important than its breathability.

Strength	11	0	breathability

Explanation: The strength of the fabric is extremely important to the overall performance of the patients' bedding. However, the breathability of the fabric is not important.

Strength	10	1	breathability

Explanation: The strength of the fabric is so important to the overall performance of the patients' bedding. However, the breathability of the fabric is slightly important.

(2) Please advise 11 points in total for each pair of statements depending on how important each fabric attribute. For example, you can rate the total points as below (***5:6 or 6:5)*** if the strength of the fabric is almost the same important as its breathability.

Strength	5	6	breathability

Explanation: The importance of the strength and breathability of the fabric is almost the same to the overall performance of the patients' bedding, though its breathability is slightly important than its smoothness.

Strength	6	5	breathability

Explanation: The importance of the smoothness and breathability of the fabric is almost the same to the overall performance of the patients' bedding, though its smoothness is slightly important than its breathability.

The First Section: The Patients' Bedding in the paediatric hospital

Q. 1 Please advise 11 points in total for each pair of statements depending on how important each fabric attribute to the patients' bedding.

Strength			Dimensional stability
Absorbency			Handle
Breathability			Pilling resistance
Weight			Thickness
Dimensional stability			Absorbency
Handle			Breathability
Pilling resistance			Weight

Q. 2 Please rank the following fabric attributes for the patients' bedding
(Rank 8 represents the most important … Rank 1 represents the least important)

A]	Handle	e.g. comfort when lying in	__________
B]	Breathability	e.g. keep ventilation	__________
C]	Absorbency	e.g. absorb sweat or urine	__________
D]	Pilling resistance	e.g. not easy to form pills	__________
E]	Dimensional stability	e.g. durable after laundering	__________
F]	Strength	e.g. withstand pulling or tearing force	__________
G]	Weight	e.g. fabric weight	__________
H]	Thickness	e.g. fabric thickness	__________

The Second Section: The Patients' Clothing in the paediatric hospital

Q. 3 Please advise 11 points in total for each pair of statements depending on how important each fabric attribute to the patients' clothing.

Handle			Absorbency
Warmth			Breathability
Thickness			Strength
Pilling resistance			Dimensional stability
Absorbency			Warmth
Breathability			Thickness
Strength			Pilling resistance
Dimensional stability			Weight

Q. 4 Please rank the following fabric attributes for the patients' clothing
(Rank 9 represents the most important … Rank 1 represents the least important)

A]	Handle	e.g. comfort when wearing	________
B]	Breathability	e.g. keep ventilation	________
C]	Absorbency	e.g. absorb sweat or urine	________
D]	Pilling resistance	e.g. not easy to form pills	________
E]	Dimensional stability	e.g. durable after laundering	________
F]	Strength	e.g. withstand pulling or tearing force	________
G]	Weight	e.g. fabric weight	________
H]	Thickness	e.g. fabric thickness	________
I]	Warmth	e.g. warmth-keeping	________

End
Thank you for your participation!

Appendix C: Questionnaire about the comparison between the new prototypes and the current ones

Questionnaire about the comparison between the new prototypes and the current ones

We are the research staff working on behalf of the Institute of Textiles and Clothing at The Hong Kong Polytechnic University. We are conducting a research project named as 'Textiles Needs of Paraplegic and Quadriplegic Patients in Paediatric Hospitals'. The data collected from this questionnaire will be used to evaluate the improvement on the performance of the newly developed prototypes of the patients' bedding and clothing by comparing with the performance of the current hospital patients' bedding and clothing in terms of comfort sensation and conclusion. The results will be useful for the modifications of the newly developed patients' bedding and clothing prototypes which benefit the child patients and medical personnel in the paediatric wards. The information you provided should be kept confidential and used for research purpose only.

I. Personal Information

Please circle one answer only.

1. Occupation:
a) Nurses
b) Nursing assistant
c) Others: ____________
2. Age:
a) 25 or below 25
b) 26-35
c) 36 or above 36
3. Gender:
a) Male
b) Female
4. How many years have you served / experienced in the hospital?
a) 1-5
b) 6-10
c) Above 10

II. Comparison between the newly developed patients' bedding prototype and the current hospital patients' bedding

Please circle one option for the newly developed patients' bedding prototype.

A] Comfort sensation

1. Quick dry property	2. Breathability	3. Improvement on prickliness	4. Fineness
Current Product (Worst) - + (Better) -5 -4 -3 -2 0 1 2 3	Current Product (Worst) - + (Better) -5 -4 -3 -2 0 1 2 3	Current Product (Worst) - + (Better) -5 -4 -3 -2 0 1 2 3	Current Product (Worst) - + (Better) -5 -4 -3 -2 0 1 2 3
5. Comfort	6. Smoothness	7. Softness	
Current Product (Worst) - + (Better) -5 -4 -3 -2 0 1 2 3	Current Product (Worst) - + (Better) -5 -4 -3 -2 0 1 2 3	Current Product (Worst) - + (Better) -5 -4 -3 -2 0 1 2 3	

B] Conclusion

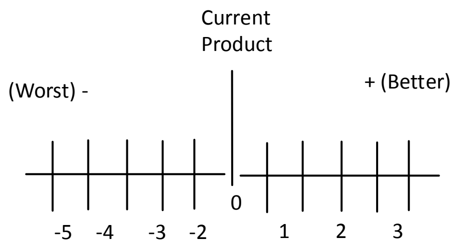
8. Overall performance
Current Product (Worst) - + (Better) -5 -4 -3 -2 0 1 2 3

III. Comparison between the newly developed patients’ clothing prototype and the current hospital patients’ clothing

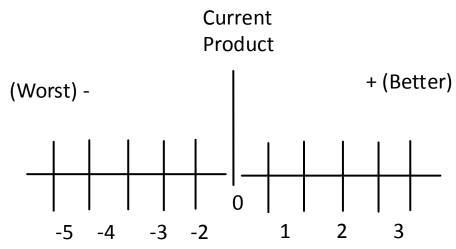
Please circle one option for the newly developed patients’ clothing prototype.

A] Comfort sensation

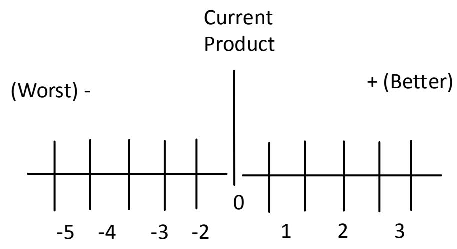
1. Quick dry property



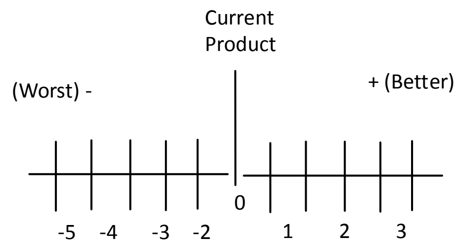
2. Breathability



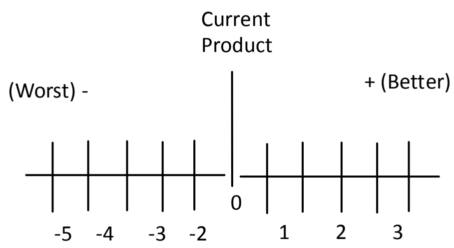
3. Improvement on prickliness



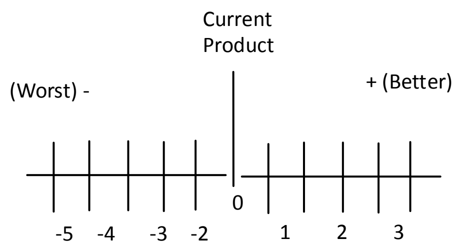
4. Fineness



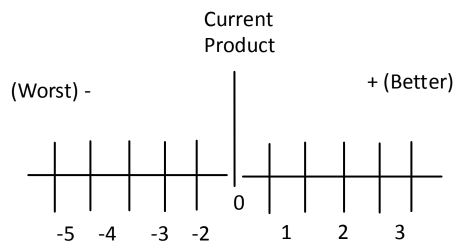
5. Comfort



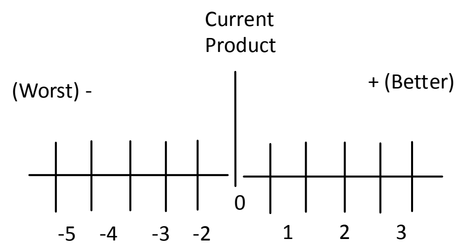
6. Smoothness



7. Softness

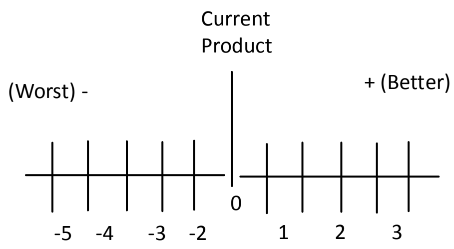


8. Improvement on stickiness



B] Conclusion

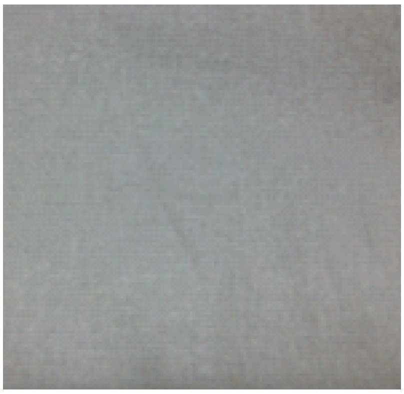
9. Overall performance



End

Thank you for your participation!

Appendix D: Fabric swatches of current hospital and new patients' bedding and clothing

 Current hospital patients' bedding	 New patients' bedding
 Current hospital patients' clothing	 New patients' clothing

Appendix E Test procedure of the wickability test

The detailed test procedure of the wickability test is described in the following:

1. 2 test specimens in the warp direction and 2 test specimens in the weft direction with 50 mm width and 150 mm height were prepared and pre-conditioned according to the ASTM D 1776-08 at standard atmosphere.
2. An indelible line was drawn across each the test specimens 10 mm and 20 mm from one end and at right angle to the longer edge respectively. The test specimen was marked for each 5 mm distance.
3. The test specimen was immersed with a clip in distilled water up to a point where the upper level of water just touched the indelible line to allow 10 mm of test specimen to rest in to a 600 ml beaker containing distilled water.
4. The height of water rise in mm at a given time, i.e. 1 minute, 3 minutes and 5 minutes, was recorded when water touched the indelible line of 20 mm from the end of the specimen.
5. The measured heights were averaged for the warp and weft directions respectively for each fabric sample.

Appendix F Measurement charts of size of the clothing

Measurement chart of top

		Size		
Measurement	Description	S	M	L
1/2 chest *	2cm below armhole	53	58	62.5
1/2 hem *	measured straight	54	58	61.5
total length *	from High Point Shoulder, without neckline piping	59	68	69
shoulder breadth *	along shoulder seam, without piping	15.5	20	21
sleeve length *		44.5	55	58
upper arm width *		21.5	22.5	24.5
sleeve hem width		16.5	18.5	18
breadth of cuff		2.5	5	5.5
breadth of neckline		13	18.5	17
neck drop front	from High Point Shoulder to center of 1st button	15.5	14.5	19
collar height, front	unfold of inside collar, center front	7	7	7
distance between buttons	from center to center of buttons	9	9.5	9.5
neck drop back	from High Point Shoulder	1	1.5	2
width of inner placket		7	10.5	12
no of button	on Center Front	4	5	5

*Critical measurement

Measurement chart of trousers

		Size		
Measurement	Description	S	M	L
1/2 waistband *	when relaxed	27.5	30	32.5
1/2 waistband under tension *	maximum width under tension	56	58	64
breadth of waistband		3	3	3
1/2 hip *	25cm down on center seam, measure at right angle to grain line	58	58.5	65
1/2 thigh *		33.5	34	39
1/2 knee	on half inseam length	24.5	28	32
leg hem width *		19.5	24	25.5
height of turn up		2	3	2.5
front rise *	along Centre Font seam, including waistband	35.5	39	40
inseam length	along inseam	56	51	60.5
back rise *	along Centre Back seam , incl. waistband	35.5	39	42.5
outside length *	measure straight including waistband	85	84.5	96

*Critical measurement

Appendix G: Record of room temperature and humidity during user trial

Room temperature and humidity of the hospital ward for the newly developed patients' bedding and clothing prototypes

Record	T:0	T:1	T:2	T:3	T:4	T:5	T:6	T:7	T:8	T:9	T:10	T:11	T:12	Mean	SD
Room temperature	21.6	21.6	22	21.9	21.9	22.4	21.8	22	21.9	21.9	22	22	21.5	21.88	0.22
Room humidity	38.4	37.9	36.4	36	36.3	35	35.9	35.6	35.3	35.1	35	34.8	35.1	35.89	1.12

Room temperature and humidity of the hospital ward for the current hospital patients' bedding and clothing

Record	T:0	T:1	T:2	T:3	T:4	T:5	T:6	T:7	T:8	T:9	T:10	T:11	T:12	Mean	SD
Room temperature	21.3	21.1	21.8	21.4	22	22.3	21.4	22.1	21.9	22.3	21.9	22	22.1	21.80	0.39
Room humidity	39.3	37.6	35.9	36	35.6	34.9	35.6	35.9	35.3	35.1	35.6	35.4	35.5	35.97	1.19

Appendix H: Mean temperature for each measuring point obtained from the user trial

Mean temperature for each measuring point obtained from the user trial of the newly developed patients' bedding and clothing

	T:0	T:1	T:2	T:3	T:4	T:5	T:6	T:7	T:8	T:9	T:10	T:11	T:12	Mean	SD
Forehead	32.7	33.3	33.2	33.1	33.5	33.7	33.5	33.7	33.4	33.7	34	33.7	32.9	33.39	0.37
Right scapula	34.6	35	34	34.8	35.3	35	35.2	35.1	35.4	35.3	34.5	34.9	34.8	34.89	0.39
Left upper chest	33.9	33.8	33.4	33.8	33.7	34.4	34.1	34.1	34.1	34.1	34.5	34.1	34.0	33.99	0.28
Right arm in upper location	32.4	32.9	32.2	33.5	33.6	33	32.9	33.4	33	33.2	33.5	33.5	33.3	33.08	0.42
Left arm in lower location	32	31.8	32.3	32.7	32.8	33.1	33	32.9	32.6	32.8	33.8	31.9	32.1	32.59	0.56
Left hand	30.6	31.8	33.4	32	32.8	31.5	32.8	32.2	32.2	33.3	33	32.8	32.6	32.39	0.77
Right anterior thigh	31.5	31	31.5	32.1	31.6	31.8	31.7	32.1	31.6	32.3	32.7	32.1	32.5	31.88	0.47
Left calf	30.1	30.4	30.8	31.6	30.5	31.3	31.5	31.7	30.7	31.1	31.7	32.2	31.3	31.14	0.61

Mean temperature for each measuring point obtained from the user trial of the current hospital patients' bedding and clothing

	T:0	T:1	T:2	T:3	T:4	T:5	T:6	T:7	T:8	T:9	T:10	T:11	T:12	Mean	SD
Forehead	32.7	32.4	33.1	33	33	33.2	33	33.5	33.7	33.4	33.5	33.2	32.8	33.11	0.36
Right scapula	34	34.1	34.3	34.3	34.4	34.9	34.8	35	34.9	34.8	35.3	34.4	34.6	34.59	0.38
Left upper chest	33.3	33.7	33.9	34.2	33.6	34.2	33.9	34.1	34.3	34.2	34	33.8	33.4	33.88	0.31
Right arm in upper location	31.7	32.1	33	33.3	33.2	33.7	33.2	32.8	33	33.5	34.1	33.2	32.5	33.00	0.64
Left arm in lower location	31.2	31.3	32.5	32.4	32.5	32.2	32.9	33.4	32.7	33.1	33.3	32.8	32.3	32.49	0.67
Left hand	29.7	29.3	30.1	30.9	31	31.4	32.1	33.2	32.4	32.3	32.5	32.5	32.3	31.50	1.23
Right anterior thigh	31.1	30.5	31.1	31.9	31.8	31.9	32.7	32.6	32.4	32.4	32	32.1	32.1	31.88	0.65
Left calf	30.5	30	30.2	31.1	32	33.4	33.1	33.1	32.3	32.6	32.6	32.4	30.9	31.85	1.18