Doctoral Dissertation (Shinshu University)

Study on the application of functional fibers for the nursing and medical care

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Content

Chapter 1

General Introduction

1-1. Background of the thesis

Nobody will deny that Japan is one of the most advanced countries in the world in terms of materialistic view point. Japan belongs to the high income country and is considered as a wealthy country. The human development index (HDI) is often used as a measure of human welfare in the country, where HDI measures the average living standard in a country from three aspects of health, education and living standard, based on various indicators such as life expectancy at birth, mean years of schooling, expected year of schooling and gross national income per capita. HDI is ranked as 10^{th} (the highest in Asian countries) in 2013 [1], but most of the Japanese do not feel that they are well cared and Japan is a happy land.

Another measure of the living standard is the quality of life (QOL), which consists of various factors including life expectancy, divorce rate, community activity, material possessions, political stability, climate, unemployment rate, political freedom and sex equality. QOL provides a technological guideline to improve elderly independence, which is rapidly becoming a significant matter in a sustainable society. QOL improves somewhat in parallel to HDI, but the Japanese QOL is lower than other countries having a similar HDI.

Those indices mentioned above include neither environmental factors nor human factors. An earlier attempt to define an indicator that measures a quality of life in terms of more holistic and psychological aspects is seen in gross national happiness (GNH) proposed by Bhutan's 4th Dragon King Jigme Singye Wangchuk. According to this index, GNH of Japan was 43rd among 60 countries [2]. The happy planet index was proposed in 2006 by Friends of the Earth to measure the happiness of the nation, and better life index was proposed by OECD to measure the holistic quality of life including housing condition, income, employment, community, education, environment, governance, health, life satisfaction, safety and work-life balance. Here Japan is ranked as 75th among 143 countries (in 2009) and 21st among 21 countries (in 2012), respectively [2]. These survey results indicate the social problem existing in Japan. That is, Japan is a comfortable country to live, but people's satisfaction is relatively low because of the feeling of isolation, unbalanced work-life time, and poor social networking (see Figure 1-1). Especially the feeling of isolation is strong among the youth and the elderly, causing a high suicide ratio in the youth and the elderly. Japan is a comfortable country, but not a land of happiness.

Japan is an advanced aging country. Declining birth rate and aging population is a serious problem in the Japanese society. The total fertility rate in Japan is as low as 1.41 in 2012 and the percentage of total population aged 65 and over is 20%. This percentage is expected to rise to 27% in 2015 and to 41% in 2050. In consequence, the support coefficient an index indicating how many active workers support one elderly person will drop to 1.4 by 2050. Although Japan has the longest life expectancy, the quality of life is poor for the elderly. A real problem for elderly care is the bedridden population of elderly in nursing homes. The percentage of the bedridden population is 4.2% in Sweden or 4.5% in Denmark, while 33.8% in Japan. When the elderly is confined to bed for a longer period, the body function will deteriorate and result undesirable health conditions including foul smell by bodily waste and skin disease as bed sour. The work of the caretakers will become heavier, and most of the caretakers are in fact tired both physically and psychologically. Moreover, the dignity of the elderly will be lost.

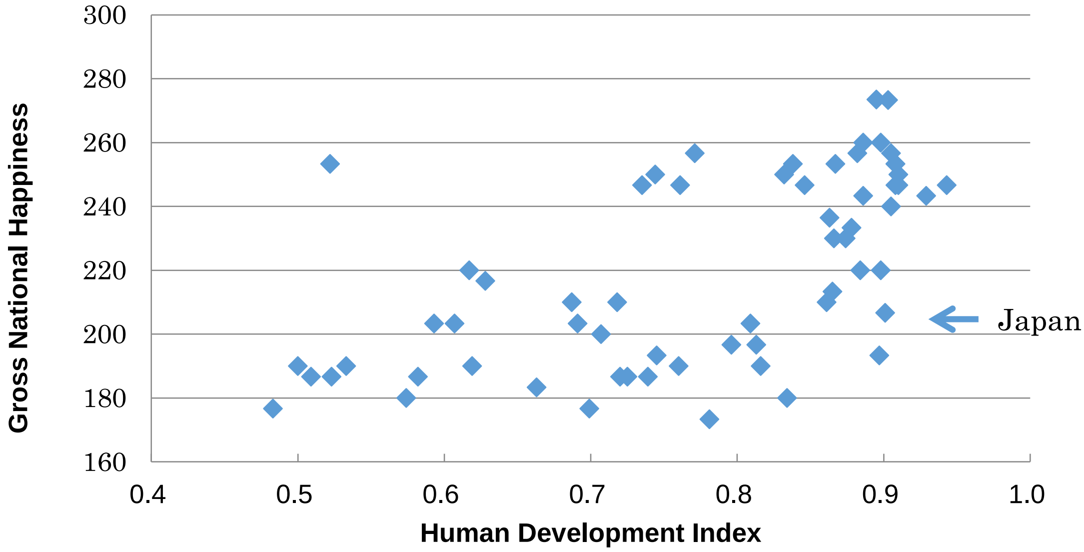


Figure 1-1 Gross National Happiness plotted against Human Development Index, where the position of Japan is indicated by an arrow.

(Reference: Human development report 2012)

The present thesis aims to reduce the burden of the caretakers and improve the environment of the nursing home by applying functional textiles. In order to reduce foul smell and the psychological burden of the caretakers, the deodorant and anti-bacteria fiber is applied. The performance of the functional fibers is evaluated, first subjectively and then quantitatively in terms of the deodorant effect and anti-allergy effect. The nursing care goods are designed and tested to reduce the physical load of the caretakers. The result is evaluated from the practical use of those goods in the nursing home. The ultimate goal of the thesis is to improve the quality of life in the nursing home, and eventually to extend the knowledge accumulate from this research to the society.

1-2 .The present situations of hospital and nursing home

As it stands in 2010, Japanese average life expectancy is 79.6 years for men and 86.4 years for women, which is the highest life expectancy in the world (IMF World Economic Outlook Database). More serious social problem is the

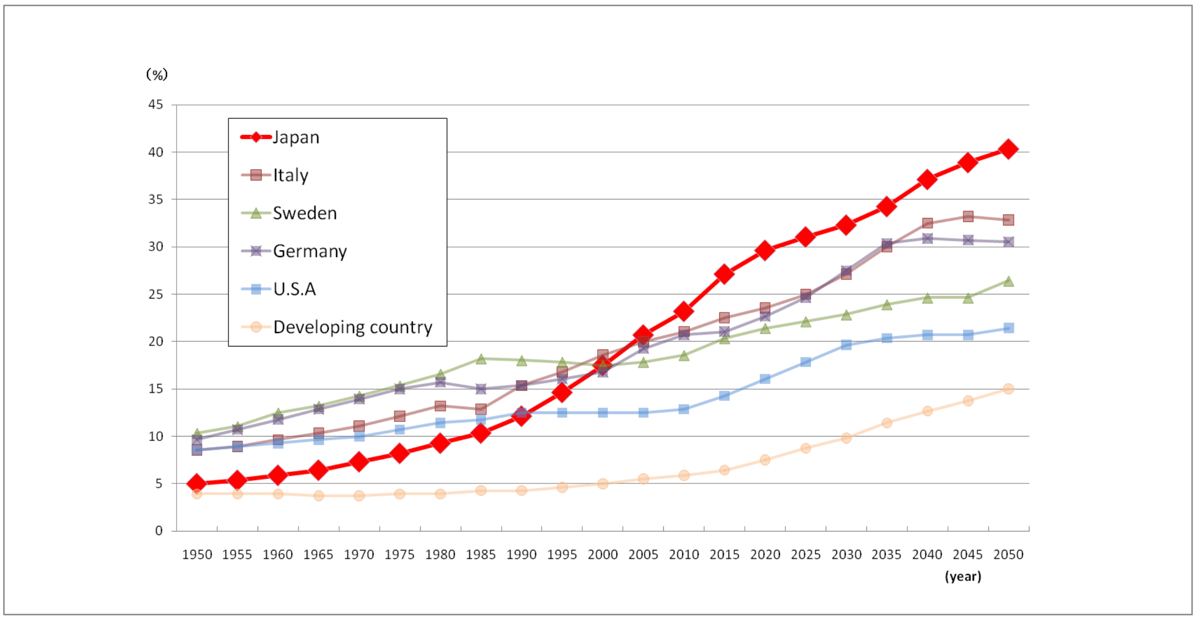


Figure 1-2 The expected after 2012 ration of the elderly population in the world.
(Reference: Senior citizen white paper 2012)

elderly population aged 65 and over, which covers 20% of the total population. In upcoming super-aging society in 2050, the ratio of the elderly is estimated to reach 50%, where one in two is the elderly. Figure 1-2 shows the change of aging rate in advanced countries. Japan exhibits the rate higher than any other country since 2005, and still seems to accelerate its rate even in 2050 when most of the nations start reducing or at least decelerating the elderly rate [3].

As getting older, we are susceptible to illness due to the deterioration of physical function. Three major causes of death of the elderly consist of a cerebrovascular accident, cancer and myocardial infarction, and count for 60% of the causes of elderly death [4]. When the elderly is divided into two groups according to the aging stage as the young-old (the elderly aged 65~74) and the old-old (those aged 75 and over), the former group is apt to suffer from dementia, osteoarthrosis and lower back pain, whereas the latter suffers more from osteoporosis, vertebral body fracture and incontinence of urine due to the deterioration of basic activities in daily living (ADL) as a self-sustained body movement would be restricted as exemplified by less frequent habitual behaviors of going to/getting out of bed, using the bathroom, taking a bath, eating and changing clothes.

The senior citizens need the support and care in everyday life due to the physical deterioration of the body by aging. The national nursing-care insurance system was introduced in 2000 in Japan. At that time the person required the physical support or the nursing care were 2,180,000. Since then, the number of the support-needed population under the national nursing care insurance system rapidly increased to 4,690,000 in 2009 [5]. Here the nursing care is classified into 5 levels according to the needed care evaluated by a local authority composed of doctors and nurses. Level 1 denotes the lightest stage of care to assist the elderly for daily shopping, washing, bathing and cooking.

Level 5 corresponds to a comprehensive care for the bedridden elderly. Content and working hour of care services are specified to each level. Care for elderly people requires a hard physical and psychological work for caretakers. Physical work includes the assistance in helping the elderly moving from a place to another, dressing/undressing, eating and bathing. During the night, caretakers are required to shift the body position of the bedridden elderly and change diapers regularly. Especially when the weight of those elderly is larger, the work required becomes harder and most of the caretakers suffer from chronic fatigue, lower back pain and other muscle pain consistently [6,7], and damage the waist or arms [8]. In consequence, many caretakers leave the elderly facility earlier [9,10].

Most serious problem in the aging society is the ratio of bedridden senior citizens. The ratio of bedridden senior citizens is as high as 33.8% in Japan, whereas 4.2% and 4.5% of Sweden and Denmark, respectively (as surveyed in the long-term care facility for the hospitalized elderly aged 65 and over ("National Livelihood White Paper" 1994 edition). Such a confinement to bed is caused mostly by the aftereffects of a cerebrovascular accident, foot fracture, falls, and debilitation [11].

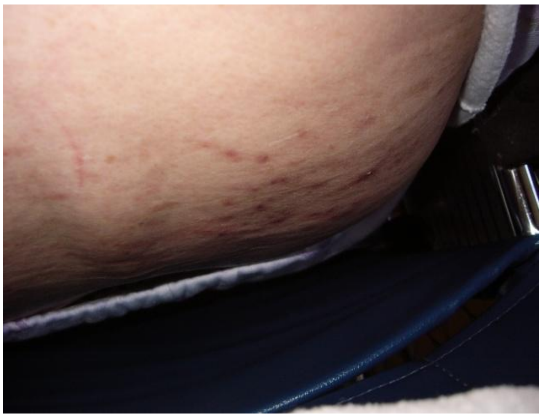
Although the number of the Japanese affected by cerebrovascular diseases is nearly equal to those of advanced countries, overwhelming number of senior citizens are bedridden in Japan in comparison with other countries as mentioned above. Multiple reasons could be considered for this discrepancy of the state in care houses, including the life style, the social environment and the caring method. The Japanese spend most of the time and sleep flat on *tatami* (a hard mat), while people spend time by sitting on a chair and sleep on bed in the

Western countries. Especially in Europe a park is provided relatively in the town center for people to take a walk easily, and the benches and chairs are also provided in the main shopping street for the elderly to enjoy shopping and walking. The nursing homes for the elderly are situated near the town center and open to the local people to use the facility in order to have more frequent contacts with the elderly. The elderly in Europe enjoy walking and the environment also allows for the elderly to walk around by themselves. The caretakers encourage and assist the elderly to walk in the nursing homes for the elderly in Europe, but the elderly are rather asked to lie down on the bed from care convenience in Japan. The difference in the life style and the social environment may have resulted in the large ratio of the bedridden population in the nursing homes in Japan. An elderly patient has a tendency to be hospitalized for a longer time than needed in Japan. When an elderly patient lie in a bed for a longer time, his/her muscular strength deteriorates and eventually he/she could become eventually unable to move and senile. The facilities and staffs for rehabilitation are poor in Japan in comparison with other countries.

For example, in Denmark, the elderly patient is sent to rehabilitation center immediately after treatment is over, when he/she is hospitalized with a cerebrovascular accident and a bone fracture. The caretakers in nursing homes take care for the elderly to spend a day sitting in a wheelchair or on sofa. The local governments are also actively involved in the elderly care by developing assistive devices and encouraging using them for nursing care free of charge. Those assistive devices could reduce the caretakers' physical work and secure a comfort of an elderly. In consequence the caretaker in Denmark suffers less from lower back pain. Those devices support the independent management of the elderly, and thus the dignity of the elderly could be kept [11]. There are three principles of welfare for the elderly in Denmark. Namely, i) Self-determination; deciding own life and live in own way as long as possible, ii) Continuity; living in the community forever as they have done up till present, and iii) Utilization of the remaining function; making the best use of the remaining function as much as possible, even though a part of physical function is deteriorated [12]. Uder these three principles of welfare, both caretakers and elderly maintain their dignity and in consequence their quality of life (QOL) is enhanced.

There seems no welfare principle established in Japan. In consequence, each nursing home in Japan operates with its own principles, and in some cases

Thigh



Back

Figure 1-3 The skin disease developed on the back and thigh.

the dignity of the elderly is neglected. Once bedridden, the elderly patient is obliged to do all ADL in bed, including excretion, eating and taking a bath with an extremely low frequency. The circumstance allows to be filled with a bad odor, caused by excretion, body, etc. and depresses not only the patients but also the staffs working in the facility. Moreover, the bedridden elderly, lying in bed all day long without shifting the body position, are susceptible to bedsores and skin diseases.　A skin disease develops on the back and thigh in touch with the bed as shown in Figure 1-3. For the benefit of the elderly, some beds are provided with an air mat on the top of the mattress (see Figure I-4). Although the air mat helps to prevent bedsores, the lack of air permeability results in the wet skin of the patients due to perspiration for a long time.

Figure 1-4 The bed which using in the elderly home.

Additionally, it is observed that some bedridden elderly suffer from the contracture of a hand and fingers as Figure 1-5 shows. The contracted muscle prevents a free movement of the joints, press hard extracapsular soft tissues, and eventually causes osteoarthrosis. Figure 1-5 shows the atrophy of an elderly patient's hand as a result of a prolonged confinement to bed. The

Flexure contracture　　Extension contracture

Figure 1-5 A contracture state of hand and fingers patient grasps the hand tightly all day long and her hand and fingers are contracted, causing an ill odor and a skin disease developed onto the palm. In summary, a confinement to bed eventually causes the skin diseases and ill odors of the patients and results in unbearable atmosphere in the nursing home.

A main aim of this thesis is to reduce the unpleasant atmosphere of the nursing home for elderly in Japan by applying functional fibers. It would be expected to improve the nursing home condition and the home care work by combining the functional fibers to ease the physical condition of the elderly patient and the design of bed clothes to reduce the labor of the caretakers. The results indicate a further application of functional fibers to a generally case of allergy as mentioned in Chapter 3.

1-3. The potential application of functional fibers in the hospital and nursing home

The characteristic odor is one of the most serious problems in hospitals and elderly facility. This characteristic odor restricts a frequent contact with ordinary people, and causes an isolation of the elderly patients from the society. The patients are anxious to go into the public because of this characteristic odor and thus hesitate to go out with ordinary people. A suitable cloth or other tool made of the deodorant fiber was found capable to remove the characteristic odor in the hospitals and nursing care facilities. If a suitable design is made for the clothes and assisting tools, there will be more chance for the elderly patients to resume an ordinary life in town.

Elderly people are classified into 3 groups according to their ability for an ordinary life, that is, those who can be independent in an everyday life (healthy), semi-bedridden (partially physical-handicapped), and bedridden. Even the healthy elderly suffer from some inability of carrying heavy luggage and walking around freely, and are in some extent treated with medicines and plasters to reduce their pain, causing a particular odor recognized by surrounding people. Semi-bedridden is in the state where you cannot go out without care, whereas a person living all day on a bed is said to be bedridden. Table 1-1 summarizes the functions required for the clothes to assist the elderly who are healthy, semi-bedridden and bedridden respectively. Senior citizen clothes should be designed according to the necessity of a wearer. Especially it is important to develop a suitable outdoor cloth for semi-bedridden elderly and provides more opportunity to mix with ordinary people in order to avoid being bedridden in future. As a physical function deteriorates by aging and some elderly people worry about a smell of their body, they tend to stay at home longer and lose the interest in enjoying their active outdoor life. In this context, the deodorant cloth is expected to play a key role for them to mingle with the outside society. Here the healthy elderly people may require more fashionable elements together with a deodorant effect, whereas the function is more important for the bedridden elderly to reduce skin irritant and smell and to ease slipping on/off the clothes. In any case, deodorization is an important factor for elderly people in order to mingle with other people.

A foul odor is caused by various substances diffusing into the surrounding atmosphere but the mode of the diffusion varies according to the types of substances and the environmental conditions including humidity and air current. In order to remove odor efficiently, we should consider all those factors and also need to trap the odor substances near the generating source.

Table 1-1 Performance of clothes for senior citizens in the different state of health

		Healthy	Partly physically handicapped	Bed-ridden
Factor of clothing construction	Body size	◎	○	×
	Slip on-off	△	◎	◎
Characteristics of material	Stimulation to skin	△	○	◎
	Deodorant	◎	◎	◎
Sensuousness	Fashion	◎	○	×

The deodorant fiber can be applied for this purpose in more general, including not only the clothes and bedding (bed covers and sheets) but also the covers for the urine collection bag and other assisting equipment at the bedside. The ventilating condition should be reconsidered to save energy and remove odor efficiently as air circulation at present is designed for a whole room. Curtain and wallpaper can be functionalized and placed in an appropriate place by considering air flow in the room. A personal ventilation system is being incorporated in the individual bed by applying air curtain system and deodorant filter in the next step.

The mechanism of odor elimination is in most cases due to the catalytic function to oxidize/decompose the odor substances. The function of deodorant substance is similar to that of detoxicating enzymes in this context, so that it could be expected to function as anti-bacteria and anti-virus agent [13]. In fact, some of the deodorant agents exhibit anti-bacteria and/or anti-virus activity. A personal ventilation system is now being developed to prevent a secondary infection in the hospital (see Figure 1-6).

Figure 1-6 A ventilation system

During the course of the study, the deodorant fiber was found to reduce bedsores and other skin diseases of the elderly patients. The bedsore is caused by bad blood circulation and subsequent sphacelus. Here the deodorant fiber is considered to decompose responsive substances by oxidation. A similar mechanism could be applied for the anti-allergic function.

According to the statistics reported by the Ministry of health, Labour and Welfare, the number of the patients of atopic dermatitis is consistently increasing from 279,000 in 2002 and 384,000 in 2005, but somewhat decreased to approximately 350,000 in 2008. Among those patients from 2005 to 2008, the age group from 1 to 4 (the babies) is the highest in number, followed by the age group from 20 to 24 (the youth). In many a case, it was considered to be cured by adolescence, but many children carry atopic dermatitis all through to their and in more cases tend to develop after adolescence [15]. The atopic dermatitis may result from multiple-causes including the toxic substances secreted by sweat and fermented by bacteria. In order to maintain healthy skin, skin surface should be kept slightly acidic (around pH 5 to 6) to suppress the growth of so-called bad bacteria[16]. Considering those circumstances, we developed new functional fiber by acidification of polyester, and examined its effect on the skin in the last chapter.

The discussion above indicates a wide range of potential applications of deodorant functional fiber in many fields. The present thesis is hoped to confirm the potential of functional fibers in the medical application, but the potential application will be much wider. .

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Chapter 2

Performance and evaluation of deodorant / antibacterial fibers

2-1. Smell generation

Smell in the hospital and elderly nursing home

Hospitals and elderly nursing homes have characteristic smell, which is unpleasant and discourages people to take more care for the patients. According to the survey with regard to the smell in hospital by questionnaires [1-3], the sickroom, ward, sanitation room and lavatory are the most unpleasant places in the hospital. The unpleasant smell consists of excrement as the most unpleasant smell, followed by the smells generated from the human body, chemicals, food, cigarette and putrefaction. The smell of excrement is generated from the bedridden patient who cannot help excreting in bed or at bed side, and dominates the room. Here the fecal smell is overwhelming to other people though temporarily, and the urine left in the urine bag at the bed side generates consistently foul smell.

The main components of human urine are water, urea, sodium chloride, and it also includes uric acid, ammonia, creatinine, etc (See Table 2-1)[4]. The foul smell of urine is caused by decomposition of “urea”, the major constituent of urine, into “ammonia” by bacterial reaction in air. The fecal smell is due to the decomposition of protein and carbohydrate into indole, skatole, ammonia, hydrogen sulfide, fatty acid, etc. by the action of putrefactive bacteria in the intestine such as *Bacteroides, Escherichia coli, Staphylococcus,* etc. together with those as *Eubacterium, Streptococcus faecalis, Clostridium*, etc. The advanced instrumental analysis revealed methyl mercaptan, dimethyl disulfide, and dimethyl trisulfide contained in the feces of healthy people with a higher concentration than indole and skatole, which are identified as the typical smell of feces [5].

Table 2-1 Content of human Urine

Organic constituent		Inorganic constituent	
Total nitrogen	10 - 15 g/day	Sodium chloride	10 - 15 g/day
Urea	13 - 30 g/day	Sodium	4 - 6 g/day
Uric acid	0.4 - 1.2 g./day	Kalium	0.8 - 1.6 g/day
Ammonia	0.3 - 1.2 g/day	Calcium	0.1 - 0.3 g/day
Creatine	10 - 50 mg/day	Magnesium	0.1 - 0.2 g/day
Creatinine	1.0 - 1.5 g/day	Chloride	10 - 15 g/day
Amino acid	0.2 - 0.7 g/day	Phoshorus	0.5 - 2.0 g/day
Hippuric acid	0.3 -0.6 g/day	Iron	0.1 - 0.2 mg/day
Indican	5 - 20 mg/day		
Keton	10 - 20 mg /gay		
Urobilinogenuria	0.4 - 2.0 mg/day		
Protein	20 - 60 mg/day		
Glucose	40 - 85 mg/day		

Body Odor

Human skin is called as a sense organ of touch, and consists of 6.3~6.9% of the body weight [6], which is the largest organ in the body. The skin functions as thermo-regulator by controlling blood flow by contracting and enlarging the blood vessel which runs through skin, in order to prevent the blood heat from radiating out of the body. Additionally, secreting from the sweat gland, sweat also works to lower the body temperature by virtue of heat of vaporization when it evaporates after spreading over the skin surface. As stated above, in direct contact with the outer environment, the skin has those roles as to excrete waste as well as to protect the body. Sweat is secreted in a vapor or liquid state from the skin surface through eccrine and apocrine sweat glands (See Figure 2-1)[7]. Contrasting with eccrine glands which cover the entire body, apocrine glands are only in and around the armpit, navel and genital organ. Most of the sweat is secreted through eccrine glands with the perspiration power of 12000cc/day, which is overwhelmingly higher than that of apocrine glands, 0.01cc/1-2days. While engaging in sports, perspiration is caused by eccrine glands. Sweat is composed 99% of water, followed by sodium chloride, lactic acid, etc (See Table 2-2)[8]. Naturally, the sweat secreted by eccrine glands has no smell, but it starts generating smell by the action of resident microbiota on the skin surface. The sweat secreted by apocrine glands contains much cholesterol [9]. There are apocrine glands in the armpit of underarm parts, where the sweat stays as covered by a cloth which gets stained yellow. In addition, cholesterol and cholesterol ester contained in the sweat secreted by apocrine glands, cause a distinctive bad smell as fermented by bacterial action [10]. Furthermore, contained in the substance secreted by apocrine glands in the underarm, *5α-androst-16-en-3-one (5α-androstenone)* and *5α-androst-16-en-3α-ol (3α-androstenol)* are the

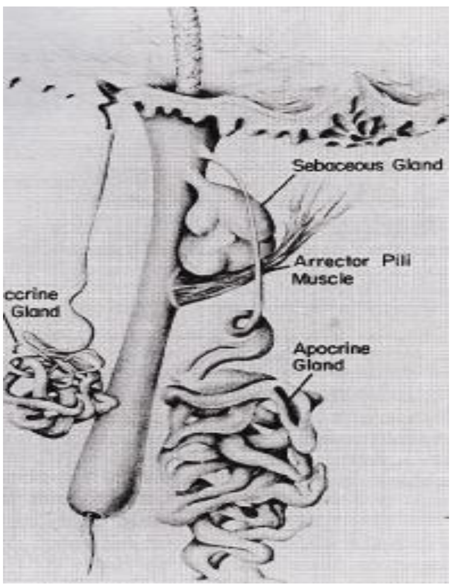

Figure 2-1 Structure of seat glant.

causal substances of armpit odor. The former is particular to men, whereas the latter to women. Recently E-3-methyl-n-hexenoic acid has been identified as a causal substance of armpit odor in the underarm [11,12].

Table 2-2 Percentage composition of sweat

Name	Content (%)
Water	99.02
Sodium chloride	0.648 - 0.987
Urea	0.086 - 0.173
Lactic acid	0.034 - 0.107
Amino acid	0.013 - 0.020
Sulfide	0.006 - 0.025
Ammonia	0.010 - 0.018
Creatinine	0.005 - 0.002
Uric acid	0.0006 - 0.0015

The bacteria are always present on the surface of the human skin, and the secreted substances with sweat are decomposed into odorous substances by the action of bacteria. It is said that the bacteria of *Corynebacterium xerosis* on the axillary acts and generates a peculiar smell [13]. Following the axillary odor, sweat odor and socks odor are a bad smell. The causative agent of smelly feet is isovaleric acid[14], in the case of sweat smell, lower fatty acids such as acetic acid and isovaleric acid is the odor substance due to acting *Staphylococcus aureus*. It is said that the main component of the smell of the head consists of aldehyde having light pungent smell mixed with the smell of short-chain fatty acid such as isovaleric acid, isobutyric acid and indole [15]. Nonenal is related to aging odor, but it has not been clarified whether involved bacterial action. In a normal condition, the pH of the human skin surface shows a weak acidity of 4.5 to 5.5. It is said that this acidity prevents bacterial invasion to the skin.

The pH of the skin surface varies by sweating and subsequent bacterial action. Depending on the pH condition on the skin surface, the bacteria on the skin surface decomposes secreted substances by sweat further into the substances generating a bad smell. Since the bacterial activity depends on the pH condition on the skin, the pH control on the skin surface could be vital to maintain the healthy state of skin.

2-2. Substance causing ill odor

There are 300-400 kinds of bad smells around us. These bad smells affect the autonomous nerve, cause a headache and an irritation, and give unpleasantness. In the case of strong stimulation by bad smell, the autonomous nerve is overstressed, and results in higher pulse rate or a rise of blood pressure [16].

There are over 100,000 smelly chemical substances. Especially, a chemical substance producing a particularly strong smell contains sulfur or nitrogen with an oxygen atom such as hydrogen sulfide, mercaptan, aldehyde, amine, indole, and skatole. These chemical substances generate unpleasant smell even with a small quantity. Table 1 shows main substance of ill odor [17]. Among these substances of ill odor, ammonia, hydrogen sulfide, methyl mercaptan and trimethylamine are called four major ill odors, represent the model agents for bad smell.

Table 2-3 The thresdhold value of substances of ill odor

Substance	Smell	Threshold value(ppm)
Hydrogen sulfate	Rotted egge	4.1×10^{-4}
Methyl mercaptan	Garlic	7×10^{-5}
Dimethyl disulfide	Onion	2.2×10^{-3}
Indol	Feces and urine	3×10^{-4}
Skatole	Feces and urine	5.6×10^{-5}
Ammmonia	Strong irritating	1.5
Trimethylamine	Rotted fish	2.7×10^{-5}
Acetaldehyde	Unpleasant	1.5×10^{-5}
Isovaleric acid	Foot	7.8×10^{-5}

2-3. Available deodorant fiber and deodorant mechanism

The generation of ill odor is a serious problem, especially the odor from the body such as bed ridden and idiosyncrasy. Figure 2-2 shows relationship between ill odor generation and deodorant method. The bad smell precursor material is decayed by bacteria or enzyme at a first stage, so that an antibacterial substance could be effective preventing ill odor generation. A bad smell is detected by absorbing a smelly substance onto a smelling cell in a ceiling part of cavity of nose, which generates electric current in the cell membrane. This electric current is then transmitted to the nerve as impulse, and our brain feel it unpleasant [18].

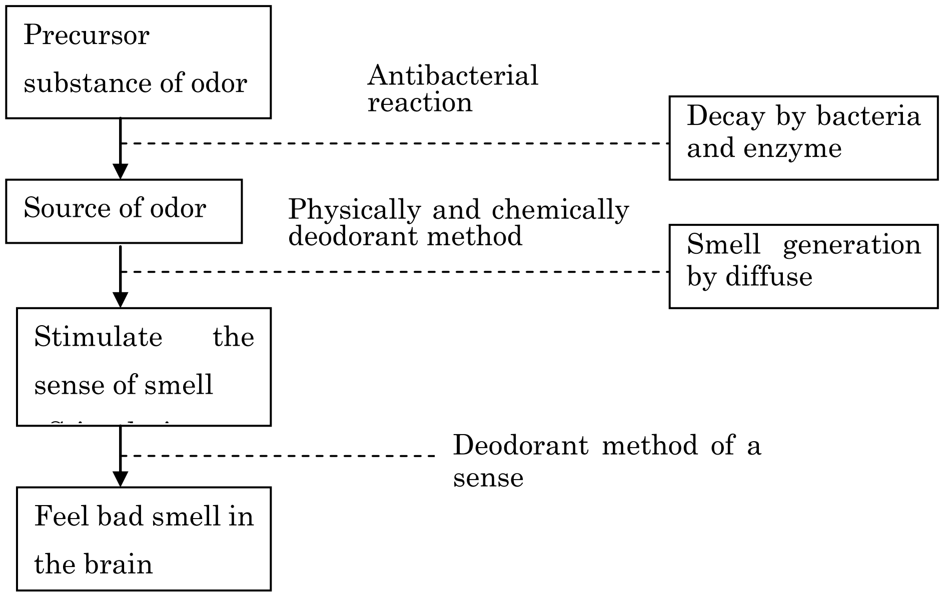

Figure 2-2 The ill odor generation and deodorant method

Odor spreads by volatilization at a second stage. Three deodorant methods are available to remove ill odor. The porous materials such as silica gel and active carbon possess small cavities which absorb odorous molecules physically (the physically deodorant method). The chemical deodorization is due to the chemical reaction such as oxidation-reduction reaction or the neutralization reaction which decomposes the odorous molecules into the odorless substances. The chemical method is represented, for example, by amines neutralized with acid, hydrogen sulfide neutralized with an alkali, and photo-catalytic reaction by titanium oxide. Phthalocyanine-processed fiber is a commercially available deodorant fiber, where odorous substances are decomposed by enzymatic function of phthalocyanine. A third method is a biological one where a microorganism or enzyme decomposes the ill odor substances into odorless substances.

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Chapter 3

Effect of weak-acidic polyester on skin condition

3-1. Introduction

Over 1 trillion normal bacterial inhabitants are active on human skin, and are classified conventionally into two groups of good bacteria and bad bacteria, where the population varies according to the physiological factors [1]. The healthy human skin is covered with the weak-acidic moisture barrier composed of good bacteria. For example, normal inhabitant such as *Staphylococcus epidermidis*, provides natural moisturizing agents to keep skin surface in a weak-acidic condition by decomposing fatty acid discharged with sweat into lactic acid [2-3]. When the population of *Staphylococcus epidermidis* decreases, skin surface inclines to an alkaline side and in consequence the weak-acidic moisture barrier is partially destroyed and the skin surface becomes vulnerable to the increasing population of bad bacteria such as *Staphylococcus aureus*. These bad bacteria decompose fatty acid in sweat into odorous substances such as ammonia, and foul smell is generated from the body as a result of sweat fermentation. Substances resulting from sweat fermentation stimulate skin and cause itching. As the patient of atopic dermatitis has a higher skin pH, the population of *Staphylococcus aureus* is higher and facilitates to generate odorous and skin-irritating substances [4-5]. In this context, the skin disease could be suppressed by keeping skin surface in a weak-acidic condition.

Although there is no direct proof that synthetic fiber itself causes allergic dermatitis, many athletes suffer from itching, and their skin becomes susceptible to inflammation by sweating and rubbing with PET fabric. Since synthetic fiber is hydrophobic, it accumulates the fatty components from perspiration which eventually turn rancid (e.g., valeric acid) by bad bacteria and become smelly [6-7]. Those components are not removed by washing and accumulated more to generate unbearable foul smell. Dermatologists suggest that the patient of atopic dermatitis should wear cotton because synthetic fiber induces skin irritation and promotes dermatitis. However, no pathological reason is clear why cotton is good for those patients.

In this study, we prepare the T-shirts made of weak-acidic PET fabrics and conduct wearing test to examine the effect of weak-acidic PET on the pH value at skin surface. The generation of foul smell and skin inflammation is expected to be suppressed by maintaining a weak-acidic condition at skin surface.

3-2. Experimental

3-2-1.Sample preparation

Polylactic acid (PLA) is known to exhibit a weak-acidic property by partial decomposition. A commercial polylactic acid (PLA) was adapted as Sample A (BIOFRONT™ from TEIJIN LIMITED) in the present study. Another weak-acidic polyethylene terephthalate (weak-acidic PET) was prepared by incorporating weak-acidic components (acetic acid and malic acid) into the amorphous region of new type PET fiber (Sample B: ECOPURE™; malic acid processed PET and Sample C: acetic acid processed PET from TEIJIN FRONTIER CO.,LTD) [8]. All samples were prepared from the knitted fabrics of the weight 150g/m^2, compose of 84 dtex, 72 filaments. The new type PET fibers produced from the copolymer of ethylene diol, terephthalic acid and a small amount of ester-forming sulfonium metal salt compound were immersed in acetic acid or malic acid exceed pH=5 at 70°C for 20 – 40 min to prepare weak-acid PET. These fabrics are partially hydrolyzed by weak-acidic groups after alkaline reduction, and free weak-acidic group are thought to localize in the vicinity of the sulfonium metal salts. These samples are subjected to skin patch test for initial screening , and Sample A and Sample B are selected for further wearing tests.

3-2-2. Characterization of sample fabrics

Buffering effect

The buffering effect of modified PET was confirmed by immersing the sample fabric in ammonia aqueous solution (pH 9.0) and monitoring the pH change of the solution. The pH was measured by a pH meter manufactured by HORIBA.

Antibacterial property

The antibacterial property was evaluated by JIS L1902, the method of fungus liquid absorption. *Staphylococcus aureus* (ATCC 6538P) was used as a source stain. The bacteria were mixed with agar and the mixture was poured onto a sample fabric previously set in a laboratory dish. The dish was held at 36 °C for 18 hours in an oven. The concentration of living bacteria was evaluated immediately after incubation.

Deodorant property

The deodorant effect was evaluated by means of the aerometric method using a vacuum type gas sampling device (Gas Tec Co., Ltd. GV-100S type) and a detector tube. Two pure chemical odor substances, acetic acid and ammonia, were used as standard sample odors. 99.7 % acetic acid solution and 28% aqueous ammonia solution were diluted 10 times and each 100 μL was injected in a bag made of vinyl fluoride (10L) by a microsyringe. Then the respective liquid in the bag was vaporized in an oven at 38 ^{o}C to generate an odor gas. After the sample fabric (1g) was placed in a bag (2L) and 1 L odor gas was injected, the bag was sealed tightly. After one hour, the gas in the bag was sampled with the gas sampling device and the concentration of the sample odor substance was measured by the detector tube. Using the value thus obtained, the odor survival rate was evaluated from the following equation

$$\text{odor survival rate} = \frac{\text{odor survival concentration with the sample (ppm)}}{\text{the original odor concentration without sample (ppm)}} \times 100$$

Here the survival concentration denotes the concentration of the sample odor substance in the gas after one hour in the bag.

3-2-3.Patch test

The safety of introduced acidic components was checked by a patch test in advance, where a patch of sample fabrics (1.5cm x 1.5cm) was fixed on the skin by a surgical tape and the skin condition was evaluated according to the standard table provided by the medical authority after 24, 48 and 72 hours.

3-2-4.Wearing test

The wearing tests were performed with the fabric of two kinds of PET (Sample A and Sample B) and untreated (regular) PET. The subjects consisted of healthy 5 women from 22 to 27 years old, and were asked to perform Ergometer exercise for 20 minutes in a constant temperature room kept at 30 ^{o}C (the humidity 65% RH). The subjects took a shower to refresh skin just before wearing test. The pH value at the skin surface was measured at 7 positions on the neck (upper neck and lower neck) and back (centre, upper right, upper left, lower right and lower left) with a pH meter (Hanna Instruments) before exercise, immediately after exercise, 10 minutes after exercise and 30 minutes after exercise.

3-3. Results and discussion

3-3-1.Buffering effect

The buffering effect of modified PET was confirmed by immersing the sample fabrics (Samples A, B and C) in ammonia aqueous solution (pH 9.0) and monitoring the pH change of the solution. As shown in Figure 3-1 the weak-acidic PET reduces the pH value of the solution while untreated PET slowly decreased because ammonia aqueous solution absorbed water in the air. Both Samples A and B reduce pH to 6.5 while Sample C reduces pH further down to 5.0. Here Sample A decomposed slightly in alkaline aqueous solution and reduced pH. It indicated that acid in PET (Sample B, C) may ooze out to ammonia solution due to lower pH value.

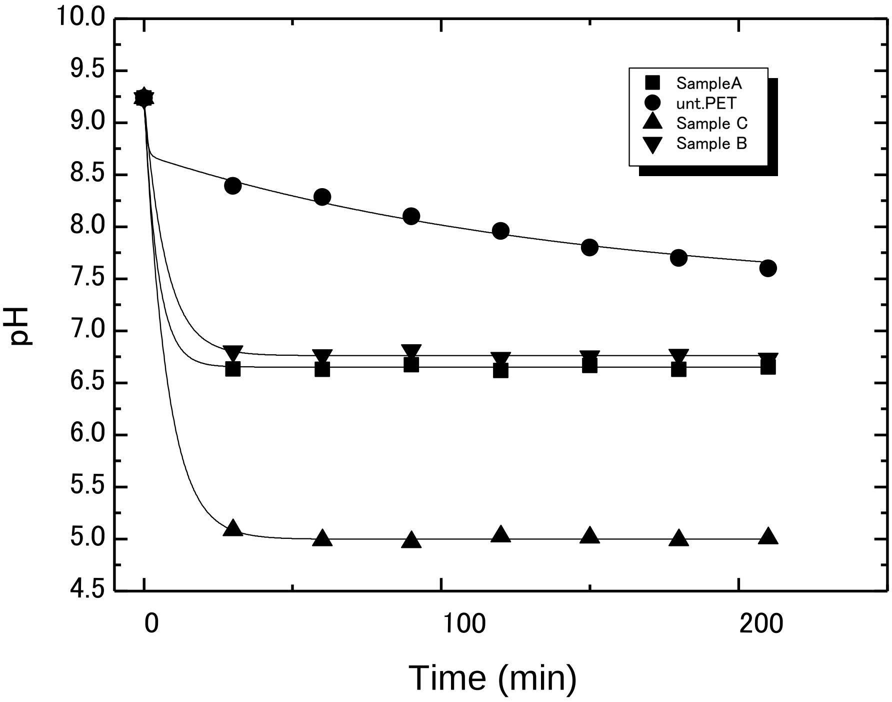

Figure 3-1 pH buffering effect of weak acidic polyester in ammonia aqueous solution (pH9.0).

3-3-2.Antibacterial property

The pH values evaluated for original PET fabrics. The pH of fabrics was

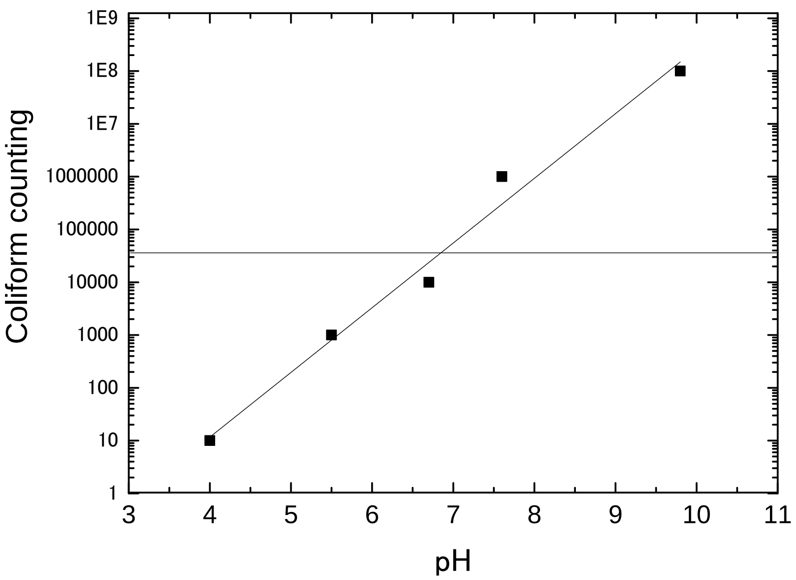

Figure 3-2 Fabric pH dependence of bacterial growth against *Staphylococcous aureus.*

measured from the change of color of pH-test paper by dropping 0.10 cc of pure water (pH7.0) on the PET fabrics. The pH value of PET fabrics ranged from 6.0 to 6.5. Here the antibacterial property was evaluated by the coliform counting for PET fabrics processed with the pH adjusted polyethylene terephthalate resin. Here the pH of PET resin was adjusted by controlling the amount of sulfonation. Figure 3-2 shows the bacteria growth on fabric surface as a function of pH and the coliform counting number (the number of living bacteria). As mentioned above, the original PET fabrics exhibited the pH value from 6.0 to 6.5. The initial number of coliform was set to 2.6×10^4, so that with the expected antibacterial property of PLA (polylactic acid) and weak-acidic PET.

Table 3-1 The Antibacterial property of various sample fabrics against *Staphylococcus aureuss*

Sample	Logarithmic value of number of living bacteria (number)		Activity of bacteriostasis＊
	Before incubation	After Incubation for 18hrs	
Sample A	4.3	2.0	4.9
Sample B	4.3	1.3	5.6
Reg PET	4.2	6.3	0.5
Standard fabric	4.3	6.9	-

＊Activity of bacteriostasis＝(Mb-Ma) –(Mc-Mo)

Mb-Ma :Difference of logarithmic value of number of living bacteria of standard fabrics before(Mb) and after (Ma)incubation, Mc- Mo : Difference of logarithmic value of number of living bacteria of sample fabrics before(Mc) and after (Mo)incubation.

The antibacterial property against *Staphylococcus aureus* was evaluated for Sample A and Sample B by the JIS method, and the results were shown in

Table 3-1. The result of untreated PET is also shown for reference. After incubation of 18 hrs, the number of living bacteria on untreated PET increased, whereas the number decreased for both Sample A and Sample B as expected. Table 1 shows the activity of bacteriostasis of three kinds of fabrics. According to the JIS L 1902, the antibacteric property appears when the activity of bacteriostasis exceeds 2.2. As the values of 4.9 and 5.6 were specified respectively for Sample A and B, there Samples are classified as antibacterial fabrics. That is, the weak-acidic fabrics represented by Samples A and B suppress the growth of bad bacteria.

3-3-3. Deodorant property

Figure3-3 shows the deodorant effect on ammonia and acetic acid for three samples including Sample ample B and untreated PET. Sample B exhibit an excellent deodorant effect on ammonia (the odor survival rate is less than 20 %). Sample A and untreated PET show the similar deodorant effect (the odor

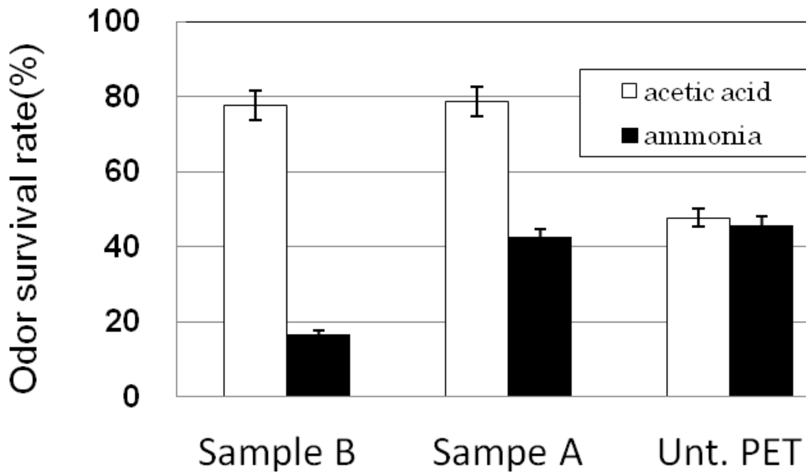

Figure 3-3 The deodorant property of weak acid PET (Sample B) and PLA(Sample A) compared with untreated PET.

survival rate is approximately 40 %). Since Sample B is acidic in nature, it shows a deodorant effect on alkaline odor by neutralization. However, hardly any deodorant effect was observed on acetic acid, since all the samples and odor substance are acidic and no reaction is expected between them.

3-3-4. Patch test

Prior to the wearing test, a patch test was conducted for all the samples. The results are summarized in Table 3-2. Except for Sample C the results are negative for all subjects, so that Sample A and Sample B were adapted for further wearing test. Sample C treated with acetic-acid has caused skin irritation on two healthy female subjects. As shown in Figure 3-1, the pH of ammonia solution immersed Sample C drastically decreased because a large amount of acetic acid oozes out to ammonia solution, and therefore the pH of the skin should not be too low despite of higher antibacterial effect.

Table 3-2 The results of patch test＊

Subject	After 24 hours			After 48 hours			After 78 hours		
	A	B	C	A	B	C	A	B	C
Subject A	-	-	+	-	-	+	-	-	+
Subject B	-	-	-	-	-	-	-	-	-
Subject C	-	-	-	-	-	-	-	-	-
Subject D	-	-	-	-	-	+	-	-	+
Subject E	-	-	-	-	-	-	-	-	-

＊ + : positive, - : negative

A : Sample A (lactic acid), B : Sample B (malic acid), C : Sample C (acetic acid)

3-3-5. Wearing test

T-shirts were prepared from the three kinds of samples. We conducted wearing test on 5 subjects and three times in each sample. Figure3-4 shows an example of the pH change at the skin surface of the subject J being a representative example at respective time intervals, wearing untreated PET and two kinds of weak-acidic PET shirts. The pH values at skin surface in this Figure were averaged over the pH values measured at 7 positions on the neck and back. Here the test was repeated three times for each fabric and subject. The skin pH of the subject before exercise was slightly acidic at 4.8 - 5.1. When the subject worn PLA and the weak-acidic PET with malic acid (Sample A or Sample B), the averaged pH value at skin surface decreased to 3.8 - 4.3 by sweating after exercise. The pH value is still low even after resting for 30 minutes, whereas the pH value lightly increased in the case of untreated PET. PLA shows a considerable decrease of the pH value at the skin surface by sweating except a subject who sweats a little and does not exercise much. By sweating, the pH value decreases but eventually increases by resting. Since acid groups will ooze out into sweat while resting, the pH value decreases further. Regular PET shows no fundamental differece of the pH value by sweating although the pH value depends on the characteristics of individual sweat. This tendency was observed for all subjects except for one who sweats only a little and does not do exercises much. The effect of PLA and weak-acidic was compared in this Figure. Since the weak-acidic groups are not chemically bonded to PET in the case of Sample B, the pH value decreases consistently over the period of an exercise cycle, whereas Sample A exhibits a slight increase of the pH value after its initial drop due to its monomer or dimer resulted from the partially degraded PLA fiber surface.

A similar effect was also observed in the wearing test of T-shirts for two weeks even repeated with washing after they were worn, where the unpleasant odor generation was considerably reduced by wearing T-shirts made of Sample A or Sample B. A remarkable effect was observed for an allergic patience as demonstrated from the picture (Figure 3-5). Red spots appeared after 10 minutes wearing the untreated PET T-shirt. However, when wearing weak-acidic PET T-shirt, no red spot appeared even after a few hours. This result indicates that the skin condition is important for preventing skin disorder. Here, the skin surface should be kept pH slightly acidic side, but not too acidic.

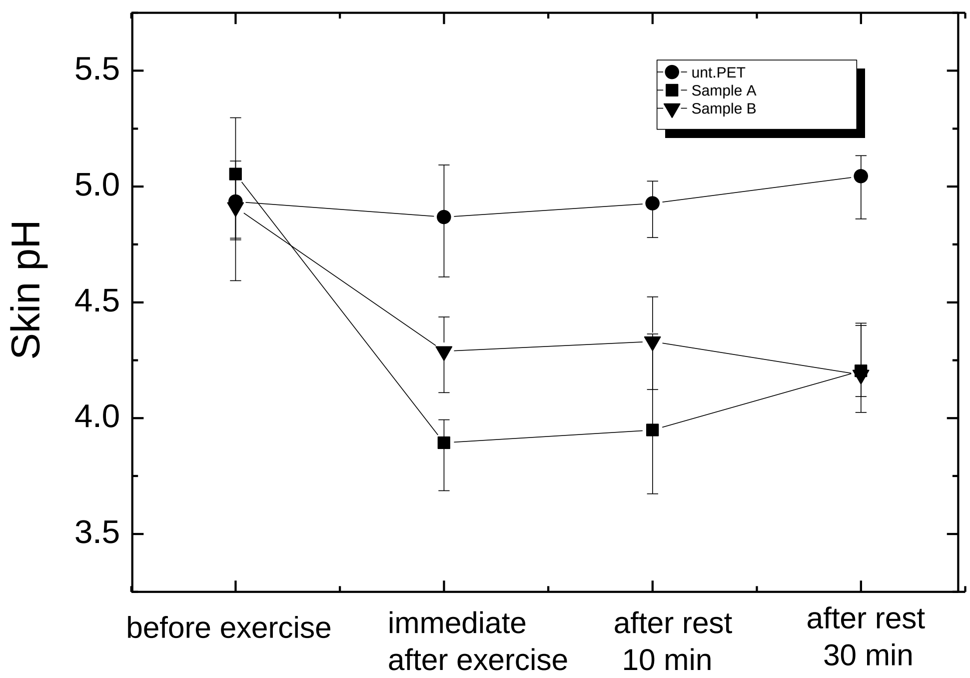

Figure3-4 Comparison of skin pH on weak acidic PET(Sample B), PLA(Sample A) and untreated PET.

Figure 3-5 Wearing test of Weak acidic PET (Sample B) and Untreated PET by an allergic patient.

3-4. Conclusion

Skin condition is known to depend on the pH value at skin surface. A healthy skin surface is weak-acidic due to weak-acidic moisture barrier (pH = 4.5 ~ 5.5). The moisture barrier consists of various components including urea, amino acids, sugar-protein complex and sodium/calcium lactate. Those components are discharged by human sweat or produced by inhabitant bacteria on the skin. Although the significance of skin surface acidity is still under dispute, weak-acidity suppresses the growth of bad bacteria such as *Staphylococcus aureus* and *corynebacterium* which cause foul smell and skin disorder. In consequence the skin condition is kept in order by the function of good bacteria *Staphylococcus epidermidis*.

Less hydrophobic weak-acidic PET fabrics are proved to order the skin condition by suppressing the growth of bad bacteria and maintaining moisture in a horny layer. Although the fabrics have no direct effect on skin conditioning, they seem to ease skin stimulation and result in improving skin condition.

Acknowledgements

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Chapter 4

Synergy Effect of Design and Deodorant/Antibacterial Function for a Grip Rod for an Immobilized Hand of Cerebral Infarction Patients

4-1. Introduction

The current elderly person population of our country has reached the ratio 20% of the total population and the super aging society have been received where one of five persons is an elderly person. As becoming older, among Japan's three major diseases such as cancer, acute myocardial infarction, cerebral stroke, the onset rate of stroke increases and the elderly persons in the nursing care states, like bedridden and dementia states, are rapidly increasing. Not moving a body like bedridden, then the soft tissues such as muscle and skin around joints lose the elasticity and become tense, which causes the contracture of the fingers shown in Figure 4-1. The contracture means the state when a joint causes the disturbance of the excursion and there are two kinds, flexion contracture in the flexion keeping state shown in the Figure and extension contracture in the extension keeping state. The contracture is caused by the case that hands and feet could not be moved from the cerebral stroke and so on and the case that the bedridden state has continued for a long time not

Flexure contracture Extension contracture

Figure 4-1 A contracture state of hand and fingers.

moved by an elderly person care, and since the number of the stroke persons all over Japan is 1,371,365 (about 666,000 males and 699,000 females) (Ministry of Health, Labour and Welfare 2005 patient investigation) , as many persons are considered to suffer the contracture. In the flexion contracture case shown in Figure 4-1, the state grasping the hands tightly was kept, so it has non-breathability, easily getting sweaty, the continuous hand wet and the heating, the smell occurred and the skin disease like athletic foot appeared in the bad cases. The bad smell like fermented cheese occurs, so the patient is forced to grasp a hand-towel and the gauze that includes tea leaves pack [1] or coffee bean cake [2] as a deodorant to remove the ill odor but the present condition is that the smell and dampness of the palm cannot be solved. The cases of Trichophyton propagation or fungal infection complication have been reported when the contracture degree is getting worse [3,4]. Therefore, to resolve the problems as the wetness and bad smell of the palm caused by the contracture are required.

For these situations, the nursing care goods to prevent the bad smell and contracture of the palm are required. The functional fiber used for the nursing care equipment must be selected which does not badly effect for the body because it directly touches the palm, as well as the deodorant property. So far, Shirai et al have developed a deodorant and antibacterial fibers, it has been deployed a number of textile products [5, 6]. In this study, the iron (III) tetracarboxy phthalocyanine-processed fabrics [7] were used which is safe for human body since it has the structure similar to the enzyme that exists in human body and applied to the nursing care goods for the applied of finger contracture patient, and then the effect have been discussed.

4-2. Experimental

4-2-1.Sample preparation

After refining and bleaching a cotton knitting (weft knitting, thickness 0.5mm, weight 110 g/m^2), it was entered into the mixture 10L with the water solution as a cationization agent of cathinone UK 50cc/L and sodium hydroxide 15 g/L with the liquor ration 1:10 and reacted at 85℃ for 45 minutes. After sufficiently rinsing the obtained cationization cotton knitting with water, it was immersed in the sodium hydroxide water solution (pH = 12) 10L of iron (III) phthalocyanine tetracarboxylic acid[8], 0.5% owf, stirred at 80℃ for 30 minutes, and then neutralized with acid. After sufficiently rinsing the obtained cotton knitting with water and drying it, the iron (III) tetracarboxy phthalocyanine-processed fabrics were obtained [9]. Furthermore, copper sulfate (II) hydrate 5g was dissolved into ammonia water solution (15cc/L) 1L and the iron (III) tetracarboxy phthalocyanine-processed fabrics were immersed into it at 30℃ for 20 minutes with stirring. This sample fabric was sufficiently rinsing with water and dried, then the iron phthalocyanine copper (II) ammonia complex-processed fabrics were prepared (it is called the iron phthalocyanine processed with copper fabrics below).

4-2-2.Deodorant property

The bad smell material (acetic acid, ammonia) 100μL was contained into a Tedlar bag and vaporized in a drier at 38℃, which prepared as the bad smell gas. The sample (10cmx10cm, 1g) was entered into a Tedlar bag and additively the bad smell gas 1L was entered, then the bag was sealed and left for the predetermined time. After the time passed, as the bad smell concentration in the Tedlar bag, using a gas detector tube and the gas sampling pump (Gastec product GV100S), the gas 50mL in the bag was sampled and the residual level was determined. The odor survival rate was calculated using the following formula.

$$\text{odor survival rate} = \frac{\text{odor survival concentration with the sample (ppm)}}{\text{the original odor concentration without sample (ppm)}} \times 100$$

As the bad smell, acetic acid which is model gas of lower fatty acid was used for the sebum origin smell ingredient developed when the sebum was secreted from the body on the contracture and decomposed and the sweat origin smell ingredient ammonia.

4-2-3.Antibacterial property

The antibacterial property followed the bacteria liquid absorption method JIS L1902 to examine the antibacterial against *Staphylococcus aureus* (ATCC 6538P). The number of the live bacteria of *Staphylococcus aureus* was measured by a pour plate culture method, the activity of bacteriostasis was calculated using the next formula.

Activity of bacteriostasis = (Mb – Ma) – (Mc – Mo)

Here, the calculation used the difference of the common logarithm values of the number of live bacteria with the reference fabric (cotton) before (Mb) and 18 hours incubation (Ma) and that for the sample fabric, before (Mc) and after incubation for 18hrs(Mo).

4-2-4.Grip rod

For provision of the finger contracture, the grip rod was made using the iron (III) tetracarboxy phthalocyanine-processed fabrics and the iron phthalocyanine processed with copper fabrics (Figure 4-2). The grip rod consisted of the grip part contacting the palm and the belt part winded around the hand and the fingers. The grip part was the pouched object the length of which was about 13cm in the warp direction of the knitting fabric and 5.5cm in the weft and which included low elasticity urethane foam as cushion form to prevent the contracture. On the other hand, the belt part was equipped with the strip form belts, 21cm length and 4cm width, where 2 above or below the grip and 4 on the right side of the grip. It was fixed on the back of the hand with the belts above or below it and worn on the fingers with the four right side belts (Figure 4-2). To examine the actual effect of the designed grip rod on the deodorant property and skin disease, the clinical test was performed at elderly homes.

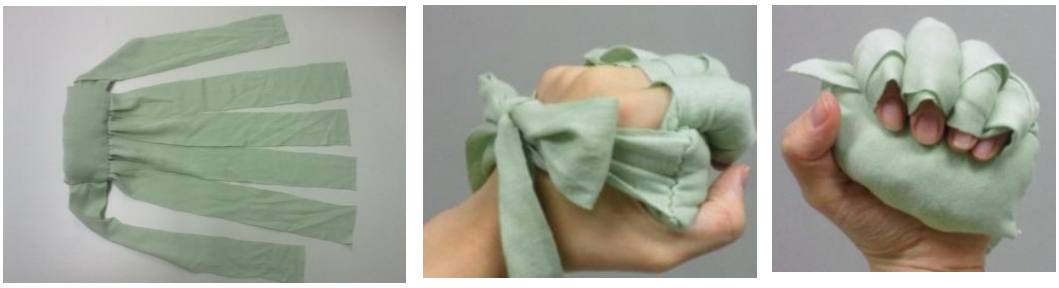

Figure 4-2 Design of grip rod.

4-2-5.Clinical Test

The clinical test was performed from March to August, 2010 at the healthcare facilities for elderly of Saku Central Hospital Health Services Facilities for Elderly (Saku city, Nagano prefecture) for 3 male patients and 3 females (75 to 83-year-old) with the finger contracture using the grip rods. In addition, for eight days of from September 14 to 21, 2010, the clinical test was performed at Mitsui sunlight garden (Koto-ku, Tokyo) for 5 female patients (from 90 years old 100 years old) with the finger contracture. At both facilities, letting the patient with the finger contracture grasp the grip rod, the change of the state of the bad smell and skin disease was compared and observed. The bad smell was examined using the six grades odor intensity measurement method (0: odorless, 1: very weak (narrowly detected odor), 2: weak(weak odor the origin of which can be determined), 3: easily detectable odor, 4: strong odor, 5: very strong odor as for the strength of the smell and the degree of the odor hedonics was examined using the nine grades odor hedonics indication method (-4: extremely unpleasant, -3: very unpleasant, -2: unpleasant, -1: rather unpleasant, 0: neutral, 1: rather pleasant, 2: pleasant, 3: very pleasant, 4: extremely pleasant by the sense of 5 persons of the stuffs and students who passed the sense of smell test with the T&T olfactometer reagent [10]. The state of the skin diseased part was examined by the visual observation. At the test, the volume of the cushion of the grip part of the grip rod was adjusted according to the examinee and the clinical test was performed. For the first procedure, the grasping grip rod was released, the hand was smelled, and the state of the skin diseased part was photographed.

4-3. Result and Consideration

4-3-1.Deodorant effect

Since the contracture patient tightly grasps the hands from the contracture, the perspiration always keeps the wet state and the smell ingredient, this ingredient are mixed ammonia generated when the sweat broken from the body is decomposed and the smell ingredient such as lower fatty acid, e.g. acetic acid, butyric acid, and isovaleric acid of sebum origin are

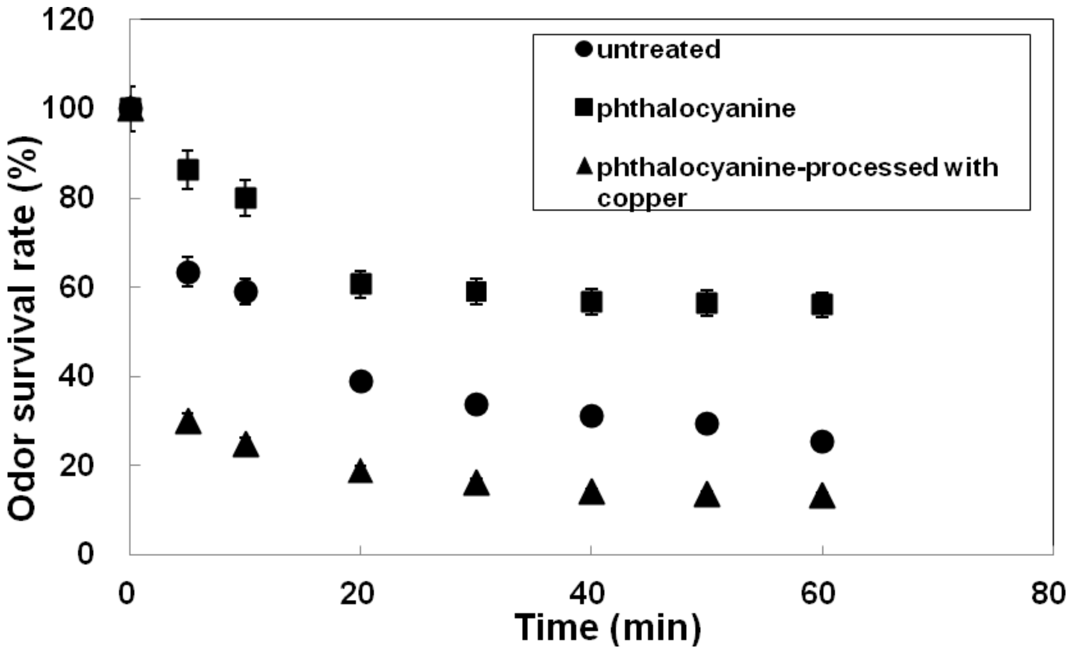

Figure 4-3 Time dependence of concentration of ammonia absorbed by sample fabrics.

developed. Focusing on the sweat origin ammonia and of sebum origin acetic acid, the following this experiment examined the deodorant of iron (III) tetracarboxy phthalocyanine-processed fabrics and iron phthalocyanine processed with copper fabrics. Figure 4-3 shows the temporal change of the odor survival rate of the sample fabric for ammonia. The result indicates that the deodorant of the iron (III) tetracarboxy phthalocyanine-processed fabric against ammonia has lower deodorant prooerty than non-processed cotton. This low deodorant was indicated because the cotton fiber was cationized before the iron (III) phthalocyanine tetracarboxylic acid was delivered into the OH group of the cotton fiber and this caused the repulsion between the cationization and ammonia. Under the reaction condition of this experiment on the iron (III) tetracarboxy phthalocyanine - processed fabric, iron (III) phthalocyanine tetracarboxylic acid was delivered at the rate of one molecule for 100 residues of the cotton fiber OH group. However, deodorant effect could be to more or less degree observed as the (-COO-) of the iron (III) phthalocyanine tetracarboxylic acid reacted with ammonia and changed into (-$COONH_4$). The deodorant of the fabric which was delivered with the copper further into the iron (III) tetracarboxy phthalocyanine-processed fabric (iron phthalocyanine with copper), had the effect that the odor survival rate was 25% for the exposure time 5 minutes. Therefore the deodorant speed was higher and had more deodorant ability than iron (III) phthalocyanine. As for the copper (II) ammine complex, the OH group of the cotton fiber and the ammonia easily made the following (see Figure 4-4) coordination bonds and the reaction formed the cellulose copper (II) complex, which means that both effects of the iron (III) phthalocyanine tetracarboxylic acid and the copper were detected [11,12,13].

Figure 4-5 shows the result to examine the deodorant effect of the sample fabric against the acetic acid smell. For the acetic acid, both samples indicated the low odor survival rate (concentration of acetic acid) around 5% for the exposure time about 5 minutes so the high deodorant effect was detected.

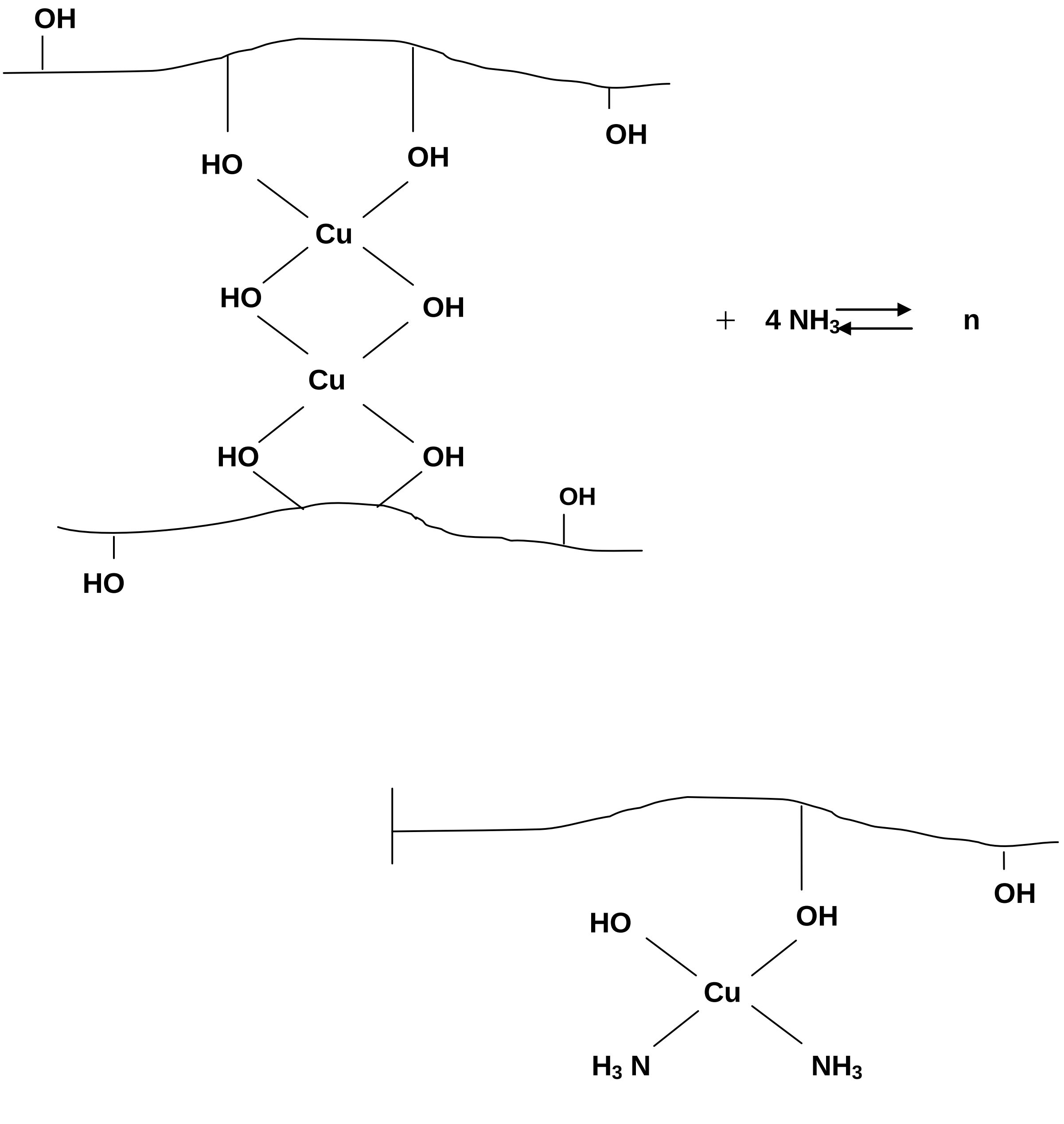

Figure 4-4 Chemical reaction.

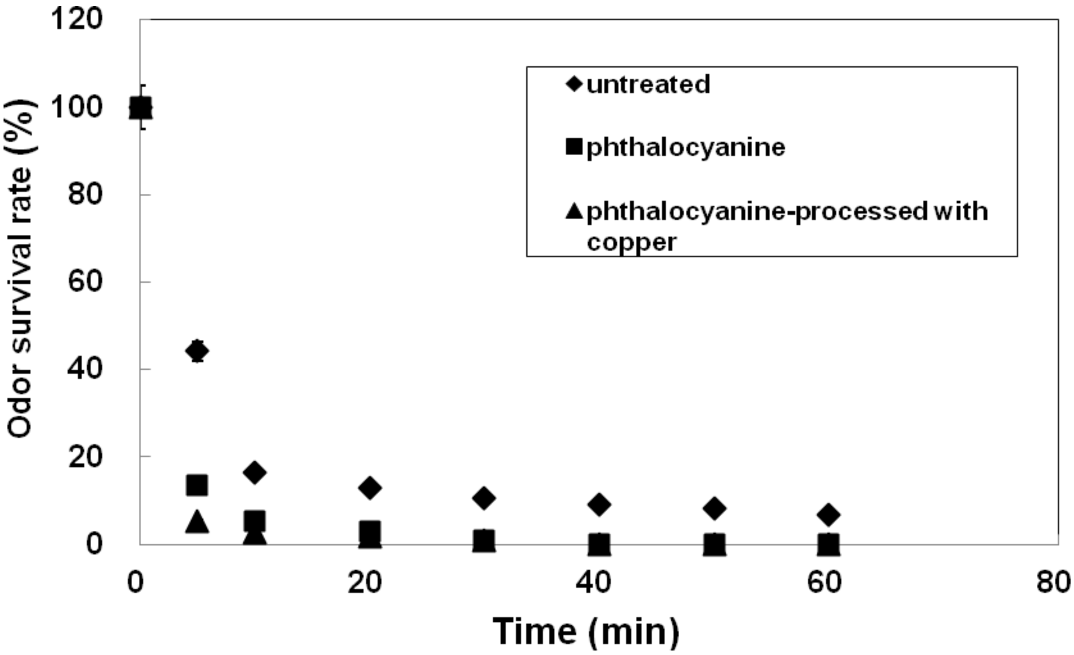

Figure 4-5 Time dependence of concentration of acetic acid absorbed by sample fabrics.

Among them, the iron phthalocyanine with copper indicated the lowest odor survival rate and the quickness of the deodorant speed. This result is considered that progressing the reaction of the copper and the acetic acid, Cu (II) $(CH_3COO)_2$ was formed. As described above, it was found that the iron phthalocyanine processed with copper fabrics was fast for the deodorant speed against ammonia and acetic acid and indicated the good deodorant effect.

4-3-2.Antibacterial effect

There exist the good bacteria and the bad bacteria among bacteria propagating on human skin surface. The good bacteria like *Staphylococcus epidermidis* decompose the sweat ingredient taking a role of keeping skin wet, while the bad bacteria like *Staphylococcus aureus* decompose the sweat to the bad smell material and develop the bad smell like ammonia smell [14]. Generally, many *Staphylococcus aureus* exist on skin surface[15], therefore the antibacterial of the iron (III) tetracarboxy phthalocyanine-processed fabric and the iron phthalocyanine processed with copper fabric against *Staphylococcus aureus* was examined and Table 4-1 show as the result.

Table 4-1 Comparison of living bacteria before/after incubation

Sample	Incubation time (hr)	A number of living bacteria (number)	Activity of bacteriostasis
Untreated	18	7.6×10^6	-
Phthalocyanine - processed	0	9.6×10^3	2.7
	18	6.4×10^3	
Phthalocyanine-processed with copper	0	8.0×10^3	3.7
	18	5.0×10^2	

In the table, the number of *Staphylococcus aureus* live bacteria is indicated and bacteriostasis activity simultaneously. The activity of bacteriostasis the iron (III) tetracarboxy phthalocyanine-processed fabric and the iron phthalocyanine processed with copper fabric achieved the valuation basis of the antiodor finishing, that activity of bacteriostasis is 2.2 or more. In particular, it was confirmed that the iron phthalocyanine processed with copper fabric had high bacterial because its activity of bacteriostasis was 3.7 which largely exceeded the evaluation basis and the number of live bacteria decreased to about 1/10 of the number of live bacteria of the iron (III) tetracarboxy phthalocyanine-processed fabric. The effect of the metal copper complex can be determined.

4-3- 3.Clinical Test

For the patients who developed the skin disease and the bad smell from the finger contracture, using the grip rod, the change of the smell and the finger skin state. First, at Saku Central Hospital from March to April, Heisei 22 year, the grip rods using the iron (III) tetracarboxy phthalocyanine-processed fabric were applied to the patients with the finger contracture. For 3 patients whose degree of the skin disease varied but whose finger contracture was intense, the grip rods were used for about 7-10 days. The person in an example whose finger contracture was especially intense and whose skin disease was severe as illustrated in Figure 4-6 shows the change of the skin disease before and after using the grip rod. The reason was determined by the dermatologist diagnosis indicating that grasping the hand for a long time from the contracture and being wet by the sweat developed, *Trichophyton* fungus propagated on the hand without the breathability. The Figure shows the skin disease state and the skin disease was recovered to the health skin state after using the grip rod for 8 days. All 3 finger contracture patients recovered the health skin state for about 7-8 days using the grip rods.

Before using hand grip After using hand grip for 8 days

Figure 4-6 Change of shin disease of the palm before and after using the grip rod.

Furthermore, the grip rod using the iron phthalocyanine processed with copper fabric was applied to the finger contracture patients as well. The part where contracture was observed alkaline by the sweat. Primarily the pH of health skin is weakly acid but it has been reported that in case that the skin pH is getting alkaline, *Staphylococcus aureus* existing on the skin surface will propagate [16]. It is estimated that the reason of the skin disease of the finger contracture patient is *Trichophyton* fungus and *Staphylococcus aureus* propagate according to the change of the hand skin pH of the finger contracture patient. More effect could be expected because the iron phthalocyanine processed with copper fabric indicates better antibacterial than the iron (III) tetracarboxy phthalocyanine. Applying the grip rod using the iron phthalocyanine processed with copper fabric to the finger contracture patients, the skin state change was examined.

Figure 4-7 Change of the skin disease among fingers using the grip rod made of the iron phthalocyanin -processed fabrics with cupper.

For the finger contracture patients this clinical test is about how much skin disease was observed at the part without breathability such as the palm or the part between fingers. Figure 4-7 shows the change of the skin diseased part of the representative person. For the grip rod using the iron phthalocyanine processed with copper fabric, it was found that letting the iron phthalocyanine processed with copper fabric directly in contact the diseased part of the finger contracture patient, as shown in the Figure. Nearly health state was recovered 3-4 days later and completely recovered for about 1 week. Applying the grip rod using the iron (III) tetracarboxy phthalocyanine-processed fabric and the iron phthalocyanine processed with copper fabric, the steps, wet skin state, dry state, then skin regeneration, and reduced redness were followed and health skin state was recovered. The skin recovery speed of the iron phthalocyanine copper was recognized faster than the iron (III) tetracarboxy phthalocyanine. The recovery effect is considered to be caused by the antibacterial effect of the active ingredient which let the cationized fiber material support the metal phthalocyanines and furthermore the metal ammine complex.

The change of the hand smell was examined applying the grip rod using the iron phthalocyanine processed with copper fabric. The persons who passed the standard sense of smell test with the T&T olfactometer reagent examined the degree of the odor hedonics and the smell strength. Figure 8, 9 shows the average value of the hand smell change of 5 contracture patients. The smell caused by the contracture is similar to the smell of the fermentation of cheese origin the sebum developed from the hand. Most people feel "rather unpleasant" against such smell. On the 3rd or 4th day after using the grip rod when the skin disease were recovered, it was deodorized like "neutral (neither unpleasant nor pleasant)", furthermore on the 8th day completely became "odorless (no odor)" and the examinees felt nothing.

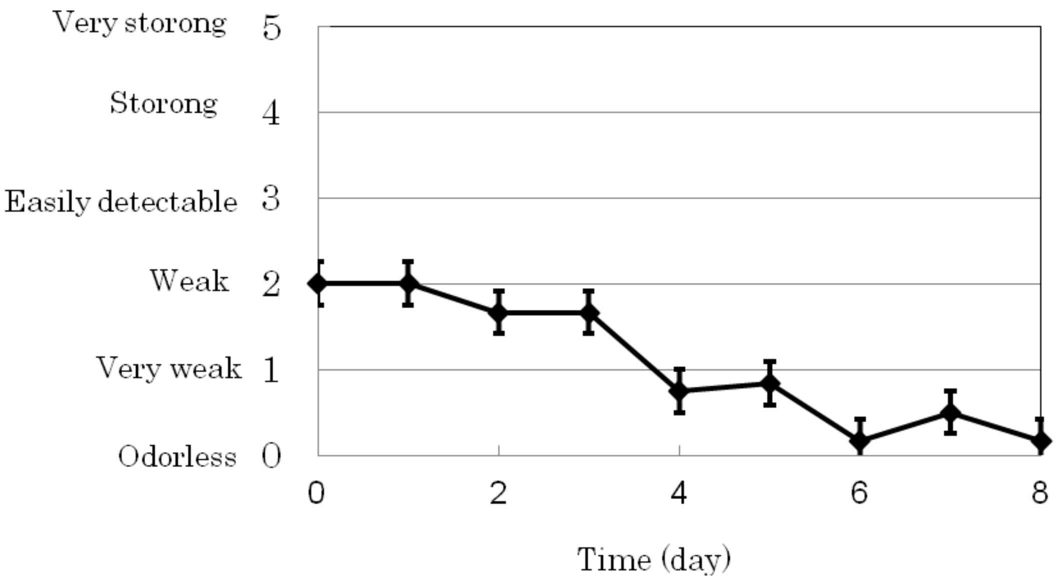

Figure 4-8 Change in sensitivity of the strength degree of hand smell.

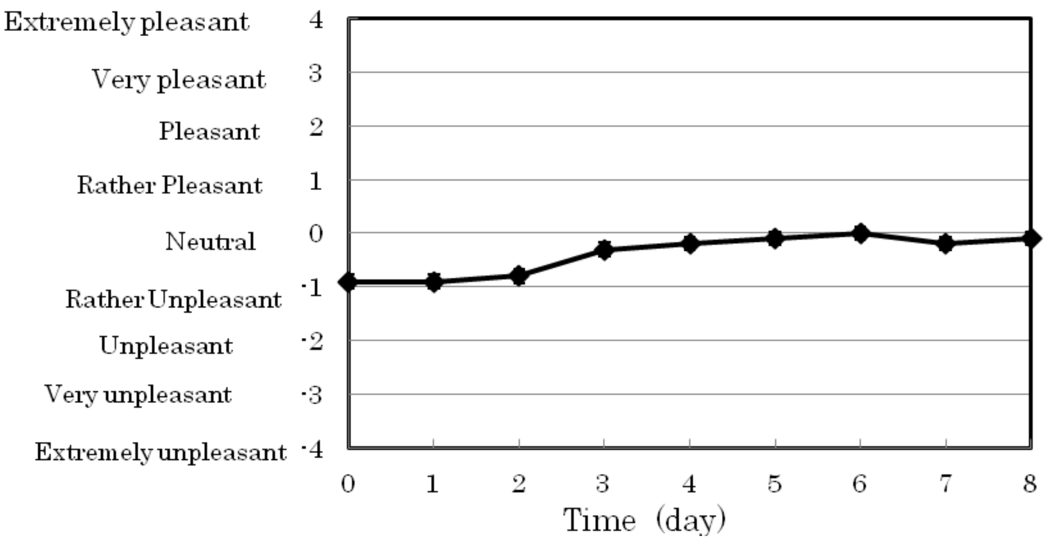

Figure 4-9 Change in the degree of pleasant/unpleasant of the hand smell.

Acknowledgement

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Chapter 5

An Assessment of Workload on Upper Limbs when Caretaker Change the Nursing Trousers

5-1. Introduction

The Japan's ageing population situation, nursing care has become a significant social issue. When preparing for the national exams to gain a license, nursing care workers are required to posse basic job techniques, ergonomic knowledge, and an understanding to body mechanics that will help them to ease the burden of nursing care [1]. It is, however too much to ask the general public, who often provide home-based care for their family members, to acquire such basic techniques and expert knowledge [2]. Such being the case, there has been a growing demand for the development of nursing care goods that ordinary people can use effectively in their homes without a great deal of expert techniques or knowledge.

As explained the situation of nursing field was shown in Chapter 1, the caretaker must change the position of the recipient for excretion and changing clothes, and this is feared to cause strain in their lower back. Since such actions also involve procedures that use one's hands, a burden is placed on the upper limbs and shoulders of the caretaker as well.

In many of the studies on nursing care movements and their associated burden, the strain on the lower back and the degree of burden on the entire body are assessed [3,4], only a few takes into the consideration of the measurement and assessment of the burden associated with the upper limb movements . This area of study should not be taken lightly as it is impossible for caretakers to carry out their jobs without using their upper limbs [5]. If the relationship between movements of the upper limbs and the resultant burden can be made clear, it may be possible to gain knowledge that would be useful for designing nursing care clothes and diapers that can be easily put on and removed.

In this research, the upper limb movements of caretakers when putting on / removing the dummy's nursing care clothes with different designs were measured using electromyography (EMG) and video filming. Caretakers' sensory assessments of the burden caused by their services were also investigated to determine how the physiological burden in the upper limbs and the sensation of burden relate to each other. In other words, the caretakers' burden was not only assessed using motion and EMG analysis, but also their sensation of burden was taken into account in order to gain a full insight of the knowledge that maybe useful for designing caretaker-friendly nursing care goods.

5-2. Experimental

5-2-1. Subjects and experiment samples

Subjects were 10 healthy women aged 23 ± 3 years, with a height of 159.7 ± 8.7cm and weight of 50.5 ± 8 kg. None of the women had any nursing care experience. For this experiment, four kinds of samples were used: Sample 1 consisted of ordinary pajama-type trousers (Figure 5-1), Sample 2 was a pair of trousers with a fastener on the side of each leg (Figure 5-2), Sample 3 had an opening under the crotch secured by Velcro for ease of changing diapers, strings on both sides that could be tied at the center, and narrow cuffs (Figure 5-3), and Sample 4 was identical to Sample 3 except that its cuffs were wider(Figure 5-4).

Figure5-1 Sample 1

Figure5-2 Sample 2

Figure5-3 Sample3

Figure5-4 Sample 4

5-2-2. Experiment procedures and measurement parameters

For this experiment, a silicon dummy mannequin named “Koharu-san” (Mitaka Supply Co., Ltd.; Height: 150 cm; Weight: 12 kg) was placed supine on a bed and the subjects were asked to put on and remove four different kinds of trousers on the dummy. Prior to the experiment, the subjects were briefed on the structures of each sample and the experiment procedures, and were given a chance to rehearse one time. To put on the clothes, the subjects were asked to put the sample that was laid out by the dummy's feet onto the dummy. To remove the clothes, the subjects were asked to take the sample that the dummy was wearing and place them by the dummy's feet. Each subject was asked to follow this process of putting on / removing the clothes once for each of the four samples (a total of eight procedures). The height of the bed was approximately 60 cm (Figure 5-5).

In order to assess the workload caused by movements during the procedures based on the amount of muscle activity, EMG measurements were taken from the right forearm at: 1. the extensor digitorum muscle (function: dorsal flexion of the hand joint) and 2. the palmaris longus muscle (function: palmar flexion of the hand muscle) (Figure 5-6). To analyze the procedures in detail, the experimental process was recorded on video (Panasonic DMC-FX-60) from the head of the dummy. After the experiment was over, in order to assess the sensation of burden from the set of movements, a questionnaire using the semantic differential (SD) method (scores: -2 to +2 pts.) was conducted for the four parameters of: ease of pulling up / down the trousers, fatigue when pulling up / down the trousers, ease of putting the trousers on around the hips, and fatigue when putting on the trousers around the hips. For EMG measurements, active electrodes (Delsys DE2-1) were used. Muscle

Figure5-5 The dummy mannequin (Koharu) on the bed.

potential signals were imported to a notebook PC at a sampling frequency of 1 kHz via an A/D converter (BIOPAC System MP150).

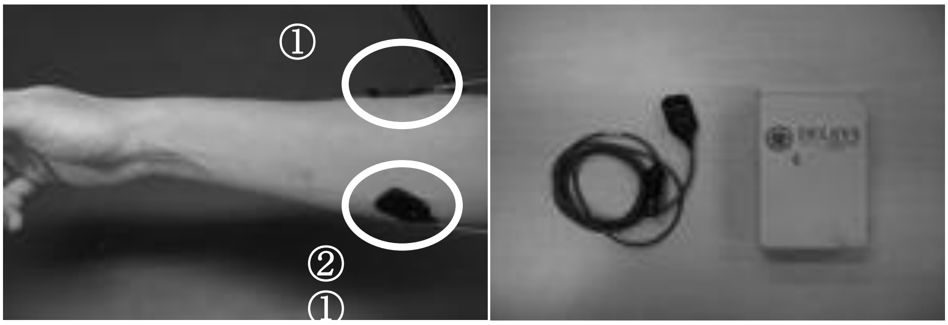


Figure5-6 Electrode attachment points and the electrodes

5-2-3. Analytical method

For the purposes of this research, in order to assess the physiological burden of the subjects, time integrated values of rectified EMG (electromyogram) and IEMG (integrated electromyogram) of the muscles being experimented on were calculated, and were then standardized with the value of maximum voluntary contraction (MVC) of voluntary movement as a reference to calculate a percentage of IEMG (%IEMG) per unit time. Additionally, in the three work processes described below, %IEMG was calculated to assess workload. For voluntary movement, the subjects were asked to clench their fists with maximum force while reaching straight outward.

$$\mathrm{IEMG} = \int_{-T}^{T} |e(t+T)|\,dt$$

e(t):EMG signal
T:time

$$\%\mathrm{IEMG} = \frac{\text{IEMG per unit time}}{\text{MVC per unit time}}$$

Figure5-7 EMG data

Figure5-8 Voluntary movement for EMG standardization

For video analysis, the time for putting on and removing nursing care trousers was measured using the recorded footage. The work process was divided into three parts and the times for each sub-process were compared: procedures around the ankles (Process 1), intermediate procedures from the ankles to the hips (Process 2), and finishing procedures such as tying the strings (Process 3). For Sample 2, Process 3 was finished when the work was completed with the fasteners closed, and for Samples 3 and 4, Process 3 corresponded to the procedures from tying the strings, etc. to the completion of the job. When removing the trousers, the order of the processes was reversed (Process 3 -> Process 2 -> Process 1), except that Process 3 is not necessary for removing Sample 1 (Process 2 -> Process 1).

For assessment of the sensation of burden, statistical analysis was made of scores from the four questions on the SD method questionnaire.

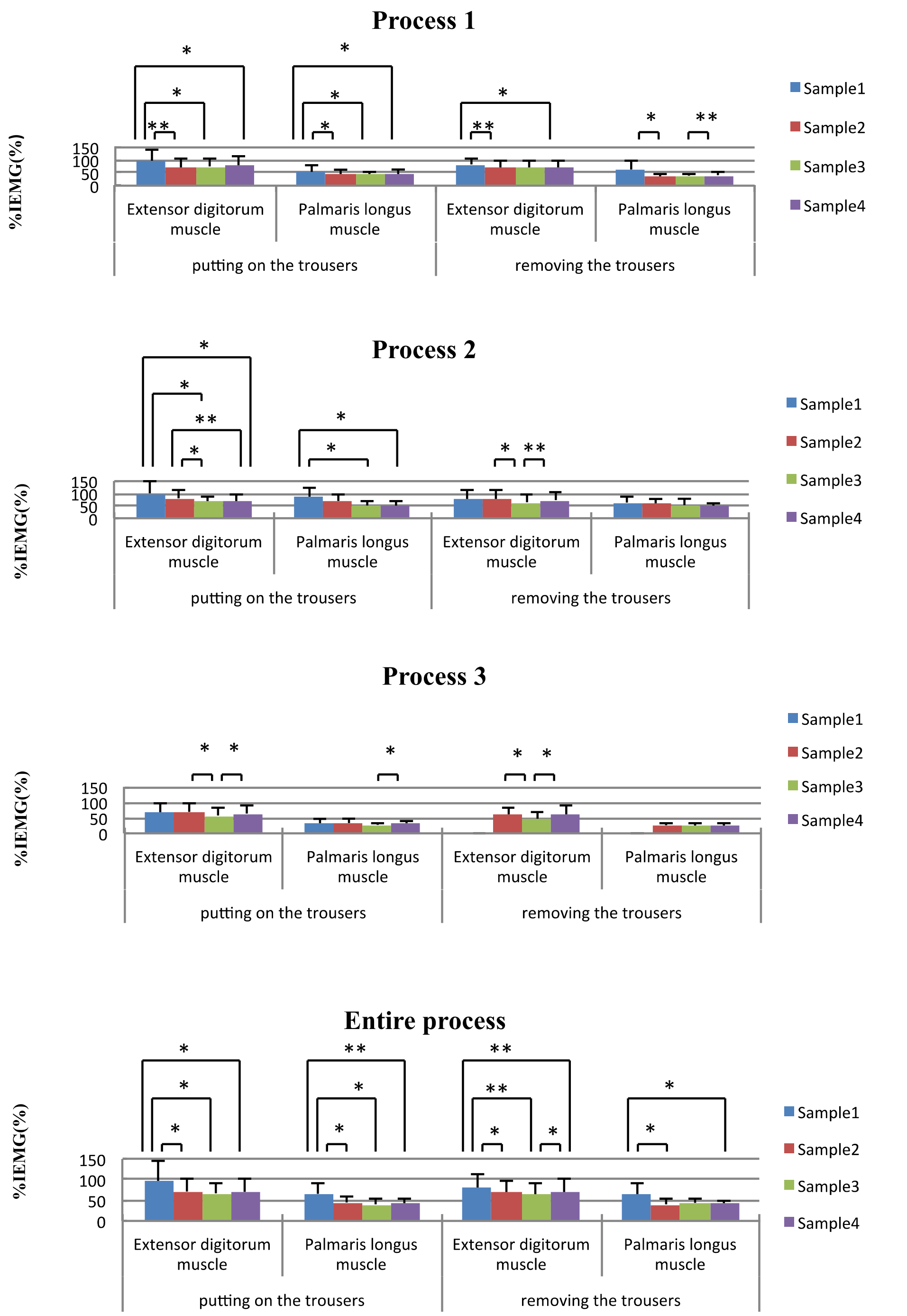
5-3. Results

5-3-1. EMG measurement

Figure 5-9 shows the results of EMG measurement. The %IEMG of the amount of muscle activity is shown on the vertical axis. The higher the value, the greater the muscle load. If we look at each sub-process during the act of putting on the trousers, the values for both the extensor digitorum and palmaris longus muscles were highest for Sample 1 in Processes 1 and 2. The value of %IEMG for the extensor digitorum muscle was significantly higher than those for other samples. In Process 3, the %IEMG values for both the extensor digitorum and palmaris longus muscles were significantly smaller for Sample 3. When removing the trousers, the value of %IEMG for the extensor digitorum muscle was significantly lower for Sample 3 in Processes 2 and 3, whereas in Process 1 the values of %IEMG for both the extensor digitorum and palmaris longus muscles were highest for Sample 1 and that for the palmaris longus muscle was lower than those of other samples for Sample 2. For the entire process, the values of %IEMG for both the extensor digitorum and palmaris longus muscles were significantly higher than those of other samples for Sample 1 when putting on and removing the trousers. For the process of removal, the value of %IEMG of the extensor digitorum muscle was significantly lower than that of other samples.

5-3-2. Work time

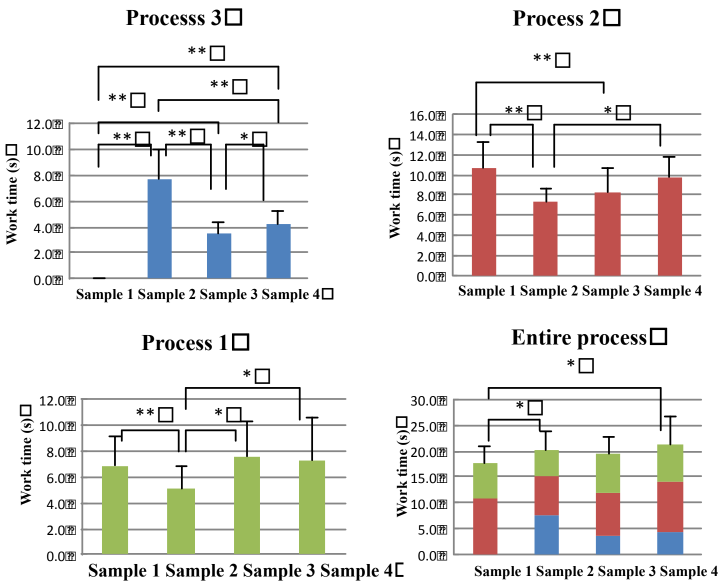
Analysis results of work time when putting on the trousers are shown in Figure 5-10, and those for removing the trousers are shown in Figure 5-11. When putting on the trousers, the work times for Sample 2 during Processes 1 and 2 were significantly shorter than those for other samples, while the time was significantly longer during Process 3. For the entire process, no significant differences could be observed among the different samples.



** p<0.01, * p<0.05

Figure 5-9 Comparison of %IEMG.

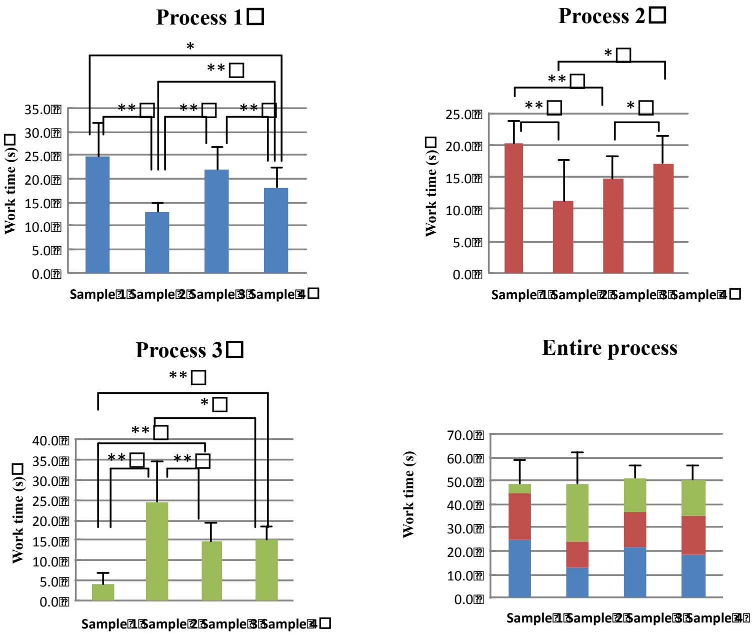
When removing the trousers, the work time for the entire process for Sample 1 was significantly shorter than those for other samples, since it did not include Process 3. The work time for the entire process for Sample 4 tended to be long because Process 2 was time-consuming.



** p<0.01

* p<0.05

Figure 5-10 Average work time for each sample (when putting on the trousers).



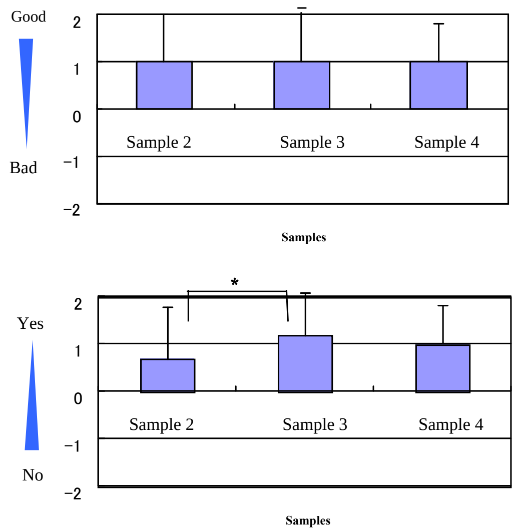
** p<0.01

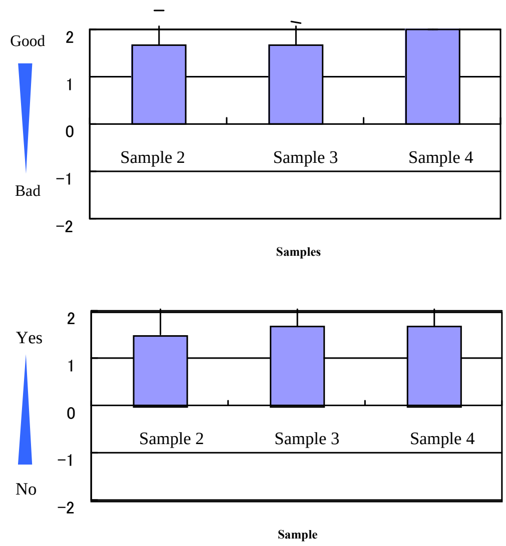
* p<0.05

Figure5-11 Average work time for each sample (when removing the trousers).

5-3-3. Sensation of burden

Shown below are the results of the questionnaire. By using the SD method, the questionnaire responses were translated into scores according to 5 grades (-2 to +2 pts.) with Sample 1 as a reference (0 pts.). There were significant differences in scores for fatigue felt when pulling up the trousers (Figure 5-12) and ease of putting on the trousers around the hips (Figure 5-14). Specifically, fatigue (burden) was less likely to be felt when pulling up the trousers for Sample 3 than Sample 2 (and Sample 1). Also, procedures around the hips tended to be easier for Samples 3 and 4 than for Samples 2 and 1.

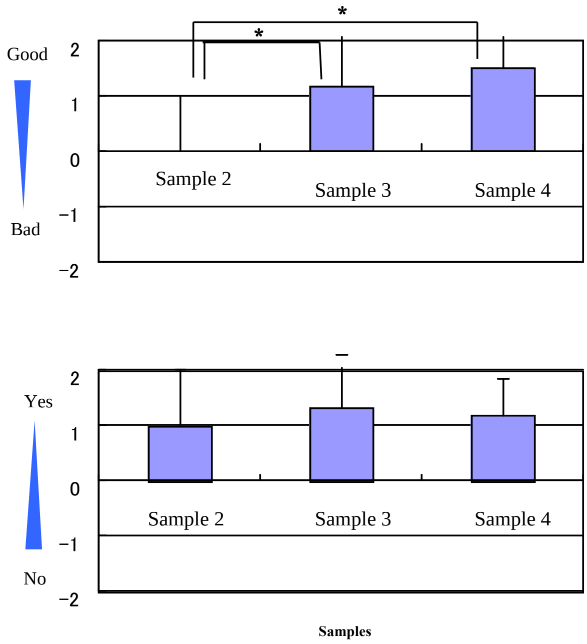




** p<0.01, * p<0.05

Figure 5-12 Questionnaire responses on pulling up the trousers
(top: ease, bottom: fatigue)

Figure 5-13 Questionnaire responses on pulling down the trousers
(top: ease, bottom: fatigue)



** p<0.01, * p<0.05

Figure 14 Questionnaire responses on work around hips. (top: ease, bottom: fatigue).

5-4. Discussion

5-4-1. Assessment of the burden on the upper limbs when putting on / removing the clothes

As shown in Figure 5-10 and 5-11, comparisons of the work times for four different samples throughout the entire process did not show any significant differences. If we are to compare the activities of the two muscles in the upper limbs when putting on / removing the clothes, the amount of such activities for Sample 1 shows significant differences compared to the other samples. Also, the %IEMG value for Sample 1 was high, which suggests that the physiological burden on the upper limbs is great. If we are to compare muscle activity (%IEMG) when putting on / removing the clothes in each sub-process of putting on the clothes, Sample 1 shows significant differences from other samples for both muscle activities for Process 1, Process 2, and the entire process, so it can be said that Sample 1 results in heavy muscle load. Similarly, when removing the clothes, a comparison among the samples for all of the sub-processes shows that Sample 1 puts a greater load on the muscle for the entire process. In this way, the physiological and by-process analyses have made it possible to make a quantitative comparison of the burden on the upper limbs, which could not be assessed based solely on the work time. Also, the results of subjective assessment revealed that Samples 2 – 4 earned higher scores than Sample 1 for most of the parameters, which leads to the belief that the physiological burden and psychological assessment largely correspond to each other. In light of this, it would be important to combine physiological measurement (EMG) and psychological assessment (questionnaires) when making qualitative evaluations of the burden caused by movements when providing nursing care.

5-4-2. Designing nursing care trousers

As indicated by the results shown in Figure 5-10 and 5-11, the two muscle activities for Sample 1 placed a large burden on the upper limbs during Processes 1 and 2 when putting on nursing care trousers. In other words, the large physiological burden suggests that the procedure of pulling up the trousers and squeezing the hips into them has a significant influence on the burden experienced. This also points to the importance of the trousers' design from the waist to the thigh. For example, if an opening is made in the upper part of the trousers as in Samples 3 and 4, a moderate degree of freedom is allowed when conducting the procedure around the hips, thus reducing the workload.

Concerning the burden on the upper limbs, there is a possibility that movements like lifting the body, places a greater burden on caretakers both physiologically and psychologically when compared to tying strings or other precision works. In other words, it is assumed that designing trousers that decrease movements such as lifting the body to change the nursing care recipients' positions would be effective in reducing the burden on the upper limbs when putting on / removing nursing care trousers.

5-5. Conclusion

In this research, the burden on the upper limbs when putting on / removing nursing care trousers was analyzed by EMG measurement, questionnaires, and videos. By combining EMG and questionnaires, it was made possible to quantify the burden on the upper limbs, which cannot be assessed solely according to work time. Differences in the workload associated with trousers having different designs were also studied. Also, the possibility was suggested that by taking such an approach, nursing care clothes may be developed that would further reduce the burden on caretakers while providing nursing care.

Acknowledgement

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Chapter 6

Conclusive Remarks

Rapidly aging with a small birth rate, Japan has an elderly (aged 65 and over) population over 20% in the total population in 2012, and is estimated to accelerate the increase of an elderly population even further. One of the biggest social problems we are facing at present is the increasing population of bedridden elderly in care houses and home in comparison with Sweden and Denmark. Once bedridden, the elderly are forced to stay in bed all the day, resulting in unpleasant problems such as fecal and body odors, skin diseases and bedsores, besides the heavy burden of caretakers due to wearing /removing clothes, changing body positions of the bedridden elderly. In consequence the caretakers often suffer from lower back pain. Those two factors of foul odor and heavy burden in elderly care houses could be our most serious social problems in near future. From this viewpoint, we have summarized the current situation and nursing conditions in elderly care facilities and hospitals in Japan in comparison with those in Scandinavian countries. Although Japan is a highly developed country (the human development index is high) and the quality of life is relatively good, a serious problem is that most of the Japanese do not enjoy the quality of life and feel not well cared. The gross national happiness index [2] indicates this trend and we need to analyze this discrepancy from a positive linearity between the QOL and GNH. However, we will not go in details of elucidating the pros and contras of welfare systems and regulations, but rather focus our attention on the application of functional fabrics and their designing for special clothes in order to reduce the burden of the caretakers and to enhance the QOL of those cared. A special emphasis is laid on the application of functional fabrics with deodorant, antibacterial and anti-allergic properties for nursing care goods.

Foul odors resulting from excrement and body odors can be reduced by applying the functional fabrics in the form of a specially designed gripping rods and coverings for urine bags. The deodorization mechanism was examined for each category of odors and a suitable device was developed to prevent foul odor to spread over the space in Chapter 2. In the case of body odor, foul odor is caused by decomposition of fatty acid discharged with sweat into ill odorous substances such as ammonia, isovaleric acid, etc. by the action of *Staphylococus aureus*, a kind of bad bacteria residing on the skin surface. Therefore, an antibacterial agent incorporated onto fabrics is effective to suppress the growth of *Staphylococus aureus* and eventually reduces the generation of ill smell. The deodorant agent removes foul smell by absorbing and decomposing smelly substances if any.

In Chapter 3, an attention was paid to the patient who has contracted hand as an aftereffect of a stroke and clutches palm tightly all the day. Because of moist and heat in the grasping palm, a skin decease is developed and generates foul odor like fermented cheese. In order to ease the symptom, a gripping rod made of gauze is applied to the palm so as not to clutch directly the palm and cut the palm by nails in the nursing home. The iron (III) tetracarboxy phthalocyanine processed fabrics having deodorant and antibacterial property, was applied to this grip rod and other nursing care goods. Iron (III) tetracarboxy phthalocyanine has a similar chemical as hemoglobin in blood and functions as an artificial enzyme. The iron (III) tetracarboxy phthalocyanine processed fabric is not effective on ammonia because of carboxylic groups but was found a good deodorant effect on acetic acid. In order to improve a higher deodorant effect on ammonia, copper (II) tetraammine was combined into phthalocyanine. The phtyalocyanine processed with copper fabrics revealed a high deodorant and antibacterial property. Based on these results, the grip rod was designed by using the phthalocyanine processed with copper, and supplied for the clinical test with the patient who has a contracted hand. Athlete's foot symptom caused by *Trichophyton* on the palm disappeared in approximately one week, while no ill odor was generated by then.

Skin diseases are serious problems not only for the elderly, but also the youth. Allergic patients are usually cured in their twenties, but a recent trend shows that more youth suffer from allergic dermatitis even after they grow older. The allergic patients can not wear the clothes made of synthetic fibers such as polyester or nylon because of their allergic reaction to synthetic fibers as revealed by the symptom of itching, red spotting and blistering. Since most of our clothes are made of polyester, we need to develop such polyester that the allergic patient can wear without causing allergic reaction.

The human skin is weak-acidic in a healthy condition, and suppresses the growth of ill-function microorganisms among resident micorbiota on skin by promoting the growth of good bacteria. Thus it is important to keep a skin with a lower pH value. Two types of weak-acidic polyesters were prepared by chemical modification and subsequent processing as described in detail in Chapter 3. We examined the deodorant and antibacterial properties of these fabrics as well as the influence on the skin. Both weak-acidic polyesters showed a deodorant effect for ammonia. The weak-acidic polyester fabrics were found effective to maintain the pH value lower at skin surface. The results indicate that the pH of sweat is buffered by weak-acidic polyester and the growth of ill-function microorganism is suppressed. In fact the generation of foul smell due to the fermentation of sweat components is less detected.

In Chapter 5, we have developed the clothes designed specially for easy dressing in order to reduce the labor of caretakers. The movements of the upper limbs of a caretaker were monitored by means of electromyography (EMG) and video filming while putting on and taking off the dummy's nursing care garments with varying designs. By the comprehensive analysis of physiological measurement (EMG) and psychological assessment (through questionnaires), the labor force required for dressing was quantitatively evaluated, and an optimal design for care garments was made by improving an opening of the garments in order to reduce the caretaker's labor for dressing.

The thesis presented an initial step for improving the QOL especially for the socially vulnerable. Although the QOL does not necessarily improve the gross national happiness as seen from Chapter 1, we are obliged to strengthen the social network including the socially vulnerable, which is more or less excluded from the present social system in Japan. The functional fibers have a potential to prepare a better condition for social networking by removing unpleasant factors preventing a good human contact.

List of Publication

Chapter 3

- Study of Weak Acidic Clothing materials developed for skin condition
  Chiyomi Mizutani, Momoe Ukaji, Naoki Horikawa, Tomoyoshi Yamamoto, Hideaki Morikawa, Kanji Kajiwara
  SEN'I GAKKAISHI , Vol.69, No.4, pp.73-77 (2013).

- Effect of Weak Acidic Polyester on Skin Condition
  Chiyomi Mizutani, Momoe Ukaji, Naoki Horikawa, Tomoyoshi Yamamoto, Kanji Kajiwara, , Proceedings of Textile Bioengineering and Informatics Symposium 2012, pp.221-226 (2012)

Chapter 4

- 消臭抗菌繊維の介護用品への応用
  水谷千代美，矢羽田明美，白井汪芳，築城寿長，森川英明，梶原莞爾，高橋勝貞，重田富美子，黒澤宏江，大塚千晶
  繊維学会誌，第 69 巻，7 号，pp. 141−145(2013).

- Application of Functional Fiber to Nursing Care Supplies: Synergy Effect of Design and Deodorant/Antibacterial Function for a Grip Rod for an Immobilized Hand of Cerebral Infarction Patients
  Chiyomi Mizutani, Akemi Yahata, Kanji Kajiwara, Katsusaza Takahashi, Tomiko Shigeta, Hiroe Kurosawa, Mika Shima, Chiaki Otsuka, Hideaki Morikawa and Hirofusa Shirai,
  Centenary Conference Proceedings of the Textile Institute, Manchester, UK , 2010, pp1-9（2010）

Chapter 5

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