Development of Indices for Back Curvature and Postural Variations of the Torso of Women Aged 55 and Older

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Nokyeon Kim

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ABSTRACT

Spinal curvature was identified as a primary factor that shows universal and progressive changes with age, causes overall postural variations in the torso, and in turn affects garment fit for older women. To incorporate spinal curvature into a garment, back curvature between the neck and the waist and seven torso regions of neck, shoulder, armhole, bust, waist, abdomen, and hip were operationally defined and interactions among the body regions were investigated.

The purpose of this study was (1) to develop a measuring method for back curvature and posture in the torso and its validation, (2) to identify interrelationships between back curvature and posture in the torso, and (3) to interpret torso variations based on back curvature classification.

A total of 21 indices were developed using 34 linear measurements and 165 body scans of females body scans aged 55 and older were analyzed from the sagittal plane. Two criteria for index development were body variations to the sagittal plane and those to the transverse plane.

Results included: (1) each criteria for index development validated its independency in each body region and respective index values provided dimensional information for pattern development, (2) posture of one body region continuously affected the adjoining body region and sequential influence of back curvature on torso posture was confirmed, and (3) the torso posture varied depending on the back curvature clusters and a prominent and forward inclined back showed larger variations and greater deviations from the ideal posture.

This study presented conceptual understanding of posture of women aged 55 and older and emphasized integration of research and practices.

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CHAPTER ONE: INTRODUCTION

Physical features of the human body may be analyzed by size, shape, and posture. Size is obtained from body measurement data; shape, as a relationship between measurements, indicates proportions of the body; posture is a spatial configuration between body segments. Kendall, McCreary, Provance, Rodgers, and Romani (2005) defined posture as “the relative arrangement of the parts of the body” (p. 51) quoting the 1947 Posture Committee of the American Academy of Orthopedic Surgeons. Thus, posture is a three-dimensional and comprehensive concept involving size and shape.

Each part of the human body is organically connected. Physical changes in any part of the body may result in overall postural variation. Clothing in general should be worn to support the wearer’s most typical posture in aesthetically pleasing and physiologically comfortable ways. Therefore, understanding of posture is important to provide optimal garment fit.

Garment fit is defined as the relationship between the body surface and a garment and pertinent to the size of the garment (Adams & Keyserling, 1996; DeLong, Ashdown, Butterfield, & Turnbladh, 1993; McKinney, Bye, & LaBat, 2012). Although fit is typified by an abstract symbol on the basis of body size, beyond measurements alone, optimized fit should address the balance of the body including interpretation of a wearer’s size, shape, and general posture. In this respect, proper fit based on the desired body/garment relationship is a crucial element for comfort as well as overall satisfaction with the garment (Ashdown & DeLong, 1995; Yu, 2013).

Among various elements that lead to postural variations that in turn affect garment fit, aging is the most universal factor. During the aging process, women commonly experience physical changes including body shortening, weight gain, added bust fullness, thickened waist, protruding abdomen, forward head, rounded shoulders, accentuated back curve, decreased front torso length, and increased back torso length (Ashdown & Na, 2008; Brown, Ringrose, Hyland, Cole, & Brotherston 1999; Campbell & Horne, 2001; Goldsberry, Shim, & Reich, 1996a; Hinman, 2004; Patterson & Warden, 1983). While these are the general trends in older women, body shape estimated by girth and horizontal measurements (Connell, Ulrich, Brannon, Alexander, & Presley, 2006; Simmon, 2002) does not progress in a linear fashion. In general, girth is tightly associated with weight (Guo, 2016; Patterson & Warden, 1983) and weight does not always increase with age. However, spinal curvature shows a progressive and consistent change with age (Boyle, Milne, & Singer, 2002; Hinman, 2004) and causes an overall postural shift in the torso by affecting the balance of front and back torso length. Spinal deformity can occur at all ages. However, post-menopausal women often experience osteoporosis and this accelerates structural changes in the spine (Hinman, 2004; Levangie & Norkin, 2005; Sinaki, Itoi, Rogers, Bergstralh, & Wahner, 1996) resulting in a decrease of vertical measurements. Therefore, older women's spinal curvature should be addressed in the fit of their garments.

From the side view, the spine is posteriorly located facing the back and traverses the upper body. To separate the upper and lower body in garment patternmaking, the waist level is commonly used as a convenient guideline (Armstrong, 2010). Thus, to incorporate spinal curvature into a garment pattern, back curvature between the neck and the waist should be operationally defined. However, as the spine extends through a longer area than the back and is connected by alternate anteriorly and posteriorly convex curves throughout the torso, back curvature should be understood within the inflection of the spine and in relation to overall torso posture. In addition, while spinal curvature causes postural variations in the torso as a whole, it may have the most direct impact on the shape of the back. Therefore, back curvature may serve as an explanatory variable that predicts changes in posture in the torso.

Despite several attempts to measure back curvature in apparel studies (Ashdown & Na, 2008; Chen, LaBat, & Bye, 2008; Cho et al., 2006; Choi & Nam, 2010; Na, 2007), the findings mainly focused on the upper body (Ashdown & Na, 2008; Choi & Nam, 2010; Na, 2007) and the aims of the studies were not to examine the range of body variations of older women (Chen et al., 2008; Cho et al., 2006; Choi & Nam, 2010; Na, 2007). However, as an important manifestation of ageing, back curvature and posture of the torso should be combined and incorporated into older women's garment fit. Therefore, in this study back curvature and seven torso segments including neck, shoulder, armhole, bust, waist, abdomen, and hip were operationally defined, and the relationship between back curvature and postural variation in the torso was explored.

Statement of Problem

According to the US census in 2016, individuals above the age of 65 in the United States represents 15.2 % of the total population (U.S. Census bureau, 2017). By 2029, more than 20% of the population will be over 65 and by 2056, the over 65-year-old cohort is expected to become larger than the under 18-year-old cohort (Colby & Ortman, 2014). As eight thousand baby boomers turn 65 every day (Moody, 2012), growth of the aging population along with an increase of life expectancy and a decrease of overall population is considered to be one of the most important demographic trends in the United States.

Consumers aged 65 and older have significant purchasing power based on discretionary income and represent an untapped profitable target market (Furlong, 2007). Wolfe and Snyder (2003) defined this group of consumers as “the new customer majority.” To be successful, retailers should be able to reach this maturing population. However, companies have little understanding of older consumers’ interests and preferences. Many retailers assume that they are less likely to buy something new or consider new brands, even though research has shown that they are willing to buy new things or switch brands if it meets their needs (Karani & Fraccastoro, 2010). More specific to the apparel side, although women over age 65 remain physically and socially active and they have needs for various types of clothing (Boyd & Lee, 2009), the apparel industry tends to focus more on fashionable younger generations and overlooks the needs of older consumers (Howarton & Lee, 2010; Lee, Damhorst, Lee, Kozar, & Martin, 2012). As a result, older women’s fit problems have been repeatedly reported by many researchers (Frazier, 1975; Goldsberry, et al., 1996a, 1996b; Howarton & Lee, 2010; Norwood, 1944), yet there has been little change in the market. Although fit issues may be mitigated in part by fabric choices or styles, this narrows garment selection. Physical changes are gradual and systemic, and therefore objective understanding of the body is necessary.

Research Question

What are the consequences of back curvature for posture in the torso with increasing age?

Statement of Purpose

The purpose of this study was (1) develop a measuring method for back curvature and posture in the torso and its validation, (2) identify interrelationships between back curvature and posture in the torso, and (3) interpret torso variations based on back curvature classification.

Significance of Study and Rationale

Among aging populations, the baby boom cohort is creating a bulge in the population pyramid. In 2017, 77 million US boomers (Moody, 2012) had reached an age between 53 and 70 years. As consumers, they have benefited from economic prosperity throughout their lives (Furlong, 2007), with female baby boomers acting as fashion trendsetters in their youth (Howarton & Lee, 2010). In this respect, baby boomer's aging will have different implications for the apparel industry compared to earlier generations of older consumers. Despite distinct design preferences and knowledge about clothing fit, they express dissatisfaction with the lack of proper fit in the current market (Howarton & Lee, 2010). Thus, understanding their age-related physical changes and providing proper garment fit are important from both consumers' perspective and the apparel industry's perspective.

Limitations

As indicated in Ashdown and Na's (2008) study, bilateral asymmetry was expected to become greater with increasing age. While bilateral posture could be examined the best from the frontal plane, this study examined posture only from the sagittal plane as asymmetrical frontal posture are not incorporated into garment patterns. Ideally, understanding of general and comprehensive postural characteristics should be explored before drawing conclusions. Thus, the results of this study contain some limitations.

Removing the arm from the scans to identify armhole shape introduced limited accuracy of the related measurements. Analysis of static armhole shapes is limiting as this area of the body changes with dynamic movement.

Definitions of Terms

Torso: the central part of the body from the neck to the crotch, excluding the head and limbs.

Posture: the typical arrangement of body parts in a relaxed standing position.

Garment pattern: a two-dimensional estimation of body/garment relationship representing a wearer's body size, shape and posture.

Patternmaking: a process of transferring the size, shape and posture of human body into a flat medium.

Garment fit: the three-dimensional construction of the body/garment relationship including a designer's intention.

Older women: The chronological age of an elderly or older person is not definite. World Health Organization (WHO, 2017) identifies the age of 65 as elderly, United Nations (UN, 2013) defines 60 years and plus as elderly, and American Society for Testing and Materials (ASTM) provides body measurements for mature women based on the age 55 and older (ASTM International, 2010). Researchers in the apparel field tend to determine the age of elderly based on their own research purposes. In this study, older women were defined as the chronological age of 55 years and older to include the baby boom cohort and to follow the ASTM age guideline for mature women's apparel.

CHAPTER TWO: LITERATURE REVIEW

This study is based on the assumptions that (1) posture of the human body changes with age requiring different garment fit, (2) age-related postural changes should be properly addressed in garment fit for older women, and (3) progressive back curvature is a prime determinant of postural variations in the torso. Thus, in this section, themes were determined to underpin the presented assumptions and to explore the previous efforts to assess posture and back curvature.

Two themes of posture and apparel fit were identified. The theme of posture discusses ideal standing posture, assessment of overall postural alignment, back curvature, back curvature in older women, and assessment of back curvature. The theme of apparel fit reviews definitions, fit assessment, and fit issues among older women.

Posture

Posture, either static or dynamic, is defined as an alignment of body segments at a given moment and can be illustrated by the joint positions and muscle balance (Kendall et al., 2005; Levangie & Norkin, 2005). Common body segments used to describe a postural alignment include the head, neck, shoulder, upper back, low back, chest, abdomen, hip and pelvis, knee, and ankle (Kendall et al., 2005; Levangie & Norkin, 2005). Kendall et al. (2005) defined the torso or trunk as body parts of the upper and low back, chest, abdomen, and pelvis in which the separation of the upper and the lower parts of the back is identified by spinal regions, thoracic and lumbar vertebral columns. Positions of each part are relative and greatly affect each other creating compensatory changes (Boyle et al., 2002;

Hardacker, Shuford, Capicotto, & Pryor, 1997; Quek, Pua, Clark, & Bryant, 2013). Among various postures, a static standing posture, especially focused on the torso segments, is of interest in this study.

Ideal Standing Posture

Good posture is achieved when the least stress and strain are placed to maintain stability of the body and to provide optimal efficiency of body parts (Kendall et al., 2005). In order to achieve the most stable and well-proportioned standing posture the line of gravity through which body weight is evenly distributed should be positioned in the center of the body (Levangie & Norkin, 2005). The three basic planes passing through the body are the sagittal, coronal, and transverse planes. The sagittal plane is vertical and maidenly separates the body into the left and right halves. The coronal plane is also vertical and separates the front body from the back body. The transverse plane is horizontal and separates the upper body from the lower body. In an ideal standing posture, the intersecting line of the sagittal and coronal planes forms the line of gravity (Kendall et al., 2005).

From the lateral view, this line passes through the lobe of the ear, midway through the shoulder, through bodice of lumbar vertebrae, slightly posterior to center of hip joint, slightly anterior to axis knee joint, and slightly anterior to lateral malleolus (Figure 1, Kendall et al., 2005).

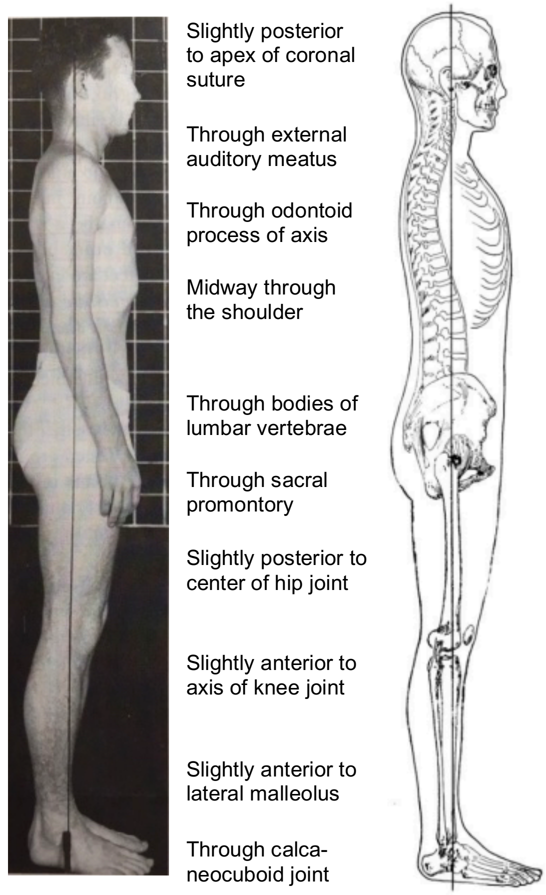


Figure 1. Standard postural alignment (Kendall et al., 2005)

Despite debates on the location of the line of gravity between the thoracic to lumbar vertebral columns (Levangie & Norkin, 2005), when the main points of the body meet the line of gravity, the head is erect with minimal strain of the neck; the spine exhibits the normal curves from the neck to the hip; the pelvis is neutrally positioned without anterior-posterior tilt (Kendall et al., 2005). This alignment was repeated by Horn and Gurel (1981) in Clothing and Textiles as an ideally proportioned body figure. Slight variations may display due to distinctive individual muscular development and body proportions that affect stable weight distribution (Kendall et al., 2005; Levangie & Norkin, 2005). If a posture that deviates from the ideal alignment is habitual and repeated over a longer period of time, muscular and ligamentous adaptation occur that results in a faulty posture (Levangie & Norkin, 2005).

Assessment of Overall Postural Alignment

Various techniques to evaluate overall postural alignment have been invented and have evolved in different fields. Two representative methods, one developed for generic use and the other devised for apparel studies, are illustrated.

Plumb line test. A plumb line is the most typical, simple, and reliable tool to assess overall postural alignment in a static standing posture (McLean, Gillan, Ross, Aspden, & Porter, 1996). A suspended plumb line with a plumb bob at the bottom to create an absolute vertical line represents the visible line of gravity. In the plumb line test, posture is viewed from the posterior and lateral perspectives and assessed in terms of deviations of the subject's reference points from the standard alignment. In the lateral view assessment, the subject's anterior edge of the lateral malleolus serves as a main point to match with the plumb line. When a test is conducted in routine clinical settings, the degree of deviations is described as 'slight', 'moderate', and 'marked' instead of exact measurements using inches or degrees (Kendall et al., 2005).

In addition to clinical settings, the plumb line test was applied to evaluate children's posture for educational purposes. The New York State Education Department devised the Physical Fitness Test for teachers to assess students' status and progress (New York State Education Department, 1972). A posture assessment was one of the seven components of the test. In the side view the plumb bob was positioned at the student's ankle bone (Figure

2). Six body parts from the posterior perspective and seven body parts from the lateral perspective were observed and scored by 5, 3, or 1 based on illustrations and descriptions on the Posture Rating Chart. In Clothing and Textiles, McRoberts, Cloud, and Black (2013, 2016) adopted a modified version of NYPR (New York Posture Rating) to evaluate postural alignment effects of posture support garments and verified the reliability of the NYPR as an assessment tool.

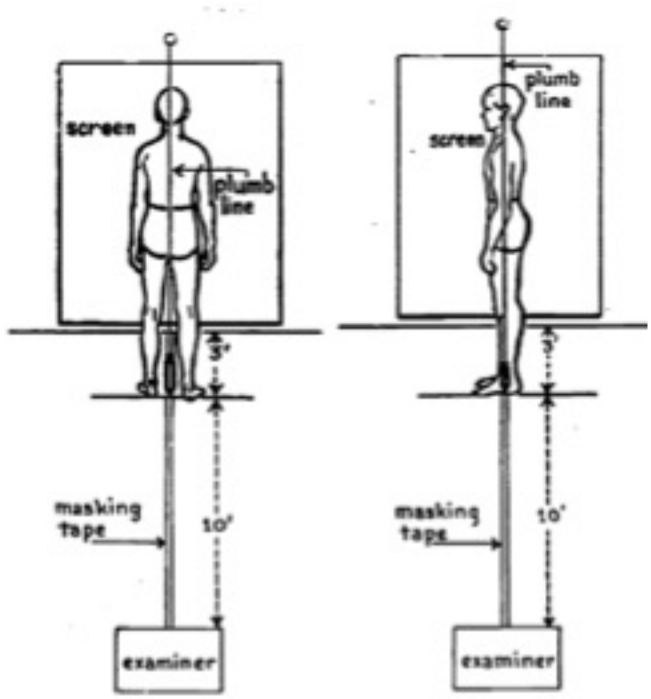


Figure 2. Physical fitness test devised by the New York State Education Department

Visual somatometry. In Clothing and Textiles, various efforts have been made to classify body types (Connell, Ulrich, Brannon, Alexander, & Presley, 2006; Johnson, 1990; Salusso-Deonier, Markee, & Pedersen, 1991; Sheldon, 1954; Simmons, Istook, & Devarajan, 2004). However, these studies mainly focused on body shapes or figure variations rather than body alignment or posture. As distinct from these studies, Douty

(1954, 1986) invented Visual Somatometry by means of photographic silhouettes projected on a grid-screen and introduced the Posture Scale.

Visual Somatometry was devised to provide apparel design students with a new, accurate, and objective way of observing human figures. Like the plumb line test, the subject was photographed from two different views, one from the back view and the other from the side view. Silhouettes from the back view were termed Somato-graph (Figure 3) through which the five-point Body Build Scale was developed for figure study. Silhouettes from the side view were termed Posture-graph (Figure 3) through which the five-point Posture Scale was developed for posture study (Figure 4). A grid on a screen served as a reference line like a plumb line. For a silhouette from the side view, front edge of the ankle bone was aligned with a reference grid line.

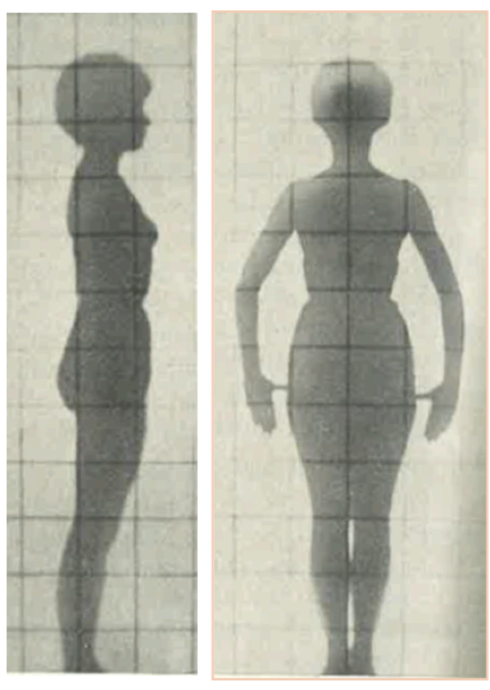


Figure 3. Posture-graph and Somato-graph (Douty, 1968)

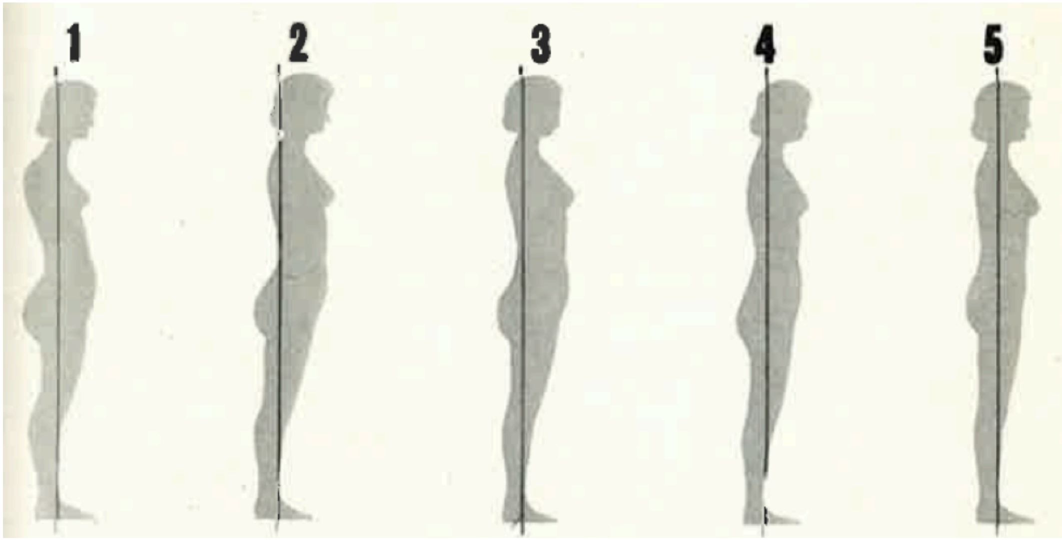


Figure 4. Posture Scale (Douty, 1968)

Bad (1)	Poor (2)	Average (3)	Good (4)	Excellent (5)
Head markedly forward / Shoulders markedly slumped / Abdomen markedly protuberant / Back markedly curved / Knees markedly tight (legs form S curve) / Balanced on toes or heels / Shoulders markedly uneven / Legs markedly irregular	Head noticeably forward / Shoulders noticeably slumped / Abdomen somewhat protuberant / Back curve obvious / Knees tight / Balanced on toes or heels / Shoulders uneven / Legs irregular /	Head slightly forward / Shoulder slightly slumped / Abdomen rounded / Back noticeably curved / Knees tense / Balance off / Shoulders slightly uneven / Legs relatively straight	Head less erect / Shoulders up or relaxed / Abdomen in but not flat / Back curve slightly increased / Knees slightly tense / Balance slightly off / Shoulders nearly level / Legs straight	Head up-chin in / Shoulders up / Abdomen flat / Back curve within normal limits / Knees flexed / Body balanced ever arches / Shoulders level / Legs straight

Back Curvature

Depending on purpose of assessment, for bilateral symmetry or anterior-posterior alignment, posture can be examined from the posterior perspective, lateral perspective, or both. In the case of back curvature and resultant variations in the torso, postural alignment may be observed the most effectively from the lateral body. As the spine helps maintain upright posture (Hamill, Knutzen, & Derrick, 2014; Martini & Bartholomew, 2016) and the shape of the back is greatly affected by spinal curves, understanding of spinal structure is necessary.

Spine. The spine consists of vertebrae and intervertebral discs and supports the body. The structure of this vertebral column is subdivided into five regions that are cervical, thoracic, lumbar, sacral, and coccygeal (Figure 5) and comprises 26 bones of seven cervical vertebrae (C1-C7), 12 thoracic vertebrae (T1-T12), five lumbar vertebrae (L1-L5), the sacrum fused five embryonic vertebrae, and the coccyx also fused vertebrae. The cervical, thoracic, and lumbar vertebrae are moveable and each vertebra in these regions except the junction of the first and second cervical vertebrae is cushioned by intervertebral discs that provide flexibility to the spinal column. The thoracic vertebrae articulate with ribs and thoracic region spans the longest area within the spine. The vertebrae increase in size from the cervical to the lumbar regions and decrease in size from the sacral to coccygeal regions (Hamill et al., 2014; Levangie & Norkin, 2005; Martini & Bartholomew, 2016; Netter, 2011). Intervertebral discs are longer in the cervical and lumbar regions and shorter in the thoracic region and occupy one third of the total vertebral column in height (Urban & Roberts, 2003).

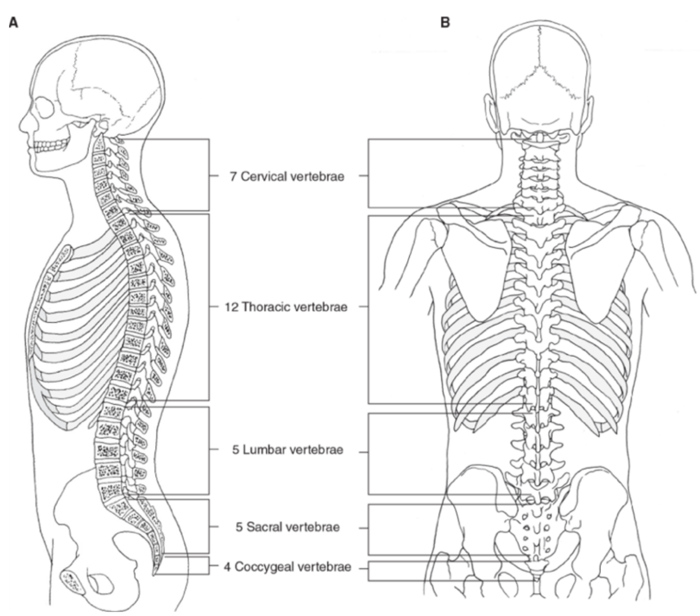


Figure 5. Five vertebral columns (Levangie & Norkin, 2005)

Spinal curves. The vertebrae are stacked one on top of another. The orientation of an individual vertebra or group of vertebrae changes within the spine and variations can be observed in the sagittal, coronal, and transverse planes. In the sagittal plane, the spine shows natural anterior-posterior curves. The neck (cervical) and lower back (lumbar) exhibit anterior convex curves and the upper back (thoracic) and the hip (sacral) exhibit posterior convex curves. In the coronal plane, the spine is straight and bisects the body. The orientation in the transverse plane is determined by variations in individual vertebral body (LaBat & Ryan, 2018).

When the spine is misaligned, abnormal distortions of the spinal curves may be observed. The term kyphosis refers to abnormal or exaggerated posterior convex curves in the thoracic and sacral regions; the term lordosis refers to abnormal or exaggerated anterior convex curves in the cervical and lumbar regions; the term scoliosis refers to abnormal lateral curves of the spine. (Martini & Bartholomew, 2016; LaBat & Ryan, 2018). An exaggerated curve in part of the spine influence overall postural changes. For example, an anterior pelvic tilt results in lumbar lordosis that in turn leads to thoracic kyphosis and cervical lordosis as compensatory changes. (Figure 6, Levangie & Norkin, 2005).

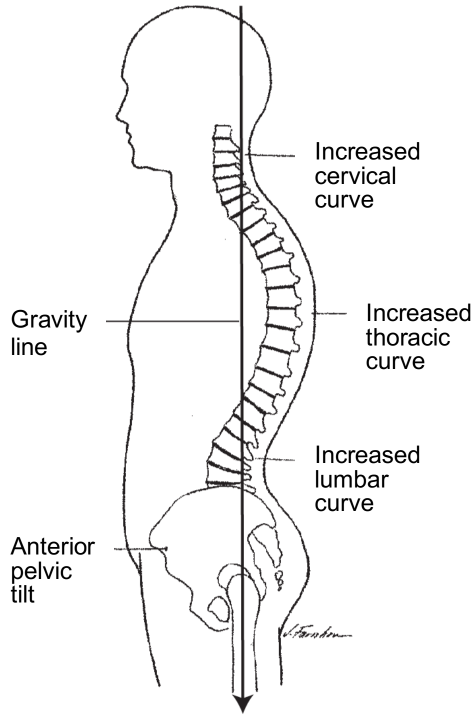


Figure 6. Compensatory changes in the spine (Levangie & Norkin, 2005)

Variations of the spinal curves may result from postural habits, osteoporotic fracture, shifts in the body's center of gravity, muscle imbalance, and abnormalities of the intervertebral discs. In addition, the intervertebral discs lose height as a result of age-related changes in vertebral body, disc dehydration, and the compressive force of gravity (Ensrud, Black, Harris, Ettinger, & Cummings, 1997; LaBat & Ryan, 2018; Manns, Haddaway, McCall, Pullicino, & Davie, 1996; Schneider, von Mühlen, Barrett-Connor, & Sartoris, 2004) Although alteration of the spinal curvature may appear regardless of age, aging accelerates these degenerative changes to the spine (Kado, Prenovost, & Crandall, 2007; Katzman, Wanek, Shepherd, & Sellmeyer, 2010; Levangie & Norkin, 2005).

While there are research findings indicating that menopause is positively associated with an increase in abdominal fat (Haarbo, Marslew, Gotfredsen, & Christiansen, 1991) and negatively associated with total lean body mass (Wang, Hassager, Ravn, Wang, &

Christiansen, 1994) both of which may result in an increase in body girth in the torso, exaggerated spinal curvature also affects increased girth measurements in older women. Due to a decrease in total length of the spine, internal organs are positioned in a relatively shorter and compact area, and consequently to maintain the same volume, horizontal dimensions around the shortened area increase (LaBat & Ryan, 2018).

Back Curvature in Older Women

Progressive spinal curvature is a noticeable postural change in the aging process. Boyle et al. (2002) examined lateral spinal radiographs of 113 males aged 18-90 years and 59 females aged 18-92 years and demonstrated that the thoracic curvature increased along with advanced age for both genders. The significant differences were initially recorded in the 45-59 age group. This tendency continued, and the magnitude augmented in a gradual manner from the 45-59 years to 60-74 years ($p= .05$) and 60-74 years to 75+ years ($p= .03$). As the kyphotic angle of the thoracic spine increases, the lordotic angle of the cervical spine also increases as a compensatory adjustment resulting in an anterior neck tilt. This outcome is consistent with the findings of Quek, Pua, Clark, and Bryant (2012) verifying the positive association of thoracic kyphosis with forward head posture in older adults aged 60 years and older.

Hammerberg and Wood (2003) radiographed 50 older adults aged 70-85 and indicated a significant correlation between the age and the anterior shift of the center of gravity of the body. In their study, the plumb line from the seventh cervical vertebra (C7) moved on average 40mm anteriorly at the first sacral vertebra (S1) level both of which should be aligned.

Hinman (2004) also illustrated the influence of age on the accentuation in sagittal posture by comparing 25 women aged 21-51 years and 26 women aged 66-88 years. Using the flexicurve ruler, a malleable ruler to conform to the spinal curve, the index of kyphosis (IK=thoracic width/thoracic length x100) was computed (Figure 7). Index values of the older group were greater indicating that thoracic curvature became more prominent with age. In addition, postural stiffness between the groups by comparing the level of flexicurve changes while standing in their usual relaxed erect posture versus standing in their maximally erect posture was investigated. The older group were recorded with lower levels of flexicurve change demonstrating that the older women had less ability to actively straighten, improve, or align their thoracic posture.

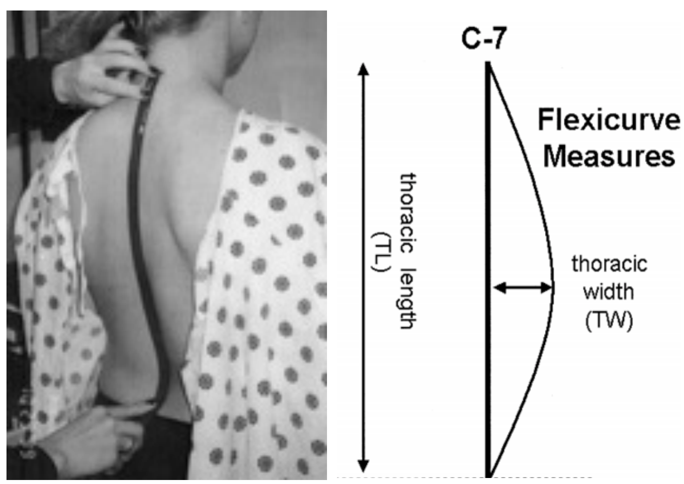


Figure 7. Flexicurve measure (Hinman, 2004)

These progressive curvature changes occur particularly in postmenopausal women who often experience osteoporosis which weakens the vertebrae and makes them vulnerable to fracture (Cortet, 1999; Ensrud et al., 1997; Hinman, 2004). Ensrud et al. (1997) demonstrated that the degree of thoracic kyphosis of older women aged 55-80 was positively associated with the number of anterior wedge compression fractures resulting from osteoporosis and that for each 15° increase in kyphotic angle, height decreased more than 4 cm.

Changes in intervertebral discs with age such as disc dehydration and loss of elastin also affect thoracic posture and height (Levangie & Norkin, 2005). Manns, et al. (1996) studied lateral spine radiographs of 100 healthy women aged 39-91 and identified that age-related thoracic kyphosis was associated with average anterior disc height rather than average anterior vertebral body height. Schneider et al. (2004) also indicated that degenerative disc disease was more common than vertebral fractures in hyperkyphosis women aged 50-96.

In addition, given that back extensor muscle strength that supports erect posture is inversely related to thoracic kyphosis and lumbar lordosis in postmenopausal women (Sinaki et al., 1996), gradual muscle weakness with age would influence back curvature and consequent postural variations.

Although exercises or clinical interventions (Katzman et al, 2010) may be conducive to mitigate or delay the spinal curvature, this is a typical postural characteristic of older women and thus should be addressed in their everyday clothing.

Assessment of Back Curvature

In order to identify an ideal method to measure back curvature and concurrent postural variations, current practices to evaluate back curvature and related body parts were explored from a broader perspective.

Clinical settings. In clinical settings radiographs (Lundon et al., 1998; Manns et al., 1996), the flexicurve ruler (Hinman, 2004; MacIntyre, Bennett, Bonnyman, & Stratford, 2011; Quek et al., 2012; Vaughn & Brown, 2007), and the Debrunner kyphometer (Ensrud et al., 1997; Lundon, Li, & Bibershtein, 1998) are the most commonly used devices for assessment of spinal curvature (Kado et al., 2007; Katzman et al., 2010). Inclinometer and goniometer have been adopted also, but the measuring mechanism is similar to radiographs or kyphometer with using angle measurements and frequency of use seems relatively low compared to other methods.

Radiographic evaluation has been employed as the gold standard orthopedic technique for assessment of spinal curvature (Katzman et al., 2010). Many researchers and practitioners have calculated angle measurements from standing lateral spine radiographs. The Cobb angle that was originally developed to assess scoliosis has been modified and widely adopted for thoracic kyphosis (Kado et al., 2007). The Cobb angle of kyphosis is calculated by drawing the first line at the superior endplate of the vertebral body (commonly T3 or T4); the second line perpendicular to the first line; the third line at the inferior endplate of the vertebral body (commonly T12); the fourth line perpendicular to the third line and measuring an acute angle between the second and fourth lines (Figure 8). The basic idea of the Cobb method is to measure the angle between the vertebral bodies represented by the first and the third lines (Katzman et al., 2010).

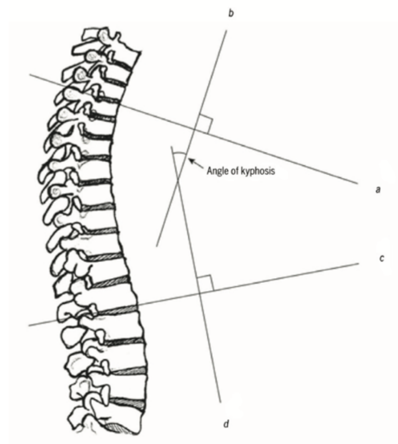


Figure 8. Cobb's angle of kyphosis (Katzman et al., 2010)

The flexicurve ruler is a malleable, metal ruler covered with plastic that can bend to conform to the subject's spine. After molding the ruler over the subject's C7 spinous process to the lumbosacral (LS) interspace, the thoracic and lumbar curves are traced onto paper. A vertical line connecting the C7 and the LS interspace and a perpendicular line at the thoracolumbar (TL) interspace are drawn. The kyphosis index is calculated from thoracic width, the greatest width from the vertical line to the thoracic curve, divided by the thoracic length, distance from the C7 to the TL interspace. See Figure 7. The lumbar index is calculated using the same formula with lumbar measurements (MacIntyre et al., 2011).

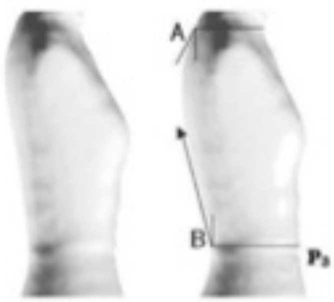
The Debrunner kyphometer is a tool to measure the kyphotic angle. Two arms are connected by a hinge-like protractor which adjusts the arm opening and measures the angle of the arms. A metal block that is large enough to cover two spinous process is attached at the end of each arm. To measure thoracic kyphosis, the upper arm is placed over the interspace of T2 and T3 and the lower arm is placed over the interspace of T11 and T12 (Figure 9). The angle from the kyphometer is basically the same with the Cobb angle, but this method is cost-effective and noninvasive compared to radiographic evaluation (Lundon et al., 1998).

Figure 9. Debrunner kyphometer measurement of kyphosis (Katzman et al., 2010)

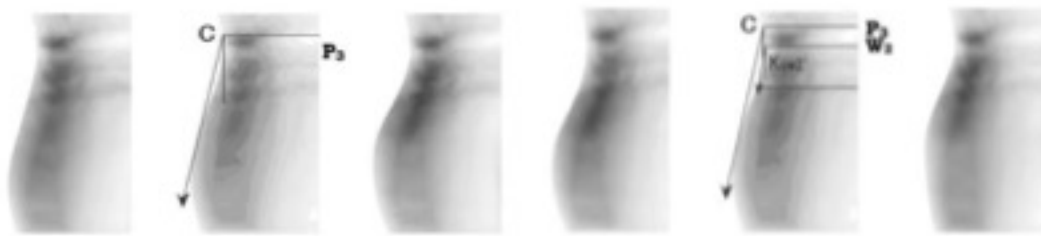
In many cases, back curvature is assessed by angular dimensions. In radiographs, a position of a certain vertebral body is additionally compared to the reference line used in the plumb line test (Hammerberg & Wood, 2003). Creating an index was considered convenient and intuitive as an index efficiently represents a concept, such as kyphosis, by a single absolute value. In addition, an index is a composite value comprised of more than one measurement, and therefore it signifies the relationship of its components. Furthermore, with an absolute value of an index disregarding its unit such as ° or cm, subjects' body dimensions, for example thoracic length to measure the degree of kyphosis, do not need to be controlled among subjects to compare.

Apparel studies. Bye, LaBat and DeLong (2006) reviewed historic and current body measurement methods for apparel and evaluated how successfully each method captures the body characteristics in terms of five elements of point, length, surface, shape, and volume. Among the identified 14 methods, body scans that construct volume by a cloud of data points were found to be the most effective systems combining all the elements. Before the advent of body scanning technology there were efforts to incorporate posture into a garment by measuring body angles from lateral body silhouettes (Brackelsberg, Farrell-Beck, & Winakor, 1986; Douty, 1954, 1968; Heisey, Brown, & Johnson, 1986). However, posture as a three-dimensional body configuration that is relevant to body volume according to Bye et al. (2006) should be assessed in the most integrated way and researchers in Clothing and Textiles have actively adopted 3D scans to posture research and other anthropometric studies. Thus, in this section, how researchers have defined back shapes and postures in the torso using 3D scans were reviewed.

In a study to develop interactive 3D body models for computerized patternmaking, Cho et al. (2006) argued that individual postural differences can be embodied in 3D models by adjusting depth of the torso, back shapes, and hip shapes. For back shapes, they measured two tangent angles, one at the back neck point and the other at the back waist point, and presented three back types: flat, average, and stooped. For hip shapes, instead of measuring tangent angles, they set two reference points on the hip at a level with the midpoint of waist to stomach and the midpoint of stomach to hip and measured respective angles by connecting each point to the back waist point. Based on the angle connecting the back waist point and the midpoint of stomach to hip, hip shapes were initially categorized as flat, average, and protruding types. Then, according to the ratio of the two angles, hip shapes were further categorized into three additional types (Figure 10). They verified that the developed 3D body model system accurately estimated real shapes.



(a) Flat back Average back Stoop back



(b) Flat hip Average hip Protruding hip Three types of the Average hip shape

Figure 10. Classified back shapes (a) and hip shapes (b) (Cho et al., 2006)

Ashdown and Na (2008) compared upper body posture and bilateral symmetry between 40 women aged 19-35 and 40 women aged 55+ using angle, linear, and proportional measurements obtained from 3D scans. Posture was operationalized mainly by angle measurements. For the back, two tangent angles at the back neck point and back waist point in the sagittal plane and two angles referring to the scapular point and midscapular point in the transverse plane were measured. For the neck, two tangent angles at the front neck point and back neck point and one angle connecting the front neck point and back neck point were measured. For the front upper body, three angels based on three reference points of the front neck point, bust point, and front waist point were measured. For the shoulder, shoulder slope, shoulder line angle, and acromion angle were measured. As a result, the older group showed more accentuated and lengthened back, rounded shoulder, forwarded neck, lower and fuller bust, farther apart bust apex, and increased bilateral asymmetry.

Chen, LaBat, and Bye (2010) identified the relationship between bra fit and physical characteristics of female college students. For physical characteristics that affect bra fit, four angle measurements of shoulder slope, bust prominence, back curvature, and acromion placement were examined on 3D scans. Shoulder slope was measured by the angel between the horizontal line crossing the side neck point on the frontal plane and the line connecting the side neck point and the acromion and categorized into three groups of square, average, and sloped shoulder. Bust prominence was measured by the angle between the horizontal line crossing the side neck point on the sagittal plane and the line connecting the side neck point and the left bust apex and categorized into large, average, and small bust. Back curvature was measured by the angle between the horizontal line crossing the side neck point on the sagittal plane and the line connecting the side neck point and the shoulder blade and categorized into flat, average, and round types (Figure 11). Acromion placement was measured by the alignment of the side neck point and acromion on the sagittal plane and categorized into back, average, and forward acromion.

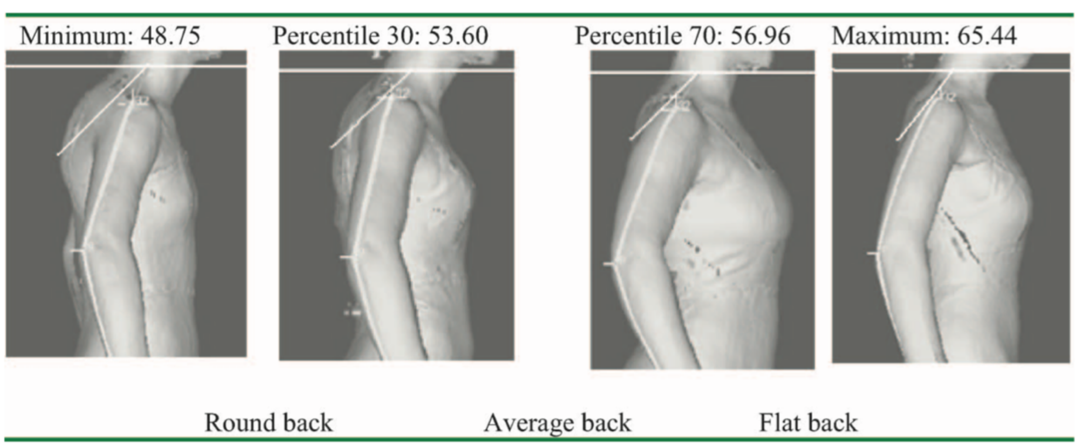


Figure 11. Figure variations of back curvature

Choi and Nam (2010) proposed an upper lateral body classification system incorporating visual assessment and statistical analysis. 3D scans of 246 women aged 18-49 were initially categorized by the author's (Nam, 1991) pre-defined four upper lateral body shapes that are straight, swayback, lean-back, and bend-forward types, then measurements of 3D scans in each category were statistically compared and evaluated. Space variables and angle variables were obtained from 3D scans. For back shapes, nine angles were measured using five reference points of the cervical point, projected shoulder point on the back, back protrusion point, projected bust point on the back, and posterior waist point.

Lyu (2016) assessed effects of the Posture Modification System using Soft materials structures (PMSS) using five angle measurements representing bilateral symmetry of the shoulder, torso alignment in the center front, torso alignment in the center back, shoulder alignment to the back neck point, and inclination of the torso based on seven reference points of front neck point, back neck point, left acromial point, right acromial point, junction of lumbar vertebrae 3 and 4, middle point of each breast on the bra, and the navel. These angels were slightly modified and applied to the later research on postural deviations caused by load carriage (Lyu & LaBat, 2016).

In general, common critical landmarks for back shape were the center back neck point or side neck point, and back waist point. Common critical landmarks for torso posture were the acromion and bust point.

For back curvature, researchers measured body angles from the sagittal plane above the waist level using either tangent angles (Cho et al., 2006; Ashdown & Na, 2008) or angles with reference point(s) (Chen et al., 2010; Choi & Nam, 2010). Body angles were considered efficient to measure curvature. Unlike linear measurements such as length and depth, a single body angle can effectively characterize body curvature. Compared to tangent angles, angles with concrete reference points appear more reliable. Since the human body consists of curvilinear shape with myriad of inflection points and is covered with soft tissues and body fat, measuring accurate tangent angles seem difficult. However, a body angle or a set of body angle does not seem to accurately represent curvature. The term curvature has many dimensions such as degree, inclination, and shape. Especially, the shape of a back curve is different from the arc, the even curve. Therefore, factor(s) to address back curve shape should be taken into consideration when assessing back curvature. In addition, older women are expected to show a rounded back and hunched shoulder, inclination of the back also deems important.

For torso posture, according to the purpose of the study, body angles were measured in the transverse plane as well as in the sagittal plane (Ashdown & Na, 2008; Lyu & LaBat, 2016) that indicates the efficiency of 3D scans for anthropometric studies. Although some researchers address the relationship between the back and other body segments (Ashdown & Na, 2008; Chen et al., 2010; Choi & Nam, 2010), they focused on the upper body and did not address postural variations as a whole.

Apparel Fit

Apparel fit is a desired relationship between the body and a garment (Ashdown & O'Connell, 2006; Bye, LaBat, McKinney, & Kim, 2008; Chen, 2007; Erwin, Kinchen, & Peters, 1979). It is an important criterion of the quality of a garment and consumer satisfaction (Bye & LaBat, 2005; Song & Ashdown, 2010) and contributes to the confidence and comfort of the wearer (Alexander, Jo Connell, & Presley, 2006). In this section, apparel fit is discussed in terms of basic components, fit assessment, and fit issues among older women.

Components of Fit

Erwin et al. (1979) defined the five elements of fit as grain, set, line, balance, and ease. Grain is the direction of the threads in the fabric and represents how well the vertical and horizontal threads of the fabric align with the wearer's body. Set indicates the way a garment contours the body without undesirable wrinkles. Line describes how well the structural lines of a garment such as side seams, shoulder seam, and hems harmonize with the lines of the body. Balance is well-proportioned representation of a garment from the right, left, front, side, and back perspectives. Ease is space between the body and a garment and consists of functional ease or wearing ease to allow body movement and design ease to create a silhouette reflecting the designer's intention. Thus, a garment silhouette is identified by a combination of body measurements, wearing ease, and design ease.

However, beyond these visually and physically measurable elements, apparel fit involves subjective personal interpretation. LaBat and DeLong (1990) indicated that an individual's satisfaction with specific body sites was positively associated with fit satisfaction at the same locations in a garment and that a fashion trend emphasizing specific body parts may influence the degree of satisfaction and body cathexis at the same body sites. In addition, Ashdown and DeLong (1995) demonstrated that individual variations appeared with respect to acceptability of ease amount as well as thresholds of apparel ease, the minimum ease amount that can be detected by the wearer. In a similar sense, Ashdown and O'Connell (2006) described that good fit is affected by the current fashion in fit, function of the garment, and the wearer's fit preference. McKinney, Bye, and LaBat (2012) also included an individual's ease preferences as a component of garment fit along with wearer ease, style ease, fabric content, and fabric structure.

Fit Assessment

Fit of a garment may be observed via three different mediums including live fit models, dress forms, and 3D virtual models and evaluated by either subjective assessment and objective assessment. Subjective assessment relies on a wearer's perceptions of fit or an expert judge's interpretation whereas objective assessment is achieved by quantitatively observable measurements without personal interpretation, such as garment dimensions. In this section, features of the three fit mediums and examples of each assessment method were reviewed.

Medium. Traditionally, research in Clothing and Textiles has utilized live fit models for wear tests (e.i. Bye & Hakala, 2005; Kohn & Ashdown, 1998; Schofield, Ashdown, Hethorn, LaBat, & Salusso, 2006). Not only is using live fit models advantageous in that body movement in a garment as well as garment appearance can be observed, it can also be valuable in accommodating the fit model's tactile perceptions of the garment. In the apparel industry, however, although fit sessions are generally conducted with live models (Bye & LaBat, 2005), dress forms are also used especially in the early stages of product development due to its availability and practicality (Yu, 2004).

Along with these two methods, as 3D scan technology evolves, virtual fit simulation using 3D virtual models has been introduced and considered to be promising. This technique enables apparel companies to simplify prototyping by reducing physical fit samples, lower overall costs in production, and facilitate communications between designers, patternmakers, and manufacturers regardless of physical distance (Lee & Park, 2017; Song & Ashdown, 2015). In addition, as consumers can create their own virtual model and virtual images can be zoomed and rotated, it is expected to help consumers find proper garment fit in online shopping, if the accuracy of virtual representation is guaranteed (Kim & LaBat, 2012). Despite these advantages, only large companies such as Target, Kohl's, and Levi's have adopted this technology (Song & Ashdown, 2015) and there is still much room for improvement in terms of accuracy and validity. Therefore, in apparel research, virtual simulation alone has not yet been adopted for examining garment fit. Instead, researchers have focused on identifying the current status of this technology, validating its efficiency by comparison between virtual fit and live fit using either 3D virtual models (Kim & LaBat, 2012; Song & Ashdown, 2015) or 3D scans of clothed subjects (Bye & McKinney, 2010; Song & Ashdown, 2010), and providing suggestions for technical improvement.

Subjective assessment. In general, research involving fit assessment has been subjectively conducted where researchers develop fit rating instruments and ask subjects or a panel of expert judges to assess garment fit according to the developed criteria. Even when quantitative data analysis is utilized, the results are inherently subjective as the assessment is based on personal interpretation such as tactile perception and visual observation.

Ashdown, Loker, Schoenfelder, and Lyman-Clarke (2004) investigated the usefulness and potential of 3D scans of clothed subjects for fit assessment. Three expert judges rated the fit of a test pant style at 13 locations using a three-point scale of acceptable, marginal or unacceptable. Bye and McKinney (2010) compared results from fit analysis using a live model versus a 3D scan of the same model in terms of the judge's ability to assess fit and reliability of fit scores. According to the provided fit criteria, six judges rated the test dress and pants on both models using a five-point scale ranging from unacceptable to excellent fit. The findings revealed variations depending on the models. Song and Ashdown (2015) examined the similarities between real and virtual fit of pants depending on fit statuses, lower body shapes, and fit locations. Nine expert judges rated the pants fit on a three-point scale with various descriptions and described issues of virtual fabric expression and effectiveness of using virtual models in the fit analysis process.

Along with expert evaluation, subject evaluation is also employed depending on the purpose of the study. In order to identify users' evaluation of accuracy and fidelity of a 3D garment simulation, Kim and LaBat (2013) developed a virtual online shopping scenario in which subjects viewed different sizes of virtual pants on their virtual model, selected the best size, evaluated the fit of the selected virtual pants at 13 critical areas using a seven-point scale. Subjects then tried the real pants of the same size and evaluated the fit with the same criteria. Researchers articulated technical limitations along with the theoretical benefits of the virtual simulation.

Sometimes, both expert and subject evaluations are combined. For improvement of pants fit for older women, Schofield et al. (2006) developed a pant prototype with two different seat shapes and tested the fit of the pants by participants as well as experts. Participants evaluated the pants fit in terms of visual assessment and comfort perception and rated their fit satisfaction on a five-point scale. In addition, participants in the pants were videotaped and three experts assessed each participant's pants fit more critically at various body locations. The importance of integrative perspectives of producers, observers, and wearer were illustrated.

As apparel fit involves both psychological aspects (LaBat & DeLong, 1990) and personal preferences (Ashdown & DeLong, 1995; Howarton & Lee, 2009; McKinney et al., 2012) and is interpreted based on an evaluator's insight and experience, fit assessment is inevitably subjective. This subjective nature may cause issues of inter- and intra-rater reliability (Kohn & Ashdown, 1998). Emphasizing the importance of consistent and effective fit assessment for both industry and apparel research, Ashdown and O'Connell (2006) validated that a tutorial fit training program with well-developed materials increases reliability of paraprofessionals' fit assessment.

Objective assessment. Although consistent and precise fit assessment is ideal, exact quantification of apparel fit is near impossible and has limits. While the wearer's comprehensive fit satisfaction, comfort in motion, and tactile perceptions are important to determine fit of a garment, these perceptual elements might not be objectively measured. However, subjective assessment also has limitations such as individual bias and perceptual error (Kohn & Ashdown, 1998). Thus, to illuminate the identified drawbacks in subjective fit analysis and to verity the reliability and validity of an objective method, Kohn and Ashdown (1998) employed the garment slash method as a means of objective assessment and compared the results of fit assessment with those using traditional methods.

This garment slash method was originally developed by Crow and Dewar (1986) to identify the location and the degree of seam stress in Canadian Forces combat clothing while donning, doffing, and posing particular stances. The degree of stress exerted in a garment was detected by the amount of slit opening in the garment. Later, Ashdown and Watkins (1992) applied this method for analyzing mobility and performance of a protective coverall design. While these two earlier studies relied on subjective assessment by expert judges, Kohn and Ashdown (1998) quantified misfit of a test garment by the percentage of opening in a specific area.

To evaluate this technique more effectively, the researchers recruited women between the age of 55 and 65 as this age group often experiences age-related postural changes that lead garment misfit. The results of the objective assessment with a subject in a slashed jacket were compared with the results of traditional methods. For traditional assessment, subjects in an un-slashed jacket viewed themselves in a mirror and rated the feel and look of the garment in terms of perceived misfit, presence of stress lines, and overall alignment at back neck, shoulder, armhole, back curve, and back width; six experts evaluated the fit of the un-slashed jacket with the same criteria; garment measurements were compared with subject body measurements. The findings indicated that although the diagnostic slash pattern needed to be refined for better results and the subjects were less sensitive in detecting misfit than the objective method or the experts. Overall, the garment slash method was reliable and a valid method to capture the body/garment relationship.

Fit Issues among Older Women

Population aging and increased demands of well-fitting garments for the elderly have been repeatedly discussed for several decades. While researchers have addressed older people's clothing needs from various perspectives of aging such as physical, psychological, social, and economical aspects, this study focuses on older women's physical changes during the aging process and apparel fit issues.

In this section, fit issues of older women were considered from both qualitative and quantitative perspectives. For qualitative perspectives, research into subject perceived fit problems, preferences, and satisfaction with ready-to-wear clothing was explored. For quantitative perspectives, research into sizing and garment patterns for older women was reviewed.

Qualitative perspectives. As an early investigation into clothing preferences, practices, and problems of elderly women, Norwood (1944) interviewed 100 white women aged 65 and older in Oklahoma and argued that "the right clothes" rather than many clothes were preferred. Fit and sizing were the primary factors of clothing dissatisfaction. Due to lack of properly sized and designed garments for older women, 95% of the participants reported that alteration is necessary to fit the body and 75% among them articulated that time and expense of alteration marred enjoyment of clothing. Common alterations among the women interviewed were shortening of blouse front, adjusting hem line, altering for round shoulders, narrowing the shoulders, increasing hip size, altering for protruding abdomen, increasing waist size, fitting a thin neck, altering for flat chest, adjusting for low bust, and altering for sloping shoulders in the order of frequency of responses.

Smathers and Horridege (1979) interviewed 38 women aged between 65 and 88 in Kentucky and indicated that 37% of homesewers among the participants shortened the waist length and 50% increased the hip girth. Although their clothing was generally tight in the torso, their tight clothing was also loose in other areas such as the shoulder representing complex misfit issues of their ready-to-wear clothing.

Richards (1981) investigated 83 women aged between 55 and 84 in Texas in terms of ready-to-wear dress fit in nine garment areas of shoulder length, bodice length, skirt length, sleeve length, sleeve width, bust height, bust circumference, waist circumference, and hip circumference. 92% of the participants mentioned that at least one area didn't fit. Overall, their dresses were long in all areas. The degree of misfit in the areas of shoulder length and bodice length was positively associated with the increase of age. Dissatisfaction in garment length was repeated in Shim and Bickle's (1993) study in which pants leg length was the least satisfied area and the petite participants showed the lowest satisfaction.

Along with an anthropometric study of older women, Goldsberry et al. (1996b) surveyed 6,652 women aged 55 and older for fit satisfaction of ready-to-wear. Over 70% of the respondents were not satisfied with garment fit. In general, garments were too tight and long. The back width was the least satisfying area on their garments. Regardless of their figure type, the respondents tended to buy Misses figure type garments. Those women purchasing Misses or Half-Size garment regardless of their actual figure type were more satisfied with their garments. This result was consistent with the findings of Richards (1981) in which those wearing Half Size dresses had fewer fit issues.

Howarton and Lee (2009) in discussing fit preferences of 299 female baby boomers indicated that about 90% of the respondents selected their stomachs as the area that they most wished to hide. Comfort was the most important criteria to choose their garments, followed by fit. On the other hand, Lee et al., (2012) argued that clothing fit was the most critical factor in making apparel purchase. In addition, the participants of their focus group interviews wished to cover their arms and neck to hide signs of aging that affected their garment purchasing decisions.

Quantitative perspectives. In general, research that explores older women's apparel fit from quantitative perspectives has compared subject body measurements or pattern measures to the present sizing for ready-to-wear or commercial patterns.

Fit and sizing. The first anthropometric survey for garment construction was conducted by the Bureau of Home Economics from 1939 to 1940 (O'Brien & Shelton, 1941). In this survey, weight and 58 measurements were taken from 14,698 women living in the United States. Based on this data, O'Brien and Shelton published "Women's measurements for garment and pattern construction" in 1941, and later in 1971 the National Bureau of Standards reapproved the data and published the voluntary standard for women's apparel, PS 42-70. However, O'Brien and Shelton's 1941 study did not adequately represent the older population. As the researchers already acknowledged in their report, older women were reluctant to participate in the survey. As a result, among the 10,042 women aged between 18 and 82 eventually included for data analysis, only 175 subjects, less than 2%, were women aged 65 and older (O'Brien & Shelton, 1941) that didn't tally with 1940 US Census in which 6.8% of the total population was above the age of 65 (U.S.

Census Bureau, n.d.). Consequently, PS 42-70 established based on 1941 study also included the imbalanced age distribution. In addition, as both standards did not provide separate sizing for older women, researchers investigated the goodness of fit of the sizing in representing older women's body dimensions.

In order to identify the effectiveness of sizing of ready-to-wear dresses and the present sizing for women's apparel, PS 42-70, to represent older women, Frazier (1975) compared three sets of measurements, 11 body measurements of 55 female subjects aged 62 and older, measurements in the same areas of 120 ready-to-wear dresses commonly purchased among the subjects, and the measurements of PS 42-70. Although the measurements from the ready-to-wear dresses and the PS 42-70 were consistent except the shoulder length, neither of them accommodated the subjects' actual body measurements, especially in age-related areas such as neck-to-bust-point, bust-point-to-waist, waist girth, back waist length, shoulder length, and cross-back. The researcher emphasized the necessity for a special size classification for older women.

Patterson and Warden (1983) compared 33 body measurements of 225 women ranging from 65 to 96 years of age living in Florida to the women's measurements in O'Brien and Shelton's 1941 study. Twenty-five out of 33 measurements showed significant differences. While height was similar with one-half inch shorter in Patterson and Warden's study, weight and most of the torso girths such as bust, waist, abdominal extension, and hip were significantly larger than the measurements in the 1941 study. The older women in the 1983 study were described as "short and stout" and shows more variability in the girth than vertical measurements. Height was the best indicator of vertical measurements and classified into 'short', 'regular, and 'long' and weight is that of horizontal measurements and classified into 'stouts' and 'slims'. Despite the efficiency of use of weight for a sizing indication, due to expected consumer reluctance and commercial feasibility, they suggested five alternative sizing of height/weight, height/bust, weight/waist height, bust/waist height, and abdominal extension/waist height using two key measurements based on the criteria of easy of measurement, balance of the vertical and horizontal measurements, balance of the upper and lower body, and inclusion of commonly used measurements for practicality. Although Patterson and Warden ascribed the measurement discrepancies of the two studies to the different age ranges and the possibility of measuring technique differences, since there existed a 40-year gap between the studies they also suggested longitudinal studies to identify secular trends.

Based on the fact that O'Brien and Shelton's 1941 study did not include a sufficient number of older women, Goldsberry, Shim, and Reich (1996a) conducted the first large-scale nationwide body measurement survey especially of women aged 55 years and older. Fifty-eight body measurements from 6,652 women representing 38 states were taken. Based on the bust, weight, and height, the subjects were classified into one of seven figure types of Junior, Junior Petite, Misses Petite, Misses, Misses Tall, Women, and Half-Size and assigned one garment size from six to ten size categories within a figure type as practiced in the PS 42-70. Then, the 55-plus measurements in each figure-size combination were compared to the same combination of the PS 42-70 data. The majority of the measurements across the sizes and figure types showed significant differences between the two datasets. The researchers characterized the 55-plus women with "the forward tilt of the head and neck; increased width across the back blade area; fuller upper arm; longer neck-to-bust measure; increase in waist thickness, abdominal seated measure, and abdominal extension; and the flattening of the derriere curvature" (p. 118). However, like Patterson and Warden's (1983) study, the researchers also acknowledged the 50-year gap between the datasets, and the results require careful interpretation. The disparity of the measurements may indicate distinct features of the older women or simply show secular variations of body measurements. For example, in most cases the chest width of the 55-plus subjects was larger than the PS 42-70 data that conflicted with a general idea of the narrower chest width of older women due to rounding the shoulder and the back. Although the researchers found that the difference between the back width and the chest width was greater in 55-plus subjects than the PS 42-70, they also specified that the present older women may have a larger chest width than women 50 years ago.

Goldsberry and colleague's (1996a) study was completed in 1993 and later the American Society for Testing and Materials (ASTM) adopted the results in establishing the sizing standard D5586, standard of body measurements for women aged 55 and older (Goldsberry et al., 1996a). The most recent update of D5586 was approved in 2010 (ASTM International, 2010).

Even after ASTM D5586 was introduced, fit issues of older women have remained. Campbell and Horne (2001) indicated that 40% of their subjects were not satisfied with the crotch of a test trouser developed using ASTM D5586. Schofield et al. (2006) demonstrated that women with the same waist and hip measurements showed different pants fit depending on seat shapes and emphasized the importance of well-classified sizing for older women. In a similar manner, Salusso, Borkowski, Reich, and Goldsberry (2006) also mentioned the necessity of more simplified but inclusive sizing for older women.

Fit and garment pattern. A garment pattern is a two-dimensional estimation of the human body. Patternmaking is a process of transferring the complex body form into a flat medium (Brackelsberg, Farrell-Beck, & Winakor, 1986; Heisey, Brown, & Johnson, 1986). In order to construct volume and to smoothly contour curved surface of the body, garment patterns adopt pattern shaping/fitting devices such as darts, seams, flare, gather, tuck, etc. to remove excessive fabric in one or more directions (Heisey et al., 1986; McKinney et al., 2012). Therefore, beyond body size, pattern implies shape and posture of the body.

After Douty (1986) introduced Visual Somatometry incorporating the lateral view to analyze the body, researchers integrated posture into patternmaking including body angle and thickness along with traditionally used body lengths and circumferences (Brackelsberg et al., 1986; Heisey et al., 1986; Winakor, Beck, & Park, 1990). However, since no accurate patternmaking method exist to create the best fit due to individual bodily variations and in many cases knowledge is not well documented and shared (McKinney et al., 2012), systematic research of patternmaking is difficult and little research has been done.

Likewise, while research into older women's garment fit problems caused by body measurement changes has been constantly investigated, few studies have tested pattern alteration in relation to older women's shape and posture. As an example of pattern shape study for older women, Woodson and Horridge (1990) underlined the necessity of inquiries on curvatures of elderly female figures for pattern drafting.

Woodson and Horridge (1990) obtained 45 body coordinates of 104 women between 65 and 95 years of age from the Body Graph Measuring method by which combinations of vertical and horizontal coordinates of the body were plotted for basic patterns of the bodice, the sleeve, and the skirt. After drafting the respective basic patterns for Misses 12, 14, 16, 18, 20, and 22, each pattern was superimposed on a corresponding size of a commercial basic pattern. The results illustrated that the commercial patterns did not properly address older women's figures. In the bodice, both front and back lengths of the 65-plus patterns were generally shorter than the commercial patterns and the front bodice length showed greater differences between the patterns. These results indicated that although the back bodice length is elongated due to the back curvature, as body height decreases with age, back bodice length was less affected than the front bodice length. On the 65-plus patterns, the length of front waist darts decreased due to the lowered bustline, the amount of back waist dart decreased due to the rounded back, and the back shoulder dart was divided into the neckline and a yoke seam on the armhole to accommodate the rounded back and shoulder. In the sleeve, cap height increased in the 65-plus patterns and the shoulder point moved forward. In the skirt, while hip level showed the largest girth measurements on the commercial patterns, abdominal extension level was the greatest on the 65-plus patterns. The length between the waist and the hip was much shorter on the 65-plus patterns. Waistline of the 65-plus patterns was higher at the center front than at the side seams to accommodate abdominal extension. Pattern shapes implied older women's rounded shoulder and back, imbalanced front and back bodice due to back curvature, lowered bustline, increased waist and abdomen girth, and shortened waist length.

Conceptual Framework

Studies have shown that changes in spinal curvature with age cause postural variations in other body segments as the body compensates. Postmenopausal women tend to experience these changes more frequently. In apparel studies, researchers have examined back curvature and posture. However, posture was mainly discussed for the upper body above the waist and posture had not been fully addressed for the whole body. Fit issues of older women have been continuously reported and were closely related to older women's physical changes with age. Therefore, based on the premise that back curvature and posture of the torso should be combined to understand older women's physical characteristics and their fit issues, correlation between back curvature and postural variations of the torso was investigated. Figure 12 illustrates the conceptual framework of this study.

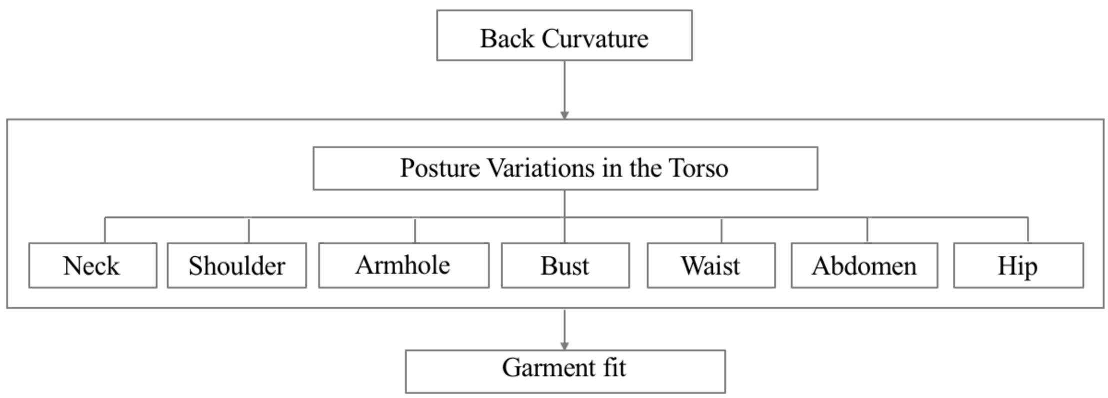


Figure 12. Conceptual framework of this study

CHAPTER THREE: METHOD

In this section, the influence of back curvature on postural variations of the torso was explored through analyzing three-dimensional body scans of secondary anthropometric data. Two secondary datasets were reviewed; the Civilian American and European Surface Anthropometry Resource (CAESAR) database and the master database of the Human Dimensioning Laboratory© (HDL) in the College of Design at the University of Minnesota.

Database

The CAESAR project was the first three-dimensional anthropometric survey for civilians conducted from 1998 to 2000 representing North America, The Netherlands, and Italy. The project included 3D scans with one standing and two seated postures, 40 traditional anthropometric measurements, 59 measurements from a set of scans, and demographic information per subject (Robinette, Blackwell, Daanen, Boehmer, & Fleming, 2002). For this study, the CAESAR North America was examined. The HDL master database has been collected since 2004 for various research purposes and includes 3D scans with a standing posture, 91 anthropometric measurements from a scan, and demographic information per subject. As 3D scans are available from both the CAESAR and the HDL master database, all the body measurements for this study were manually obtained from the scans.

In terms of the standing posture to be assessed in this study, the subject in the CAESAR survey stood up straight with weight distributed equally on both feet and the arms were straight and down naturally with the hands 20 cm away from the body. The subject's feet were positioned on foot outlines 10 cm apart at the inside of the heel and 30° angled at the toes (Robinette et al., 2002). In the HDL scan project, the subject placed his or her feet on foot outlines 25.4 cm apart at the inside of the heel and parallel at the toes. The arms are lightly bent at the elbow with hands 15.2 cm away from the body. The feet and arm positions in each dataset are slightly different. However, since height dimensions of this study were not measured based on the ground and the arms were excluded in the data collection, the postural difference between the datasets was minimal.

The use of secondary data streamlines data collection procedures and expands representativeness of the sample by providing a larger number of samples compared to data from a primary source. Thus, the CAESAR and the HDL master database were considered as useful sources for this study. Although the majority of the 3D scans utilized in this study were not scanned recently, as the main purpose of the study was to investigate physical characteristics that were distinctive but universal during the aging process, time when the data was collected does not limit the scope of interpretation.

Sample Selection

The sample was comprised of women 55 years of age and older. A total of 177 female scans, 155 scans from the CAESAR North America and 22 scans from the HDL master database were initially inspected. Final subjects were selected based on three additional criteria in consecutive order: (1) subjects whose 3D scan was complete and usable for data collection as all the body dimensions for this study were manually measured from individual scans, (2) subjects who did not exhibit excessive postural imbalance from the frontal plane, and (3) subjects whose 3D scan was still intact for data collection after arm exclusion.

For the first criterion, visual observation of individual scans was conducted.

For the second criterion, scans were also visually inspected. However, as indicated in the literature, perfect postural balance is almost impossible especially with advancing years (Levangie & Norkin, 2005). Thus, only when postural imbalance from the frontal plane was too extreme to collect the data from one side of the body was the scan excluded from the sample pool. Instead, the sample's frontal posture was indicated by a set of 10 balance measures (Table 1) that included a horizontal alignment in the shoulder, six vertical alignments in the torso, and three anteroposterior alignments of front and back neck, left and right shoulder, and center front and center back waist points. The horizontal alignment (θ_A) and vertical alignments (θ_B & θ_C) among the 10 balance measures were adopted and reproduced from Lyu and LaBat's (2016) assessment method (Figure 13).

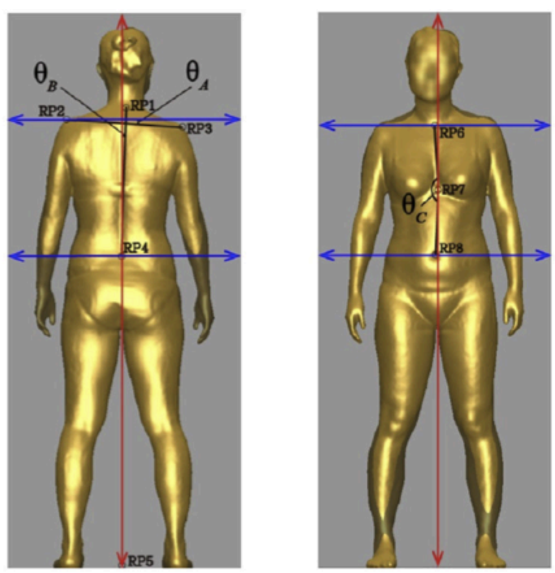


Figure 13. Body angle to assess postural imbalance (Lyu & LaBat, 2016)

Table 1.

Posture balance measures from the frontal plane

Descriptions	Evaluations
(1) Horizontal alignment of the left and right acromion	Angle measurement (adopted from Lyu and LaBat, 2016)
(2) Vertical alignment between the back neck point and the center back waist point	Angle measurement (reproduced from Lyu and LaBat, 2016)
(3) Vertical alignment between the back neck point and the crotch	Angle measurement (reproduced from Lyu and LaBat, 2016)
(4) Vertical alignment in the back torso	Angle measurement (reproduced from Lyu and LaBat, 2016)
(5) Vertical alignment between the front neck point and the center front waist	Angle measurement (reproduced from Lyu and LaBat, 2016)
(6) Vertical alignment between the front neck point and the crotch	Angle measurement (reproduced from Lyu and LaBat, 2016)
(7) Vertical alignment in the front torso	Angle measurement (reproduced from Lyu and LaBat, 2016)
(8) Anteroposterior alignment between the back neck point and the front neck point	Comparison of coordinates between the front and back neck points in the fontal plane
(9) Anteroposterior alignment between the center back waist point and the center front waist point	Comparison of coordinates between the front and back waist points in the frontal plane
(10) Anteroposterior alignment of the left and right acromion	Comparison of coordinates between the left and right acromion in the frontal plane

For the third criterion, sample selection was contingent upon successful completion of arm exclusion. For ease of data collection from the lateral plane, the right arm was cut from the frontal plane of the scans. Reference points of arm exclusion were the acromion, and anterior and posterior axillary folds (Figure 14). A cut line of the arm was softly curved representing an armhole in a garment. In an ideal upright posture, respective anterior and posterior axillary folds are placed on different levels, but in the same sagittal plane as shown in Figure 14 (Netter, 2011).

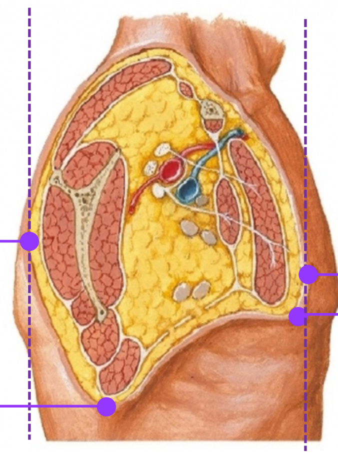


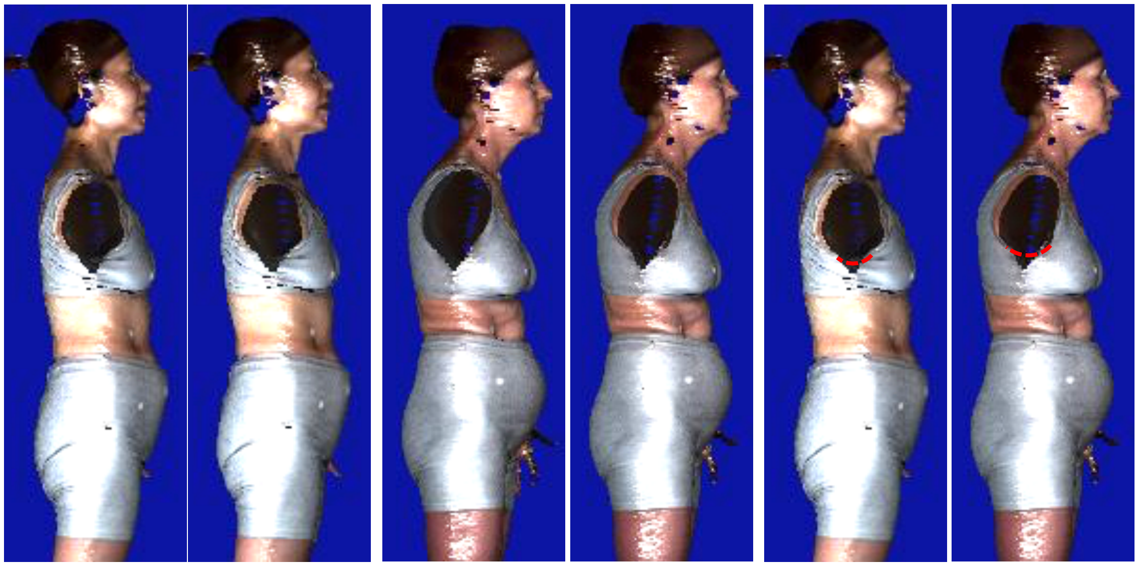
Figure 14. Oblique parasagittal section of axilla (Reproduced from Netter, 2011)

Although arm exclusion was essential to identify obscured parts of the body such as areas under the arm and to acquire measurements at the junction of the arm and the torso that were not discernible without arm exclusion, it required special attention. First, an exact location of the anterior axillary fold on the scans was not always clearly identifiable depending on arm position, thickness of the upper arm, or size of the bust. Secondly, while cut-out in the scans was not available in an angled plane, with a rounded back and hunched shoulders that frequently occur with the advance of age, the anterior axillary fold was generally positioned more inward to the center of the body compared to the posterior axillary fold. Therefore, if the arm was cut alongside the sagittal plane from the anterior view, the posterior armhole shape on the cross section would not exhibit the actual body.

As a solution for the first issue, Body Mass Index (BMI) of each subject was reviewed as weight is a major factor of body thickness and bust size (Patterson & Warden, 1983; Brown et al., 1999). If a subject was classified as obese with a BMI index greater than 30 (National Heart, Lung, and Blood Institute, n.d.) and her anterior and posterior axillary folds were not distinguishable, the scan was excluded from the sample pool.

For the second issue, the arm was cut from respective anterior and posterior views of a scan and both armhole shapes were considered for data collection. This method was beneficial as well as necessary because if anterior and posterior axillary folds were located on different sagittal planes, it signified a postural shift in the arm and the shoulder requiring armhole shape modifications in a garment. In Figure 15, although both subject A and B show different front and back armhole shapes depending on whether the arm is cut from anterior or posterior view, subject B who has a rounded back displays more significant distinction between the front and back armhole shapes.

Nevertheless, when the arm was excluded, there was another issue of measuring underarm areas. As the underarm was occluded by the upper arm during scanning, especially when the arm was placed too close to the body, a scanner did not capture this region completely thus creating holes in the scan. This occurred rather frequently in many scans. In general garment construction, the position and shape of the underarm should be taken into consideration to avoid surplus or lack of fabric in this region that may cause discomfort for the wearer. O'Brien and Shelton (1941) located the underarm midpoint "with reference to natural folds in the armpit and the total width of the shoulder" (p. 9) and indicated it as an important landmark. However, in this study, although the area of holes was limited only to the underarm and the armhole shape was predictable in this region, any measurements with reference to the underarm point were excluded from data collection to avoid inappropriate assumptions.



Cut from the anterior view | Cut from the posterior view | Cut from the anterior view | Cut from the posterior view | Reshape of underarm
Subject A | Subject B

Figure 15. Front and back armhole shapes after arm exclusion

Data Collection

Data collection protocol included establishment of reference lines, landmark identification on the scans, body measurement calculation using the coordinates of the landmarks in relation to the reference lines, index development representing back curvature and posture in the torso, and index calculation using the body measurements.

The coordinates of the landmarks were obtained from 3D scan measurement software ScanWorX by Human Solutions. In the coordinate system, the X-axis increased from bottom to top indicating the height dimension; the Y-axis increased from posterior to anterior indicating the depth dimension; the Z-axis increased from left to right from an observer's perspective, but from right to left on the scanned body and indicated the width dimension. Thus, respective XY, XZ, and YZ planes were equivalent to the sagittal, frontal, and transverse planes. Each coordinate was recorded using the metric system, the millimeters (mm).

Instead of using linear measurements to describe body parts, indices are generated. An index is an efficient tool to quantitatively define an abstract concept for which statistical analysis is available (Frankfort-Nachmias, Nachmias, & DeWaard, 2015). In addition, while back curvature and posture cannot be measured by a single linear measurement, an index, a composite measure combining two or more measurements, effectively represents the overall characteristics of the concept if it is based on concrete criteria covering all attributes of the concept and verifies its validity. Two criteria for developing indices of each torso segment are variations respective to the sagittal plane and to the transverse plane in relation to the reference lines. For variation in the sagittal plane, either anteroposterior inclination or relative depth of the body is identified. For variation in the transverse plane, relative height of the body is measured. Therefore, at least two indices are included to examine posture in each body part.

Reference Lines

Two vertical reference lines and two horizontal reference lines were drawn on the right lateral view of the individual scans. The vertical reference line was identified based on ideal standing posture in the literature in which the line of gravity passed through the external auditory meatus, midway through the shoulder, slightly posterior to the midway of the thorax, through bodices of lumbar vertebrae, slightly posterior to the hip joint, slightly anterior to the knee joint, and slightly anterior to the lateral malleolus. When the indicated parts of the body aligned in a straight line, the body was the most balanced and stable with a minimal stress or strain (Kendall et al. 2005; Levangie & Norkin, 2005). As the subjects in this study were not expected to show perfect postural balance due to physical changes with age, the main body points of the suggested reference line for an ideal posture would not be met. Thus, a reference point instead of a reference line was initially defined on the basis of three criteria; (1) the point must be on the suggested reference line for the ideal posture, (2) the point must remain less affected by postural variations from back curvature but effectively show the variations of body segments in the torso, and (3) the point must be essential for garment pattern construction and fit in terms of balance of a garment. Through these criteria, the underarm point was initially considered as a possible reference point because this was the top point of the side seam in a garment by which front and back bodices are joined. In addition, as this point was placed approximately midway between the neck and the waist, relative positions of other body segments were effectively identified.

However, as mentioned above, it was deemed difficult to find a consistent location for the underarm due to the missing part of the scan in this region. Instead, a point anterior to the lateral malleolus was selected as a reliable reference point. Although this point was less related to a torso garment, it was more stable with a fixed base. As the line of gravity provided a concrete standard for posture, body variations of older women were expected to be more accurately evaluated. In addition, this reference point was visually recognizable with a shadow around the lateral malleolus on scans and the CAESAR scans had a salient landmark on the malleolus. Thus, a vertical line passing through the point anterior to the lateral malleolus was established as the vertical reference line.

For the first horizontal reference line, a waist level was identified on the3D scans. As both the CAESAR and the HDL master database had pre-defined landmarks for the waist level, each was initially inspected to verify that both datasets had common criteria to set the waist. The CAESAR study identified the waist based on the subject's "preferred" waist level to wear their pants (Blackwell et al., 2002, p. 64), whereas the HDL master database sets the waist at the subject's smallest circumference between the lowest rib and the pelvis that was identified based on the most inferior point from the lateral side of the body by bending the torso to the side. Due to the differences in measuring techniques, waist circumference of each scan was inspected. In many cases, the subjects' waist was not set on the smallest circumference. Often, waist circumference was greater than the abdominal area or the thorax. Therefore, the waist reference line for this study was defined as the subject's preferred waist level to wear their pants. This level seemed to have a more practical indication of the waist in terms of garment pattern construction. In the HDL dataset, the preferred waist level was identified at the top edge of the subject's bottom scan garment.

After setting the horizontal waist reference line, the second vertical reference line to identify the center waist depth point at the midpoint of the waist depth (Table 2) was indicated. In index development, this line was drawn to identify relative volume of the body, especially in the bust, abdomen, and buttocks (Figure 26, 28, & 29). Although relative depth of the body parts can be evaluated in relation to the main vertical reference line, placement of the reference line may vary depending on the individual. For example, although the distance between the back waist protrusion point and the buttocks protrusion point of two different subjects was the same, the prominence of the buttocks were calculated differently when using the main vertical reference line as a guideline. When the vertical reference line was closer to the back waist protrusion point, the prominence of buttocks was calculated at greater value. Therefore, the vertical line referring to the center waist depth point was established as the second vertical reference line. Using this line, prominence of anterior body parts and that of posterior body parts were compared simultaneously. In addition, in garment construction, shaping devices for the front and back patterns as well as the upper and lower patterns are determined based on the intersecting point at the waist line and side seam. As this vertical center waist reference line was limited to indices representing torso depth, the main vertical reference line was named the vertical reference line.

For the second horizontal reference line, the crotch level, the highest level between the right and left legs and the lowest level of the torso, was identified from the frontal plane. In order to illustrate configuration of body parts below the waist, the crotch level served as a guideline.

Landmarks

A total of 20 landmarks, 17 identified on the individual scans and 3 calculated points, were identified. Definitions of the selected landmarks were described in Table 2. As landmarks on the body represent points of body segments, they were marked based on the anatomical structure. In CAESAR, landmarks were located with reference to palpable or definite points of the skeleton. However, muscles and fat attached to the skeletal system made finding the precise location of each landmark difficult, especially when landmarking on scans. Therefore, when a landmark was not based on a prominent bony point, the landmark identification method differs from standards. For example, the ASTM D5219-15 (2015), Standard Terminology Relating to Body Dimensions for Apparel Sizing, stipulates a hip level by the region of the lateral part of the pelvis and the upper part of the femur. CAESAR defined it at the maximum circumference level below the top of the pelvis and suggested measuring approximately 2 cm above the maximum protrusion of the buttocks for ease of application (Blackwell et al., 2002). O'Brien and Shelton (1941) who established the first women's measurements for garment and pattern construction sets the hip at the most prominent point around the trochanter major from both left and right sides and averages the levels. ANSUR (Anthropometric Survey of U.S. army personnel) did not use the term "hip", however, the trochanterion, the superior point of the greater trochanter of the femur, was marked as a representative landmark around the hip (Gordon et al., 2014). Patternmaking literature indicated a hip level as the widest area on the hip (Armstrong, 2010). The fundamental idea of this study was to articulate the relationship between postural variations and its implications for garment fit, thus definition of the landmarks was decided in relation to reference points on a garment.

Among the 20 landmarks, two landmarks of the anterior axillary fold and the posterior axillary fold were used only for an arm exclusion guideline; two landmarks at the center front waist point and the center back waist point were used only for the subject's posture balance from the frontal plane.

Besides the center waist depth point, two more landmarks at the side neck point and the center front waist point were calculated rather than directly indicating on a scan. One rational was that both sites were not marked on the original scans, and any reference point to identify these landmarks, such as the navel for the center front waist, was not discernible on the scans. Technically, to locate a side neck point for garment construction, a thin neck chain passing over the front neck point and the back neck point is placed around the neck, then the intersecting point between the neck chain and the anterior border of the trapezius muscle is marked (O'Brien & Shelton, 1941). Although an imaginary neckline might be pictured on a scan, the trapezius muscle was not palpable making anatomical landmarking impossible. As the side neck point in this study was used to describe a relative position of the acromion and the acromion is ideally positioned approximately midway between the front and back neck points in the depth dimension (Kendall et al., 2005), a side neck point was calculated as the median point of the line connecting the front neck point and the back neck point. To locate the center front waist point, the coordinates of left and right waist depth dimensions were averaged. Although the body may not be symmetrical and the navel may not be placed at the same distance from the sides, front bodice patterns are symmetrical in general supporting this approach to locate the center front.

On the 3D scans from CAESAR and the HDL master database, the landmarks for front and back neck point and the acromion were pre-defined. Additionally, in CAESAR, the lateral malleolus, anterior and posterior axillary folds, and bust points were marked. Therefore, the pre-defined landmarks were maintained for data collection.

Table 2

Landmarks for 3D scans

Landmarks on scans	Definitions	Reference points on a garment
(1) Lateral malleolus	Most prominent bony point on the side of the ankle	
(2) Front neck point	Anterior point on the neckline, anatomically identified as a top midpoint between the right and left collarbones Ideally, located in the median sagittal plane	Center front / Neck
(3) Back neck point	Outermost point on the back neck, anatomically identified as the center of the 7th cervical vertebra Ideally, located in the median sagittal plane	Center back / Neck
(4) Acromion	Top edge of the junction between the arm and the torso, anatomically identified as the most lateral point of the lateral edge of the acromial process of the scapula	Shoulder seam / Armhole
(5) Anterior arm point	Foremost point on the front armhole after arm exclusion as seen from the side	Armhole / Across chest
(6) Anterior axillary fold	Lowest point of the front arm where the arm separates from the torso as seen from the anterior view	
(7) Posterior arm point	Outermost point on the back armhole after arm exclusion as seen from the side	Armhole / Across back
(8) Posterior axillary fold	Lowest point of the back arm where the arm separates from the torso as seen from the posterior view	
(9) Back protrusion point	Most protruding point on the back as seen from the side	Pivot point for back shaping device(s)
(10) Bust point	Apex of the breast as seen from the side, identified based on the bust point	Bust point (or) Pivot point for front shaping device(s)

Table 2

Landmarks for 3D scans (continued)

Landmarks on scans	Definitions	Reference points on a garment
(11) Front waist protrusion point	Most protruding point on the front waist as seen from the side	Determinant of the amount of front waist shaping device(s)
(12) Side waist point, left and right	Outermost points on both left and right ends on the waist level as seen from the frontal plane	Side seam / Waist
(13) Center back waist point	Posterior point on the waist level, marked on the spine, Ideally, located in the median sagittal plane	Center back / Waist
(14) Back waist protrusion point	Most protruding point on the back waist as seen from the side	Determinant of the amount of back waist shaping device(s)
(15) Abdominal protrusion point	Most protruding point on the abdomen as seen from the side	Pivot point for shaping device(s) in the front lower pattern
(16) Buttocks protrusion point	Most protruding point on the buttocks as seen from the side	Pivot point for shaping device(s) in the back lower pattern
(17) Crotch	Top edge between the legs as seen from the frontal plane, identified as the lowest point of the torso	Intersecting point of the inside seams of pant legs with the crotch seams
Landmarks calculated	Definitions	Reference points on a garment
(18) Side neck point	Midpoint between the front and back neck points as seen from the side	Neck / Shoulder seam
(19) Center front waist point	Anterior point on the waist level, calculated as a midpoint between the left and right side waist points Ideally, located in the median sagittal plane	Center front / Waist
(20) Center waist depth point	Center of the waist depth as seen from the side, calculated as a midpoint between the front and back waist protrusion points	

Measurements and Index Development

Measurements from the 3D scans were obtained from the right side of the body.

Back curvature. Back curvature was operationally defined by three criteria: (1) back protrusion level, (2) degree of curvature, and (3) inclination of curvature. Although researchers had empirically verified the gradual and general changes in adult spinal posture, its representation varied depending on the individual. In addition, although many fields have suggested various ways to measure back curvature, each study had different objectives and there was no absolute standard. Thus, the criteria for this study were established based on each criterion contribution to desired garment fit.

As the human body consists of concave and convex surfaces, a garment as an abstract symbol of the body should represent these features through pattern shaping devices, such as darts and yoke seams. To contour the back, back protrusion level should be considered as a guideline to locate the fitting device. Figure 16 illustrates the examples of different back protrusion levels.

In addition, the degree of curvature is closely associated with the amount of shaping (Figure 17). Besides the overall curvature, degree of upper back curvature above the back protrusion point should be also identified. With the same degree of curvature, the proportion of the curve may vary that requires proper distribution of the amount of each upper and lower shaping devises on a back bodice pattern.

Inclination of curvature is important to balance the front and back bodices in a garment. Inclination can increase or decrease depending on whether the back curvature is inclined forward or backward. Although both subject A and subject B in Figure 18 show similar degree of curvature, each form shows a different inclination and postural variation based on the vertical reference line.

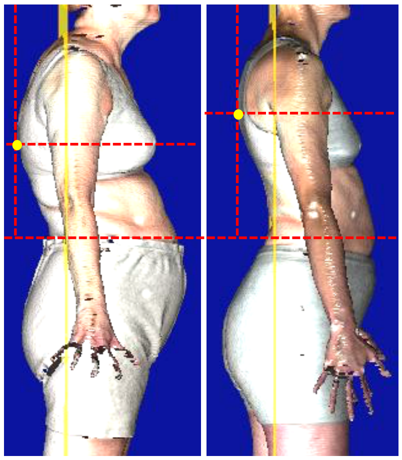


Figure 16. Level of a back protrusion point

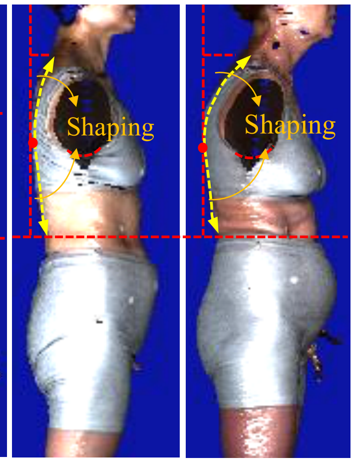
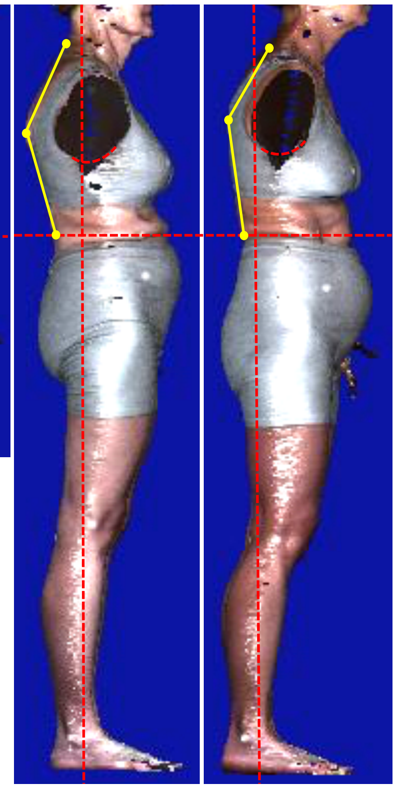


Figure 17. Degree of curvature



Subject A Subject B

Figure 18. Inclination with similar degree of curvature

To measure back curvature, the three criteria were defined by four indices using seven measurements (Table 3 & 4). Figure 19 illustrates the measurements on a scanned body and the scan shows a slight anterior pelvic tilt.

First, level of back protrusion was defined by the ratio of back protrusion height to back waist height. Index values have positive numeric values that are less than 100. The greater index values, the higher the level of back protrusion point from the waist.

Second, in apparel studies, although researchers have devised different methods for individual research purposes, back curvature has been inspected by measuring body angles, either tangent angles (Cho et al., 2006; Ashdown & Na, 2008) or angles with reference points (Chen et al., 2007; Choi & Nam, 2010). However, in this study, to measure degree of curvature, length and height dimensions instead of angle measurements were used for three reasons. First, an angle is multidimensional. As shown in Figure 18, it implies inclination as well as degree of curvature unless relevant reference lines and reference points are clearly established. Second, as the human body consists of continuous points of inflection, tangent angles on the body surface may increase measurement errors and may not be reliable. Third, linear measurements were considered more intuitive for interpretation and useful for patternmaking. Therefore, degree of curvature is defined by the ratio of back waist length to back waist height. Along with the overall curvature, upper back curvature above the back protrusion point is also measured using the same concept: the ratio of upper back protrusion length to upper back protrusion height. For both indices, index values close to 100 represent a straight back type in either the overall or the upper back region. The greater index values, the curvier the back.

Third, inclination of curvature was identified by the ratio of horizontal distance between the back neck point and the back waist protrusion point to waist height. Typically, a back neck point and a back waist protrusion point are located on the left side to the vertical reference line. Thus, when both points are located further to the left from the vertical reference line, posterior depth referring to these points increases. However, with a rounded back and an anterior neck tilt, the back neck point may be on the right of the vertical reference line. In this case, the posterior neck depth has a negative value (Figure 20). The same is applied to the posterior waist depth. With a back waist protrusion point on the right side of the vertical reference line, the posterior waist depth has a negative value. The greater the index values, the more forward incline. In addition, although there is no principle that the back neck point and the back waist protrusion point must be aligned in the same coronal plane, the smaller the index values, the more balanced the back curvature based on the vertical reference line. Negative index values illustrate that the back neck point is located posteriorly to the back waist protrusion point indicating a backward incline.

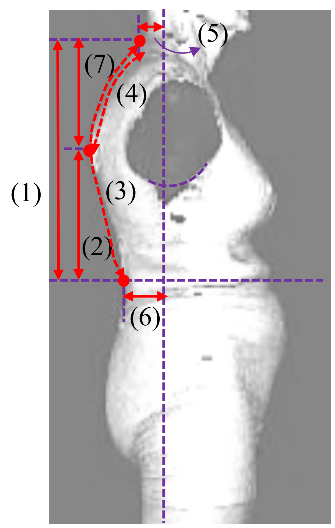


Figure 19. Measurements for back

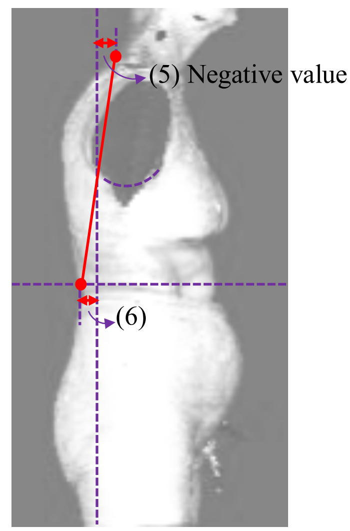


Figure 20. Inclination with a rounded back

Table 3

Measurements of back curvature

Measurements		Definitions
Heights	(1) Back waist height	The vertical distance from the back neck point to a point level with the waist
	(2) Back protrusion height	The vertical distance from the back protrusion point to a point level with the waist
Lengths	(3) Back waist length	The surface distance from the back neck point to the center back waist point, taken along the spine
	(4) Upper back protrusion length	The surface distance from the back neck point to the back protrusion point, taken along the spine
Depths	(5) Posterior neck depth	The horizontal distance from the back neck point to the vertical reference line
	(6) Posterior waist depth	The horizontal distance from the back waist protrusion point to the vertical reference line

Composite	(7) Upper back protrusion height	The vertical distance from the back neck point to the back protrusion point, (1) Back waist height – (2) Back protrusion height

Table 4

Indices of back curvature

Criteria		Indices
Level of back protrusion		(2) (Back protrusion height) / (1) (Back waist height) x 100
Degree of curvature	Back curvature	(3) (Back waist length) / (1) (Back waist height) x 100
	Upper back curvature	(4) (Upper back protrusion length) / (7) (Upper back protrusion height) x 100
Inclination of curvature		[(6) (Posterior waist depth) – (5) (Posterior neck depth)] / (1) (Back waist height) x 100

Neck. Neck posture is defined by two criteria: (1) neck height and (2) neck inclination. These criteria are operationalized by two indices using four measurements (Table 5 & 6, Figure 21). Neck height represents a relative level of the back neck point in relation to the front neck point. With a rounded back, the front neck point is expected to lie lower than that in an ideal erect posture and the back neck point may be the opposite. Index values are always greater than 100. Values further away from the index average may imply postural shifts in the neck requiring neckline adjustment in a garment.

Neck inclination illustrates a front neck disposition from the vertical reference line. As mentioned above, in the majority of cases, the front neck point is located to the right of the reference line and the back neck point mainly to the left. Therefore, using the reference line as a center, anterior neck depth has a positive value when it falls to the right and posterior neck depth has a positive value when it falls to the left. In an ideal standing posture, the vertical reference line in this study passes slightly anterior to the cervical spine

(Levangie & Norkin, 2005) and through the odontoid process (Kendall et al., 2005) that almost bisects the neck at the neckline from the lateral view. Therefore, index values close to 50 indicate a balanced neck position. The greater the index values from 50, the more inclined forward the neck. Index values greater than 100 indicate both front and back neck points are on the right to the vertical reference line signifying an anterior neck tilt. The degree of tilt is determined by how far the value is from the baseline, 50.

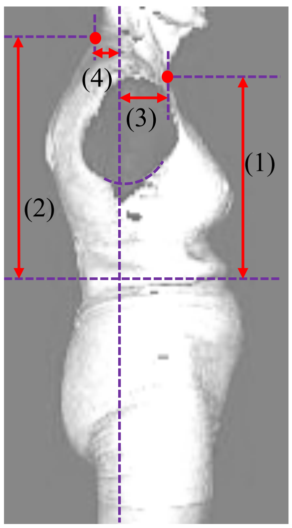


Figure 21. Measurements for neck

Table 5

Measurements of neck

Measurements		Definitions
Heights	(1) Front waist height	The vertical distance from the front neck point to a point level with the waist
	(2) Back waist height	The vertical distance from the back neck point to a point level with the waist
Depths	(3) Anterior neck depth	The horizontal distance from the front neck point to the vertical reference line
	(4) Posterior neck depth	The horizontal distance from the back neck point to the vertical reference line

Table 6

Indices of neck

Criteria	Indices
Neck height	(2) (Back waist height) / (1) (Front waist height) x 100
Neck inclination	(3) (Anterior neck depth) / [(3) (Anterior neck depth) + (4) (Posterior neck depth)] x 100

Shoulder. Shoulder posture is defined by two criteria: (1) acromial level and (2) acromial inclination. These criteria are explained by two indices calculated from seven measurements (Table 7 & 8, Figure 22). The position of the acromion is critical in a garment as it serves as an intersecting point of the front bodice, back bodice, and sleeve. In addition, it creates a shoulder line when connected to a side neck point and front and back armhole lines when connected to an underarm point. Thus, the acromion, marked as the shoulder tip in a garment, must be clearly identified to develop a well-proportioned garment. To develop indices, posture of the shoulder is examined in relation to a side neck point. The side neck point, calculated by the median point between the front and back neck points as seen from the side, was not anatomically identified and differs from the side neck point that is commonly used in garment patternmaking. Therefore, the measure of the side neck point of this study may not be applied for garment construction. However, it does illustrate the relative location and balance of the acromion to the neck.

The acromial level relates to the slope of the shoulder. Therefore, an index was generated by the proportion of the acromion height to the side neck height. In most cases, index values of acromial level are less than 100 as the acromion generally positions lower than the side neck point. However, it may have values greater than 100 with an anterior neck tilt and rounded back. The greater the index values, the higher the acromial level, the less shoulder slope in a garment.

In an ideal standing posture, the line of gravity passes through the midway of the shoulder (Kendall et al., 2005; Levangie & Norkin, 2005) and approximately bisects the neck at the neck base from the side. Thus, the acromion and the side neck point are expected to be on the vertical reference line in this study creating anterior acromion depth close to 0 and with the respective anterior and posterior neck depth of equal value. With a forward inclined back curvature, both anterior acromion depth and anterior neck depth increase, whereas posterior neck depth decreases. Therefore, to examine how far the acromion deviates from the side neck point, horizontal distance to the front neck point and the horizontal distance to the back neck point both from the acromion are compared. As the subjects are likely to lean forward at the shoulder in general, an acromion point that is positioned to the right of the vertical reference line reflects positive values. The greater the index values, the more inclined forward the acromion. Index values close to 100 indicate a balanced shoulder position in relation to the neck. In addition, index values greater than 100 signify a hyperextended shoulder whereas index values less than 100 signify a hunched shoulder.

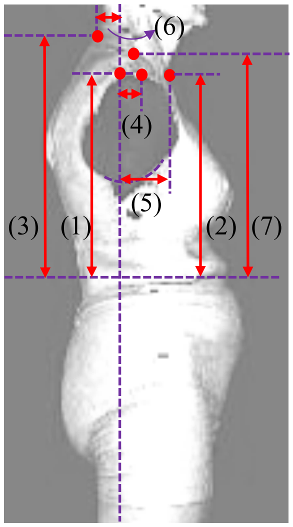


Figure 22. Measurements for shoulder

Table 7

Measurements of shoulder

Measurements		Definitions
Heights	(1) Acromion height	The vertical distance from the acromion point to a point level with the waist
	(2) Front waist height	The vertical distance from the front neck point to a point level with the waist
	(3) Back waist height	The vertical distance from the back neck point to a point level with the waist
Depths	(4) Anterior acromion depth	The horizontal distance from the acromion to the vertical reference line
	(5) Anterior neck depth	The horizontal distance from the front neck point to the vertical reference line
	(6) Posterior neck depth	The horizontal distance from the back neck point to the vertical reference line
Composite	(7) Side neck height	The vertical distance from the mid-level between front neck point and the back neck point, [(2) (Front waist height) + (3) (Back waist height)] / 2

Table 8

Indices of shoulder

Criteria	Indices
Acromial level	(1) (Acromion height) / (7) (Side neck height) x 100
Acromial inclination	[(5) (Anterior neck depth) – (4) (Anterior acromion depth)] / [(6) (Posterior neck depth) + (4) (Anterior acromion depth) / 100

Armhole. The armhole, or armscye, in a garment is an opening between the bodice and the sleeve. Although there is no anatomical term referring to this exact body segment connecting the torso and the upper arm, ASTM D5219-15 (2015), Standard Terminology Relating to Body Dimensions for Apparel Sizing, stipulates an armscye girth as "the circumference taken from the shoulder joint through the front break-point, the armpit, the back break-point and to the starting point" (p. 3) indicating that this measurement is closely related to the shoulder, front and back upper torso, and underarm areas. Thus, an armhole line typifies the shape of the junction of the arm and the torso. As seen in Figure 14, respective front and back armholes are different in terms of curve and protrusion level from the side, the widest part in each front and back armhole curve, both of which are susceptive to postural shifts in the torso. An underarm point serves as an important reference when drafting an armhole in bodice patterns, however this point is disregarded for index development due to unavailability on the scans.

Posture in the armhole was defined by three criteria: (1) anterior arm indentation level, (2) posterior arm indentation level, and (3) armhole inclination. Three indices representing the three criteria were generated by 12 measurements (Table 9 & 10, Figure 23 & 24).

The anterior arm indentation level was identified by the anterior arm point. In a front bodice pattern, this level corresponds with the most indented level of a front armhole as well as the narrowest width of the front bodice. Although patternmaking literature generally identifies the level of anterior arm indentation as a mid-level between the acromion and the underarm (Armstrong, 2010), flexed postures common in older women may affect the overall arm positions and result in armhole shape modifications for desired fit. The posterior arm indentation level was identified by the posterior arm point, the outermost point in a back armhole curve on the body from the right lateral view. In a back bodice pattern, this level corresponds with the most indented level of a back armhole as well as the narrowest width of the back bodice. In patternmaking literature, the level of posterior arm indentation is defined by one fourth of the distance between the back neck point and the back waist point (Armstrong, 2010). As with the anterior arm indentation, this point is also affected by postural shifts in the torso. The index of the anterior arm indentation level is calculated by anterior arm point height to acromion height. The same applies to the index for posterior arm indentation level. Index values have positive numeric values that are less than 100.

Armhole inclination is evaluated by anterior upper arm slope and posterior upper arm slope using three landmarks of the acromion point, anterior arm point, and posterior arm point. Both slope measures are calculated by the ratio of upper arm height above the arm points to depth to each arm point from the acromion point. Using the vertical reference line as a center, anterior arm point depth has a greater positive value to the right, whereas posterior arm point depth has a greater positive value to the left. The greater the slope, the upper part of the armhole in between the acromion and the arm point is relatively flat. The greater the index values, the flatter in the front upper armhole indicating that the overall armhole shape has a forward tilt.

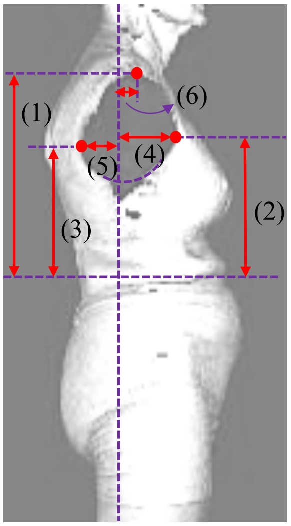


Figure 23. Measurements for arm indentation level

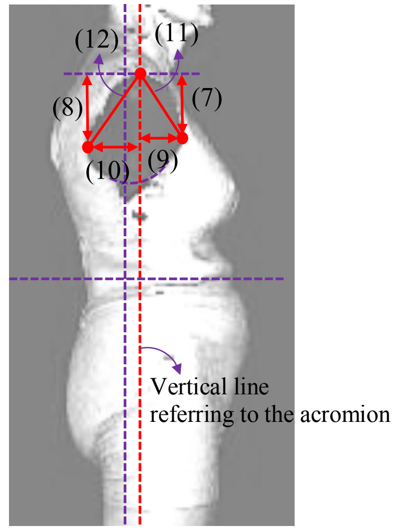


Figure 24. Measurements for armhole inclination

Table 9

Measurements of armhole

Measurements		Definitions
Heights	(1) Acromion height	The vertical distance from the acromion point to a point level with the waist
	(2) Anterior arm point height	The vertical distance from the anterior arm point to a point level with the waist
	(3) Posterior arm point height	The vertical distance from the posterior arm point to a point level with the waist
Depths	(4) Anterior arm point depth	The horizontal distance from the anterior arm point depth to the vertical reference line
	(5) Posterior arm point depth	The horizontal distance from the posterior arm point depth to the vertical reference line
	(6) Anterior acromion depth	The horizontal distance from the acromion to the vertical reference line
Composite	(7) Anterior upper armhole height	The vertical distance between the acromion and the anterior arm point, (1) (Acromion height) – (2) (Anterior arm point height)
	(8) Posterior upper armhole height	The vertical distance between the acromion and the posterior arm point, (1) (Acromion height) – (3) (Posterior arm point height)
	(9) Anterior armhole depth	The horizontal distance between the acromion and the anterior arm point, (4) (Anterior arm point depth) – (6) (Anterior acromion depth)

	(10) Posterior armhole depth	The horizontal distance between the acromion and the posterior arm point, (5) (Posterior arm point height) + (6) (Anterior acromion depth)
	(11) Anterior upper arm slope	The ratio of the anterior upper armhole height to the anterior armhole depth, (7) (Anterior upper armhole height) / (9) (Anterior armhole depth)
	(12) Posterior upper arm slope	The ratio of the posterior upper armhole height to the posterior armhole depth, (8) (Posterior upper armhole height) / (10) (Posterior armhole depth)

Table 10

Indices of armhole

Criteria	Indices
Anterior arm indentation level	(2) (Anterior arm point height) / (1) (Acromion height) x 100
Posterior arm indentation level	(3) (Posterior arm point height) / (1) (Acromion height) x 100
Armhole inclination	(11) (Anterior upper arm slope) / (12) (Posterior upper arm slope) x 100

Bust. Position of the bust is defined by three criteria: (1) bust point level , (2) under-bust level, and (3) bust prominence. These criteria are operationalized by four indices using six measurements. (Table 11 & 12, Figure 25 & 26). Bust point in a garment serves as a pivot point for pattern shaping devices and is considered the most prominent part of the upper front body. However, depending on the degree of postural variations, the bust point moves in terms of the level and prominence in the torso.

For bust level, two indices of bust point and under-bust levels are computed in relation to the front waist height. The greater the index values of level of bust point, the higher the bust point is in relation to the upper body above the waist. Index values less than the average signify a lowered bustline. The same applies to the level of under-bust point.

Bust prominence is determined by relative bust depth compared to the anterior waist-center waist depth and abdominal protrusion-center waist depth. The value 100 indicates that the prominence of the bust and the other parts is the same. As an index value moves above 100, the prominence of the bust steadily increases. Index values less than 100 indicate that other body parts are more prominent than the bust, and that typical waist darts in the front bodice pattern should be modified accordingly.

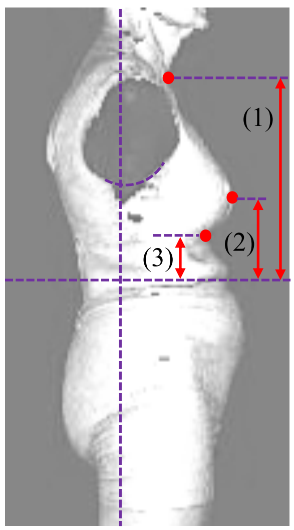


Figure 25. Measurements for bust level

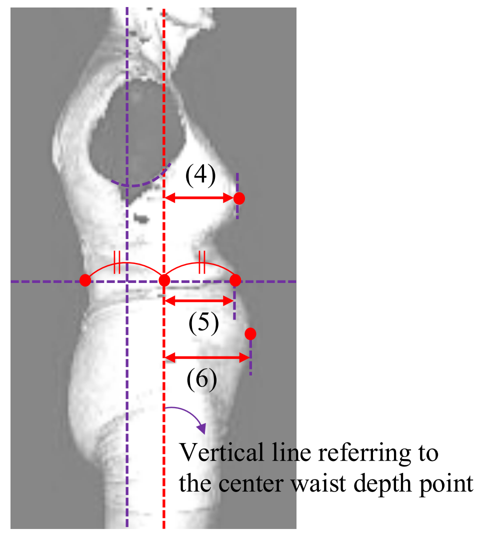


Figure 26. Measurements for bust prominence

Table 11

Measurements of bust

Measurements		Definitions
Heights	(1) Front waist height	The vertical distance from the front neck point to a point level with the waist
	(2) Bust point height	The vertical distance from the bust point to a point level with the waist
	(3) Under-bust height	The vertical distance from the under-bust level to the waist level
Depths	(4) Anterior bust point-center waist depth	The horizontal distance between the bust point and the center waist depth point
	(5) Anterior waist-center waist depth	The horizontal distance between the front waist protrusion point and the center waist depth point

	(6) Abdominal protrusion-center waist depth	The horizontal distance between the abdominal protrusion point and the center waist depth point

Table 12

Indices of bust

Criteria		Indices
Bust point level		(2) (Bust point height) / (1) (Front waist height) x 100
Under-bust level		(3) (Under-bust height) / (1) (Front waist height) x 100
Bust prominence	Bust to waist	(4) (Anterior bust-center waist depth) / (5) (Anterior waist-center waist depth) x 100
	Bust to abdomen	(4) (Anterior bust-center waist depth) / (6) (Abdominal protrusion-center waist depth) x 100

Waist. Position of the waist is defined by two criteria: (1) waist level, (2) waist inclination. Two indices are created from five measurements (Table 13 &14, Figure 27). Although there is no separation between the upper and lower body, the waist level serves as a convenient reference line in a garment dividing the upper and lower parts. As the torso in this study is identified as the center part of the body excluding the head and the limbs, an index for the waist level is defined by back waist height to height between the back neck and the crotch. Compared to the front neck point, the back neck point is located higher. To accommodate the maximum height of the torso, a back neck point instead of the front neck point is used for the index. The greater the index values, the longer the relative proportion of the upper body in the torso.

Waist inclination is examined by the ratio of anterior waist depth to the total anteroposterior waist depth. In an ideal standing posture, the vertical reference line in this study passes the bodices of lumbar vertebrae (Kendall et al., 2005; Levangie & Norkin, 2005). As the vertebral column is typically positioned toward the back of the body, anterior waist depth is expected to have a greater value than posterior waist depth. Therefore, index values would be greater than 50. Index values higher than the average imply a more forward inclined waist possibly due to swayback posture or abdominal extension. Index values greater than 100 signify that the back waist protrusion point is positioned on the right of the vertical reference line.

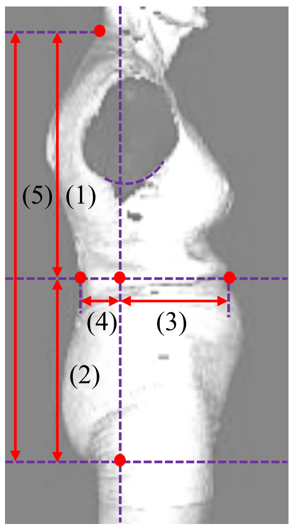


Figure 27. Measurements for waist

Table 13

Measurements of waist

Measurements		Definitions
Heights	(1) Back waist height	The vertical distance from the back neck point to a point level with the waist
	(2) Crotch height	The vertical distance from the front waist point to a point level with the crotch
Depths	(3) Anterior waist depth	The horizontal distance from the front waist protrusion point to the vertical reference line
	(4) Posterior waist depth	The horizontal distance from the back waist protrusion point to the vertical reference line
Composite	(5) Back torso height	The vertical distance from the back neck point to a point level with the crotch, (1) (Back waist height) + (2) (Crotch height)

Table 14

Indices of waist

Criteria	Indices
Waist level	(1) (Back waist height) / (5) (Back torso height) x 100
Waist Inclination	(3) (Anterior waist depth) / [(3) (Anterior waist depth) + (4) (Posterior waist depth)] x 100

Abdomen. Position of the abdomen is defined by two criteria: (1) abdominal protrusion level, and (2) abdominal prominence. Two indices are created from four measurements. (Table 15 & 16, Figure 28). Pattern shaping devices on the waist for a bottom garment are necessary to accommodate the curve below the waist. For front pattern shaping, identifying the position of abdominal protrusion is important. While the girth difference between the waist and the abdomen decides the amount of shaping, the abdominal protrusion point determines the location of a pivot point for the shaping. Changes in the thoracic curve result in compensatory variations in the lumbar region that alters the configuration of the abdomen. Abdominal protrusion level is identified between the waist and the crotch. The greater the index values, the lower the level of the abdominal protrusion point. Index values have positive numeric values that are less than 100. When a subject's front waist protrusion point is the most protuberant for the lower body, abdominal protrusion height is 0 and the index value is 0.

Abdominal prominence is determined by the relative position of the abdominal protrusion point to the front waist protrusion point. When a subject's front waist protrusion point is the most protuberant for the lower body, the index value is 100. The further away the index values are from 100, the more protruding the abdomen.

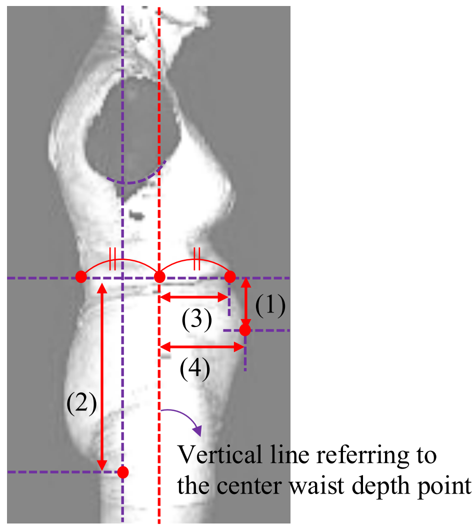


Figure 28. Measurements for abdomen

Table 15

Measurements of abdomen

Measurements		Definitions
Heights	(1) Abdominal protrusion height	The vertical distance from a point level with the waist to the abdominal protrusion point
	(2) Crotch height	The vertical distance from the waist level to the crotch level
Depths	(3) Anterior waist-center waist depth	The horizontal distance from the front waist protrusion point to the center waist depth point
	(4) Abdominal protrusion-center waist depth	The horizontal distance from the abdominal protrusion point to the center waist depth point

Table 16

Indices of abdomen

Criteria	Indices
Abdominal protrusion level	(1) (Abdominal protrusion height) / (2) (Crotch height) x 100
Abdominal prominence	(4) (Abdominal protrusion-center waist depth) / (3) (Anterior waist-center waist depth) x 100

Hip. Both patternmaking literature (Armstrong, 2010) and anthropometric surveys, such as CAESAR and ASTM indicate the hip level as the fullest part between the waist and the top of the pelvis. Therefore, hip level is defined by hip girth where the hip has the maximum circumference. As this level might not be easily detectable from visual inspection, CAESAR provides a guideline "approximately 2 cm above the maximum protrusion of the buttocks" (Blackwell et al., 2002, p. 53) and suggests moving a measuring device up and down from this level to locate the largest dimension. When the level spans a broad area, the midpoint of the area is to be set as the hip level. In addition, when the waist or abdomen has a greater girth measurement than the hip, a hip level is defined as the fullest part "below the top of the pelvis" (Blackwell et al., 2002, p. 54). Therefore, hip location in this study is identified in relation to the buttocks. Instead taking the maximum hip circumference, the most protruding point of the buttocks from the right lateral body is referenced to obtain hip depth. As with the abdominal protrusion point, while the girth difference between the waist and the hip determines the amount of shaping, the buttocks protrusion point determines the location of a pivot point for the shaping.

Position of the hip is defined by two criteria: (1) buttocks protrusion level, and (2) buttocks prominence (Table 17 & 18, Figure 29). Two indices representing the two criteria are calculated from four measurements. The greater the index values, the lower the buttock protrusion level, and the more prominent the buttocks to the back.

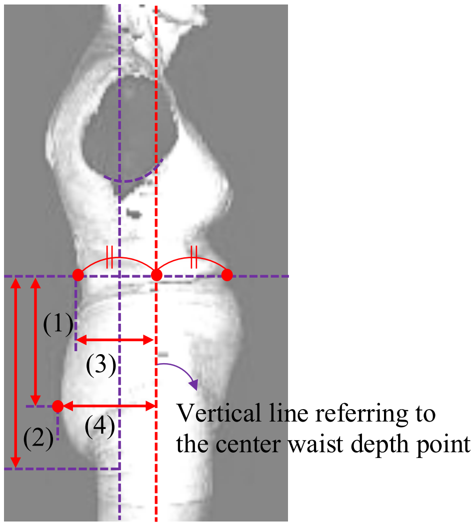


Figure 29. Measurements for hip

Table 17

Measurements of hip

Measurements		Definitions
Heights	(1) Buttocks protrusion height	The vertical distance from a point level with the waist to the buttocks protrusion point
	(2) Crotch height	The vertical distance from the waist level to the crotch level
Depths	(3) Posterior waist-center waist depth	The horizontal distance from the back waist protrusion point to the center waist depth point
	(4) Buttocks protrusion-center waist depth	The horizontal distance from the buttocks protrusion point to the center waist depth point

Table 18

Indices of hip

Criteria	Indices
Buttocks protrusion level	(1) (Buttocks protrusion height) / (2) (Crotch height) x 100
Buttocks prominence	(4) (Buttocks protrusion-center waist depth) / (3) Posterior waist-center waist depth) x 100

In summary, a total of 21 indices from 34 measurements including nine composite measurements were created to represent 8 body segments (Table 19 & 20).

Table 19

Measurements

Measurements		Definitions
Heights (11)	Front waist height	The vertical distance from the front neck point to a point level with the waist
	Back waist height	The vertical distance from the back neck point to a point level with the waist
	Back protrusion height	The vertical distance from the back protrusion point to a point level with the waist
	Acromion height	The vertical distance from the acromion point to a point level with the waist
	Anterior arm point height	The vertical distance from the anterior arm point to a point level with the waist
	Posterior arm point height	The vertical distance from the posterior arm point to a point level with the waist
	Bust point height	The vertical distance from the bust point to a point level with the waist
	Under-bust height	The vertical distance from the under-bust level to the waist level
	Abdominal protrusion height	The vertical distance from a point level with the waist to the abdominal protrusion point
	Buttocks protrusion height	The vertical distance from a point level with the waist to the buttocks protrusion point
	Crotch height	The vertical distance from the waist level to the waist level
Lengths (2)	Back waist length	The surface distance from the back neck point to the center back waist point, taken along the spine
	Back protrusion length	The surface distance from the back neck point to the back protrusion point, taken along the spine
Depths (12)	Anterior neck depth	The horizontal distance from the front neck point to the vertical reference line
	Posterior neck depth	The horizontal distance from the back neck point to the vertical reference line
	Anterior acromion depth	The horizontal distance from the acromion to the vertical reference line
	Anterior arm point depth	The horizontal distance from the anterior arm point depth to the vertical reference line
	Posterior arm point depth	The horizontal distance from the posterior arm point depth to the vertical reference line
	Anterior bust point-center waist depth	The horizontal distance between the bust point and the center waist depth point
	Anterior waist depth	The horizontal distance from the front waist protrusion point to the vertical reference line
	Posterior waist depth	The horizontal distance from the back waist protrusion point to the vertical reference line
	Anterior waist-center waist depth	The horizontal distance between the front waist protrusion point and the center waist depth point
	Posterior waist-center waist depth	The horizontal distance from the back waist protrusion point to the center waist depth point
	Abdominal protrusion-center waist depth	The horizontal distance between the abdominal protrusion point and the center waist depth point
	Buttocks protrusion-center waist depth	The horizontal distance from the buttocks protrusion point to the center waist depth point

Table 19

Measurements (continued)

Measurements		Definitions
Composite (9)	Side neck height	The vertical distance from the mid-level between front neck point and the back neck point, (Front waist height + Back waist height) / 2
	Upper back protrusion height	The vertical distance from the back neck point to the back protrusion point, (Back waist height – Back protrusion height)
	Anterior upper armhole height	The vertical distance between the acromion and the anterior arm point, (Acromion height – Anterior arm point height)
	Posterior upper armhole height	The vertical distance between the acromion and the posterior arm point, (Acromion height – Posterior arm point height)
	Back torso height	The vertical distance from the back neck point to a point level with the crotch, (Back waist height + Crotch height)
	Anterior armhole depth	The horizontal distance between the acromion and the anterior arm point, (Anterior arm point depth – Anterior acromion depth)
	Posterior armhole depth	The horizontal distance between the acromion and the posterior arm point, (Posterior arm point height + Anterior acromion depth)
	Anterior upper arm slope	The ratio of the anterior upper armhole height to the anterior upper armhole depth, (Anterior upper armhole height) / (Anterior armhole depth)
	Posterior upper arm slope	The ratio of the posterior upper armhole height to the posterior upper armhole depth, (Posterior upper armhole height) / (Posterior armhole depth)

Table 20

Indices

Body parts	Criteria		Indices
Back curvature (4)	Back protrusion level		(Back protrusion height) / (Back waist height) x 100
	Degree of curvature	Back curvature	(Back waist length) / (Back waist height) x 100
		Upper back curvature	(Upper back protrusion length) / (Upper back protrusion height) x 100
	Inclination of curvature		[(Posterior waist depth) – (Posterior neck depth)] / (Back waist height) x 100
Neck (2)	Neck height		(Back waist height) / (Front waist height) x 100
	Neck inclination		(Anterior neck depth) / [(Anterior neck depth) + (Posterior neck depth)] x 100
Shoulder (2)	Acromial level		(Acromion height) / (Side neck height) x 100
	Acromial inclination		[(Anterior neck depth) – (Anterior acromion depth)] / [(Posterior neck depth) + (Anterior acromion depth)] / 100
Armhole (3)	Anterior arm indentation level		(Anterior arm point height) / (Acromion height) x 100
	Posterior arm indentation level		(Posterior arm point height) / (Acromion height) x 100
	Armhole inclination		(Anterior upper arm slope) / (Posterior upper arm slope) x 100
Bust (4)	Bust point level		(Bust point height) / (Front waist height) x 100
	Under-bust level		(Under-bust height) / (Front waist height) x 100
	Bust prominence	Bust to waist	(Anterior bust-center waist depth) / (Anterior waist-center waist depth) x 100
		Bust to abdomen	(Anterior bust-center waist depth) / (Abdominal protrusion-center waist depth) x 100
Waist (2)	Waist level		(Back waist height) / (Back torso height) x 100
	Waist inclination		(Anterior waist depth) / [(Anterior waist depth) + (Posterior waist depth)] x 100
Abdomen (2)	Abdominal protrusion level		(Abdominal protrusion height) / (Crotch height) x 100
	Abdominal prominence		(Abdominal protrusion-center waist depth) / (Anterior waist-center waist depth) x 100
Hip (2)	Buttocks protrusion level		(Buttocks protrusion height) / (Crotch height) x 100
	Buttocks prominence		(Buttocks protrusion-center waist depth) / (Posterior waist-center waist depth) x 100

Data Analysis

Twenty-one indices from 25 measurements describing eight body parts were analyzed using SPSS (Statistical Package for the Social Sciences).

The aim of this study was to examine the influence of back curvature on posture in the torso of women aged 55 and older. Three research objectives to achieve the aim included (1) develop a measuring method for back curvature and posture in the torso and its validation, (2) identify interrelationships between back curvature and posture in the torso, and (3) interpret torso variations based on back curvature classification. For the first objective, 21 indices measuring back curvature and posture in the torso were initially suggested for data collection. Data analysis was guided by the presented research objectives and conducted in the following order: (1) sample description, (2) a summary statistics of measurements and index interpretations, (3) validation of developed indices, (4) interrelationship of indices between eight body regions, and (5) classification of back curvature and corresponding postural variations in the torso.

Descriptive statistics were employed to review the subjects' age and ethnicity, basic body measurements, and the location of the vertical reference line. To evaluate the subject's postural balance from the frontal plane, 10 balance measures representing horizontal, vertical, and anteroposterior alignments were evaluated using one sample t-test. In a balanced posture, those alignment measures were either 0 or 180.

For descriptions and interpretations of the measurements and indices, normality assumptions using skewness and kurtosis were illustrated to determine if the dataset was normally distributed. As a large random sample representing a population tended toward a normal distribution, accurate statistical inference in general required normality of the data.

However, as the human body varies greatly with age, the sample data in this study may not have been enough to be normally curved and to correctly predict information about the population. Some subjects may have had unusual dimensions compared to the others. Therefore, the purpose of the normality test in this study was not to eliminate outliers and to verify the normal curve; instead, when a measurement or an index indicated a significant deviation from a normal distribution, outliers notably distinct from the other values were carefully reviewed. They may have contained meaningful implications for this study.

For validation of developed indices, inter-index correlations of the respective eight body parts and how each index reflected a different dimension of the corresponding body part were reviewed. When a measure was developed, reliability of the measure was generally tested for internal consistency, the extent to which a set of measuring items was tightly associated. However, in this study, each index of one particular body region was developed using a different criteria to characterize unique features of the body. Therefore theoretically, indices of one body part should have had relatively low internal consistency with each other. To verify this concept, principal component analysis was applied to identify components to construct the body part. Ideally, the number of components had the same number of criteria used for index development per body part. Taking the back curvature as an example, three criteria of back protrusion level, degree of curvature, and inclination of curvature should have been identified by three different components. To avoid redundancy, one criterion was converted to one index in principle. When the criterion was specified by more than one index for desired garment fit, such as degree of curvature measured across the back as well as limited to the upper back, they have combined to one component. The original purpose of principal component analysis was to combine a large set of measuring items into a small set that shared common underlying dimensions, principal components. Therefore, items under each component had high internal consistency. However, in this study, Cronbach's alpha to test internal consistency was reviewed as to each individual body part.

Although indices within a body part were expected to have minimal correlation pairwise, indices across the body parts may have been associated. Therefore, correlation analysis was first utilized to see how the indices were interrelated with each other in terms of strength and direction. Correlation coefficients were reviewed at a significance level of .05. If the pattern looks reasonably linear on a scatterplot and the correlation was moderate to high ($r \geq .40$), a simple linear regression between the indices was applied to determine how one particular body part was connected with the other body part.

To classify back curvature, three indices of level of back protrusion point, degree of curvature, and inclination of curvature were utilized. Back curvature was initially described by four indices including the degree of upper back curvature with the above three indices. However, as the degree of back curvature and the degree of upper back curvature shared similar characteristics, only the degree of overall curvature was applied for the classification. Each of the three indices were divided by three groups using standard deviation as a guideline: Group 1 was below 0.5 standard deviation of the mean (30.9%), Group 2 was within 0.5 standard deviation of the mean (38.2%), and Group 3 was above 0.5 standard deviation of the mean (30.9%) (Figure 30). Justification for the group division was as follows: first, in most cases, anthropometric characteristics of a population were approximately normally distributed and 5th, 50th, and 95th percentiles were the most commonly used ranks to communicate the data boundaries (Proctor & Van Zandt, 2008).

Therefore, the standard deviation was expected to effectively quantify the variance of the data. Second, to classify the subgroups with similar variance explained, 0.5 standard deviation was applied. Although groups could have been divided by four, with two groups on each side of the mean, one group should include the mean to exhibit the central tendency of the data. In addition, as the middle group contained the overall mean of the data as the center value, it was more representative compared to the other groups. As this group covers a broader area on the graph, balance of typicality for each group was obtained. Therefore, Group 2 had a slightly greater portion of subjects.

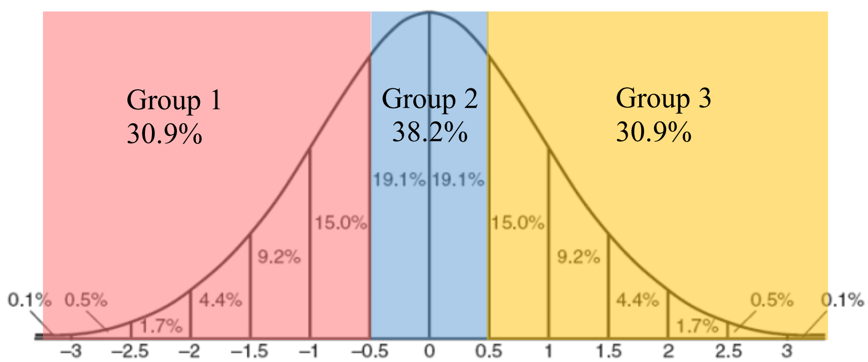


Figure 30. Group division based on standard deviation

Based on the three indices and three groups per index, a total 27 subgroups were generated for back curvature (Figure 31). Descriptive statistics included a frequency table and a range of measurements summarized the data. Although some of the subgroups had the desired number of subjects for statistical analysis, the number of subgroups was too great to identify reliable pattern of body variations with the limited research subjects. The purpose of the classification was to categorize homogeneous features of back curvature and to demonstrate postural differences in the torso between the subgroups. Therefore, a cluster analysis that created fewer subgroups was alternatively conducted for back curvature classification. To analyze the difference among the subgroups, analysis of variance (ANOVA) was applied and Bonferroni test or Dunnett's T3 were additionally adopted at a 5% confidence level for post hoc comparisons.

			Inclination of back curvature		
		Degree of back curvature	Group 1	Group 2	Group 3
Back protrusion level	Group 1	Group 1	1 – 1 – 1	1 – 1 – 2	1 – 1 – 3
		Group 2	1 – 2 – 1	1 – 2 – 2	1 – 2 – 3
		Group 3	1 – 3 – 1	1 – 3 – 2	1 – 3 – 3
	Group 2	Group 1	2 – 1 – 1	2 – 1 – 2	2 – 1 – 3
		Group 2	2 – 2 – 1	2 – 2 – 2	2 – 2 – 3
		Group 3	2 – 3 – 1	2 – 3 – 2	2 – 3 – 3
	Group 3	Group 1	3 – 1 – 1	3 – 1 – 2	3 – 1 – 3
		Group 2	3 – 2 – 1	3 – 2 – 2	3 – 2 – 3
		Group 3	3 – 3 – 1	3 – 3 – 2	3 – 3 – 3

Figure 31. Classification of back curvature

Validity is how accurately a measuring instrument, a set of indices in this study, can measure the originally intended concepts. When the measuring instrument can empirically verify the conceptual framework of the study, construct validity of the measures is achieved (Frankfort-Nachmias, 2015). Therefore, if the indices of back curvature successfully predict postural variations in the torso, then validity of the indices can be achieved. In addition, if clustered subgroups show distinctive postural patterns in the torso, validity of the research design can be achieved.

Although the overarching objective of this study was to identify the relationship between back curvature and postural variations in the torso, the major premise of this study was that postural variations in the torso caused by back curvature result in garment fit issues for older women. Therefore, the scope of data interpretation was not limited to a hypothesis testing, but rather explanatory as to body/garment relationship. See Figure 32 for analysis process.

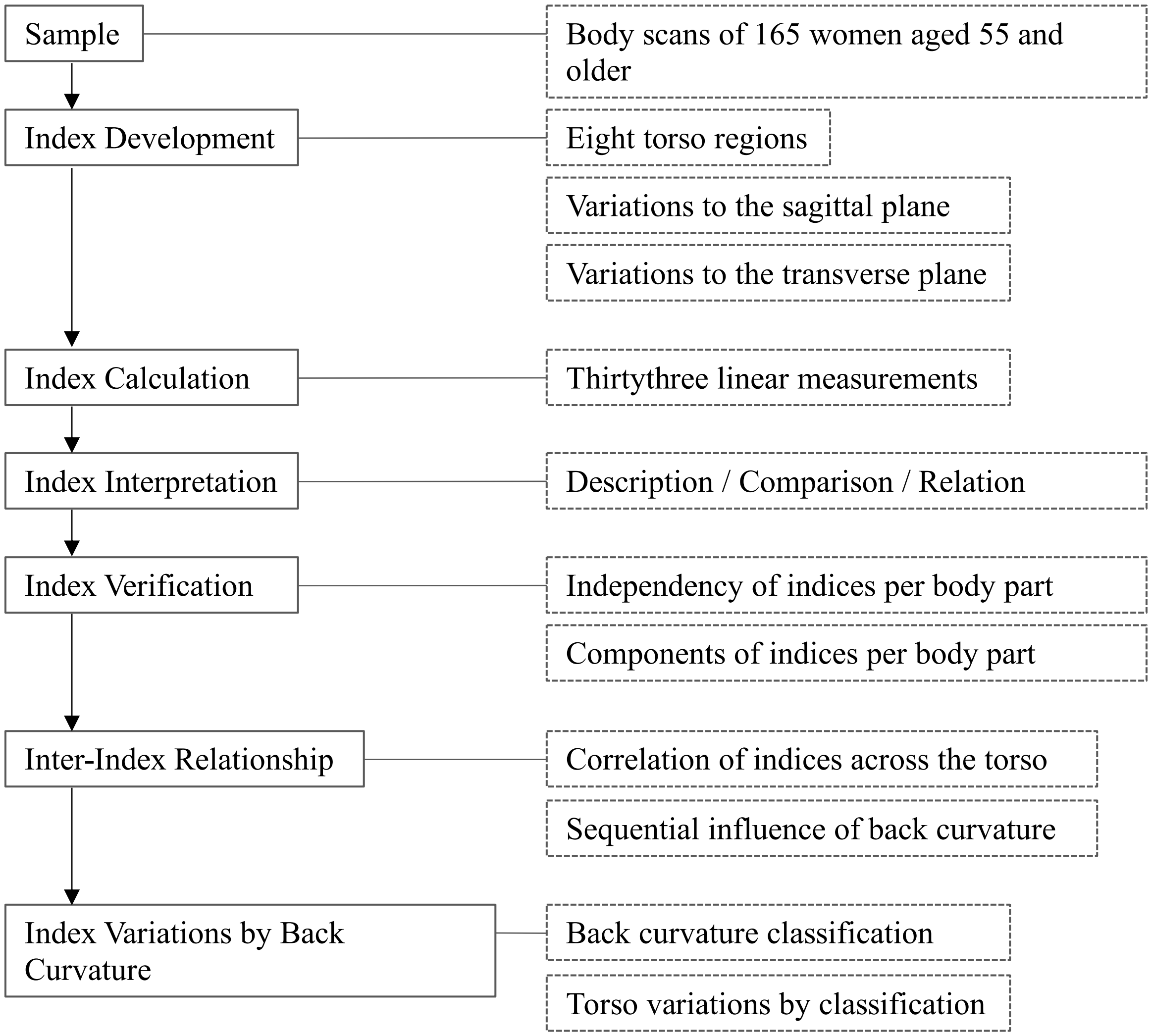


Figure 32. Analysis process

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter presents data analysis and discussion of the results. The first section contains the sample profile and preliminary data descriptions, and the following sections include analysis of three research objectives: validation of developed indices, inter-index relationships, and associations between back curvature and torso variations.

Sample Description

Demographic Profile of Subjects

A total of 165 female 3D body scans,152 from CAESAR and 13 from the master HDL database were analyzed in this study. The subjects were between 55 and 78 years of age (M = 60.01, SD = 3.64). The age group was mainly distributed between 55 and 64, at 91.6% (n=151). The majority of the subjects (88.5%) were White/Caucasian, and 6.1% were Asian. The BMI category was 44.8% normal, with 51.5% being overweight or obese (M = 26.78, SD = 6.67). See Table 21 for the demographic profile of subjects.

Table 21

Age, ethnicity, and BMI of subjects

Age	F	%	Ethnicity	F	%	BMI	F	%
55-59	75	45.5	African American	3	1.8	Underweight (<18.5)	6	3.6
60-64	76	46.1	Asian	10	6.1	Normal (18.5 – 24 .9)	74	44.8
65-69	13	7.9	Hispanic / Latino	1	0.6	Overweight (25.0 – 29.9)	50	30.3
70-74	0	0.0	White / Caucasian	146	88.5	Obese (> 30.0)	35	21.2
75-79	1	0.6	Other	5	3.0			

Note. F: frequency, %: percentage

Height, Weight, and Basic Girth Measurements for Garment Construction

The subjects' height, weight, and basic girth measurements for garment construction were illustrated in Table 22. In a symmetrical bell-shaped distribution, both skewness and kurtosis were 0. Skewness was a measure of uneven distribution of the data based on the central value. A positive skew indicated that the dataset was piled up on the left and had extreme values more on the right tail, and thus the mean was larger than the median. A negative skew was the opposite. Kurtosis was a measure of dispersion of the data, the extent to which the dataset was converged to the center. Both measures were highly sensitive to outliers. When extreme values fell more on one side in the distribution curve, skewness increased. When infrequent extreme values set a minimum or maximum value increasing the total range of the data, the other values appeared relatively close together at the center, and thus kurtosis increased. Absolute values of skewness and kurtosis between 0 and 1 verified normally distributed data.

Based on this standard, the shape of distribution for weight, waist girth, abdominal girth, and hip girth of the subjects was skewed to the right and centrally converged compared to a normal curve. In this skewed distribution, since the mean was affected by outliers, the median better represented the central tendency of the subjects for those four measurements. As one of the most common graphical methods to illustrate the data, the boxplots of six measurements are displayed in Figure 33 (Appendix A). In general, all the measurements had outliers on the right tail demonstrating that the larger the body size, the greater the variations.

Table 22

Height, weight, and basic girth measurements (Unit: mm, kg)

	Height	Weight	Bust girth	Waist girth	Abdomen girth	Hip girth
Mean	1624.97	70.47	1018.69	888.47	1030.29	1074.67
SD	68.60	18.28	134.83	156.63	146.47	138.84
1st Qu.	1580	57.94	921.00	777.50	937.50	982.00
Median	1620	67.40	1000.00	866.00	1004.00	1046.00
3rd Qu.	1674	7.44	1102.00	972.50	1107.00	1120.50
Minimum	1460	41.50	765.00	646.00	671.00	813.00
Maximum	1794	154.88	1497.00	1473.00	1662.00	1691.00
Skewness	.12	1.60	.77	1.08	1.13	1.51
Kurtosis	-.32	4.05	.75	1.46	2.85	3.24

Vertical Reference Line

To set the vertical reference line, the horizontal distance between the most prominent point of the lateral malleolus and its anterior edge was recorded using its coordinates. Depending on the individual, the prominence of the lateral malleolus was not always conspicuous on the scan and may have affected accurate identification of it anterior edge. Therefore, instead of applying each individual’s measurements, the distance between the two points was averaged and applied to all the subjects. The vertical reference line was set 18.1 mm anterior from the most prominent point of the lateral malleolus (Table 23). SMG, HKT, and Sachin (2015) measured the lateral malleolus using radiographs of 20 adult volunteers and indicated that the maximum sagittal width of the lateral malleolus was 23.5 mm. Based on the result, the location of the vertical reference line in this study was considered reasonable.

Table 23

Vertical reference line of subjects (Unit: mm)

	Mean	SD	1st Qu.	Median	3rd Qu.	Min.	Max.	Skewness	Kurtosis
Distance between the lateral malleolus and its anterior edge	18.11	1.74	16.80	17.90	18.95	15.20	23.7	-.93	-.80

Postural Balance in the Frontal Plane

In an ideal posture, the body had bilateral symmetry based on the median plane that passed the spinal cord. Therefore, the left and right acromion were at the same height as well as in the same depth dimension. A line connecting the center neck point, center waist point, and crotch point was perpendicular to the floor. The center front and center back neck points as well as the center front and center back waist points were aligned with the median plane. Although this study analyzed the right side of the body from the sagittal plane, accuracy of the results was guaranteed when the assumption of bilateral and anteroposterior balance of the body was verified. Therefore, the subjects' postural balance from the frontal plane was identified.

Ten measures of frontal posture were examined using a set of one-sample t-test. Null hypothesis (H_0) for all 10 measures were established based on the ideal posture. Seven measures of the horizontal and vertical alignments that were adopted or reproduced from the previous study (Lyu and LaBat, 2016) were evaluated using angle measurements, and three anteroposterior alignments were tested using coordinates in millimeters (mm). See Table 24 for results.

Table 24

Posture balance from the frontal plane

Alignment		Descriptions	H_0	M	SD	*t*
Horizontal	Acromion	Left – Right	M = 0	-0.80	1.89	-5.46***
Vertical	Back Torso	Neck – Center waist	M = 0	-0.19	1.59	-1.52
		Neck – Crotch	M = 0	-0.29	1.25	-2.96**
		Neck – Center waist – Crotch	M = 180	180.26	2.73	1.20
	Front Torso	Neck – Center waist	M = 0	0.29	1.69	2.18*
		Neck – Crotch	M = 0	0.02	1.34	0.22
		Neck – Center waist – Crotch	M = 180	180.54	2.22	3.15**

Antero-posterior	Neck	Back – Front	M = 0	3.73	5.82	8.22***
	Acromion	Left– Right	M = 0	-8.76	16.69	-6.75***
	Waist	Center back – Center front	M = 0	0.90	6.05	1.91

Note. *$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Six out of the 10 measures were significantly different from the ideally balanced posture at the .05 significance level. Overall, the subjects' left shoulder was higher (t = -5.46, $p < .001$) and inclined 8.76 mm backward compared to the right shoulder (t = -6.75, $p < .001$). On average, the front neck point was 3.73 mm tilted to the left compared to the back neck point (t = -6.75, $p < .001$). In terms of the torso, the center front waist had a right tilt compared to the front neck point (t = 2.22, $p <.05$) that resulted in a right-side curvature in the front torso based on the waist (t = 3.15, $p < .01$). In the back torso, the back neck point was inclined to the right compared to the crotch point (t = -2.96, $p < .01$). The findings illustrated that the subjects' frontal posture was not perfectly balanced and required three dimensional understanding of the posture.

Previous research (Ashdown & Na, 2008) verified an increase in bilateral body variations with age. This may have caused difficulties standardizing the body from only one anatomical plane. This study assumed that understanding of the subjects' typical posture was necessary to improve garment fit and that posture is inspected the best from the sagittal plane to address back curvature. However, findings of this study will need to be carefully incorporated in their pattern development, and consider individual bilateral variations.

Descriptive Statistics of Measurements

The posture of eight torso segments was converted to indices using linear measurements and each measurement had different implications when applied to indices.

Therefore, to describe basic characteristics of the data, components of indices, 34 linear measurements were first summarized in Table 25 and illustrated using the boxplots in Appendix A. As dimensional characteristics of the measurements were interpreted in relation to other measurements using indices in the following section, this section focused on the distribution shape and variability of the data.

Some of the statistics for skewness and kurtosis were out of the range of normality assumption. Four measurements, two depth dimensions and two slopes in bold in Table 25, were skewed right indicating that the right tail extended far out. Figure 43 and 44 (Appendix A) showed this tendency of the measurements.

Compared to skewness, kurtosis exhibited more deviation from a normal distribution indicating that some measurements in bold in Table 25 contained extreme values in either one or both tail(s) that affected the dispersion shape of the data. For example, Figure 36 (Appendix A) illustrates different kurtosis of the anterior upper arm height (0.91) and the posterior upper arm height (5.60). Although both measurements had a similar range, 115.70 and 107.70 respectively, and both contained outliers that were displayed with the circles representing mild outliers and the asterisks representing extreme outliers, the box length indicating the interquartile range (IQR) equivalent to the middle 50% range was shorter with the posterior upper arm height (12.10) than the anterior upper arm height (20.00). Therefore, outliers of the posterior upper arm height were relatively more distant from the center, thus resulting in larger kurtosis. This was also verified by a smaller standard deviation of the posterior upper arm height.

Both anterior upper arm slope and posterior upper arm slope had large values of kurtosis, 6.59 and 10.18 respectively, but showed slightly different patterns with the previous example. Total range of anterior upper arm slope was broader (3.55) than the posterior upper arm slope (2.29), however, its IQR was also relatively broader (0.45) than the posterior upper arm slope (0.3). Therefore, it had less extreme kurtosis (Figure 44 in Appendix A).

Overall, outliers were detected from 30 out of 34 measurements in the boxplots and values of 11 measurements were not normally distributed. As outliers were expected in the sample, all the data were applied to index calculation and the normality of indices was further evaluated.

Table 25

Descriptive statistics of measurements used to calculate indices

	Heights						
	Front waist	Back waist	Side neck	Acromion	Back protrusion	Upper back protrusion	Anterior arm point
Mean	310.10	385.49	347.80	322.23	215.58	169.91	234.11
SD	24.34	25.41	23.86	26.28	25.88	20.52	29.70
1st Qu.	295.75	367.45	331.45	302.70	200.00	154.65	213.40
Median	308.70	387.60	347.60	323.50	214.70	168.00	234.50
3rd Qu.	325.85	402.45	363.13	340.10	233.90	181.80	250.85
Min.	255.60	316.10	288.85	258.30	118.90	111.20	153.00
Max.	397.60	469.10	426.80	402.80	290.00	239.70	320.80
Skewness	.30	.08	.19	.21	-.34	.37	.40
Kurtosis	.62	.27	.52	.05	**1.07**	.50	.66
	Heights						
	Anterior upper armhole	Posterior arm point	Posterior upper armhole	Bust point	Under-bust	Abdominal protrusion	Buttocks protrusion
Mean	88.11	233.86	88.36	146.27	91.32	71.42	176.53
SD	19.83	25.06	11.90	25.59	26.54	34.55	21.69
1st Qu.	81.05	216.50	81.95	128.10	74.30	51.50	164.45
Median	90.90	233.30	87.30	146.70	93.20	80.90	177.10
3rd Qu.	101.05	249.65	94.05	166.65	110.95	95.20	189.10
Min.	22.40	151.60	36.50	81.40	10.10	0.00	95.10
Max.	137.10	294.00	144.20	204.50	155.90	141.30	230.60
Skewness	-.85	.06	.18	-.08	-.22	-.74	-.55
Kurtosis	.91	.27	**5.60**	-.54	.07	-.34	**1.04**

	Heights		Lengths		Depths		
	Crotch	Back torso	Back waist	Back protrusion	Anterior neck	Posterior neck	Anterior acromion
Mean	288.99	674.48	405.49	181.59	99.09	16.20	40.19
SD	19.33	29.70	28.39	24.04	23.47	29.84	25.85
1st Qu.	274.65	655.00	385.50	165.00	82.45	-1.90	24.05
Median	289.00	671.70	405.00	177.00	99.40	16.70	42.30
3rd Qu.	302.50	691.40	423.50	195.50	114.20	33.10	56.95
Min.	243.70	607.90	340.00	115.00	40.30	-74.80	-27.00
Max.	332.20	767.30	523.00	266.00	177.50	90.10	123.50
Skewness	-.05	.26	.43	.60	.13	.09	.07
Kurtosis	-.43	.24	**1.00**	**1.13**	.50	.11	.31

	Depths						
	Anterior arm point	Anterior upper armhole	Posterior arm point	Posterior upper armhole	Anterior bust bust-center waist	Anterior waist	Posterior waist
Mean	94.65	56.46	39.21	79.41	116.41	200.59	44.72
SD	22.43	15.81	29.43	16.97	21.24	36.50	30.06
1st Qu.	80.20	43.65	20.75	71.05	104.48	175.20	23.30
Median	94.20	53.40	37.00	79.50	114.45	197.40	42.70
3rd Qu.	109.35	63.15	57.00	88.70	130.60	223.70	63.35
Min.	43.10	19.40	-55.40	30.70	65.65	127.00	-20.70
Max.	157.80	109.20	110.40	167.10	168.50	313.10	171.80
Min.	.18	.52	.10	.70	.08	.66	.71
Kurtosis	-.00	.51	.44	**4.22**	-.13	.46	**1.53**

	Depths				Slopes	
	Anterior waist-center waist	Posterior waist-center waist	Abdomen protrusion-center waist	Buttocks protrusion -center waist	Anterior upper arm	Posterior upper arm
Mean	122.66	122.66	138.12	173.44	1.69	1.15
SD	27.38	27.38	24.56	33.33	0.45	0.27
1st Qu.	103.10	103.10	122.25	149.10	1.41	0.98
Median	116.45	116.45	134.85	166.40	1.62	1.12
3rd Qu.	137.88	137.88	148.43	190.75	1.86	1.28
Min.	81.95	81.95	94.55	116.75	0.76	0.60
Max.	229.35	229.35	241.05	281.55	4.31	2.89
Skewness	**1.09**	**1.09**	**1.27**	.99	**1.60**	**2.06**
Kurtosis	**1.38**	**1.38**	**2.71**	.80	**6.59**	**10.18**

Index Descriptions and Interpretations

Twentyone indices representing eight body regions are described in Table 26. To visualize the shape of distribution and outliers, boxplots for all the indices are included in Appendix B. Four out of 21 indices skewed right, and kurtosis of eight indices violated the normality assumption. When the index was skewed, the median instead of the mean was used for index interpretation. When the index had kurtosis greater than 1, the boxplot was reviewed to describe extreme values. See Appendix C for the average and extreme postures per body part.

In terms of back curvature, two indices measuring degree of curvature were skewed right with large extreme values (Figure 45 in Appendix B) and all four index values were converged to the center creating a leptokurtic distribution. The average back protrusion level was 55.86% above the waist between the back neck point and the waist level. The middle 50% values lied between 53.05 and 58.98. Therefore, this level appeared to be appropriate as a pivot point for back bodice shaping. However, the total range between the minimum and the maximum was fairly dispersed between 37.61 and 69.16 indicating that the back protrusion level varied greatly depending on the individual.

In terms of degree of curvature, the back waist length was on average 5.03% longer than the back waist height, and the upper back length was on average 6.42% longer than the upper back height. This value signified the amount to contour the back to maintain a balanced waist level in both front and back bodice patterns and desired fit around the armhole when constructing a garment. Although patternmaking has traditionally not used height, but rather surface measurements, the degree of curvature provides a general idea about shaping in a pattern. In terms of proportion of curvature, a paired sample t-test was conducted to identify the mean difference between the overall back curvature and the upper back curvature. The result indicated that the upper back above the back protrusion point had more curvier than the back as a whole ($t = -8.923$, $p < .001$). Based on the IQR, degree of upper back curvature showed greater variability (4.94) ranging from 104.02 to 108.96

when compared to degree of overall back curvature (2.96) ranging from 103.32 and 106.28. While both indices had similar minimum values, degree of upper back curvature had a 9.43 unit greater maximum value of 123.40. Different proportions of the back curvature would require more sophisticated shaping in a pattern beyond a single back shoulder dart.

On average, inclination of curvature was 7.34. In other words, the back neck point was inclined forward by 7.34% of the back waist height compared to the back waist point. Twenty subjects (12.1%) had negative index values indicating that their back neck point was posteriorly positioned to the back waist protrusion point. In the boxplot (Figure 46 in Appendix B), three outliers were detected, and the maximum inclination was 28.96.

For two indices representing the neck, both statistics of skewness and kurtosis were within the normality assumption. Neck height suggested that the back neck point was generally 24.53% higher than the front neck point, namely the front neck point was defined as one fifth of the distance between the back neck point and the waist level. While the IQR was 5.07, the total range was 27.07.

In terms of neck inclination, an index value close to 50 was considered to be a balanced neck position based on the vertical reference line. However, the mean was 87.77 signifying an anterior neck tilt. Fortyeight subjects (29.1%) had index values greater than 100 in which their back neck point was located to the right of the reference line. Adjustment of the front and back balance in a neckline would be required with a forward incline of the neck.

For the two indices representing the shoulder, the acromial point fell at 92.16% of the vertical distance between the side neck point and the waist. This value determined the shoulder slope in a garment. While the distribution of the acromial level was considered as a normal curve, one value calculated as 101.06 was detected as an outlier on the boxplot (Figure 48 in Appendix B). This value signified a higher acromial point than the side neck point. The middle 50% values ranged from 90.38 to 94.67.

Acromial inclination required careful interpretation because its distribution showed a significant deviation from a normal curve (Figure 49 in Appendix B). Based on the boxplot, the data had an extremely positive skew. The median as a central value was 99.51 indicating a balanced shoulder position in relation to the neck, and the middle 50% values ranged from 75.13 to 144.79. While no outlier was identified on the left tail, 15 outliers were detected on the right tail by using the equation of outlier detection (Lock et al, 2013) in which the values larger than Q3 + 1.5(IQR) were considered abnormally distant from other values. Among them, four values were identified as extreme outliers marked with the asterisks in the boxplot and calculated as larger than Q3 + 3(IQR). These values greatly affected the statistics of skewness and kurtosis. When the four extreme outliers were dropped, skewness and kurtosis were reduced to 1.40 and 1.68 respectively. They were still out of the range of normality assumption, but less extreme than the original. Although outliers may have changed the result of further analysis, outliers in this study were in principle not excluded since they were observed from the sample pool and correctly measured and entered during the data collection. In a large sample, they might not have been identified as outliers. However, the four extreme outliers ranged from 372.86 to 995.10 and caused an exceptionally large standard deviation (105.53) and a great gap between the mean (127.80) and the median (99.51). Therefore, the inclusion of those subjects for further analysis was tentatively reserved.

In terms of the armhole, the anterior indentation was set at the 72.57% level between the acromion and the waist, and the posterior indentation was at the 72.49% level between the same distance. Therefore, when drafting an armhole in a bodice pattern, this level suggested a critical point constructing the narrowest width between the armhole and the center front/back. Both indices had similar mean values, and there was no significant mean difference between the two levels (t = 0.157, *p* = .875). However, the posterior indentation level had a smaller standard deviation (3.69) creating a narrower IQR (4.00) compared to the anterior indentation level (6.35) and large kurtosis (3.92). In the boxplot (Figure 48 in Appendix B), three extreme outliers were detected, two extremely large outliers (86.91 and 87.78) and one extremely small outlier (58.69). Those subjects were also tentatively reserved for further analysis.

Armhole inclination had a positive skew and a more centrally converged curve than a normal distribution. Based on the median (147.55) as central tendency, the anterior upper arm slope was approximately 1.5 times greater than the posterior upper arm slope. This demonstrated that the subjects' armhole had a forward tilt resulting in a flatter upper armhole shape in the front and a more rounded upper armhole shape in the back. While the previous indices illustrated the indented level of an armhole, this index depicted the depth of an armhole at the indented level. While the IQR was 51.15 ranging from 122.02 to 173.17, the total range was 282.86 with two extremely large outliers as shown in the boxplot (Figure 49 in Appendix B). As with other extreme outliers, those subjects required further inspection.

For the bust, all four indices met the normality assumption. On average, the bust point was positioned at the 47% level between the front neck point and the waist, slightly lower than the middle level, and the under-bust was at the 29.20% level between the same distance that was 17.80% lower from the bust point level. IQRs for both indices were similar, 9.20 and 9.09 respectively. While there were no outliers at the bust point level, for the under-bust level, two outliers were detected in the boxplot (Figure 50 in Appendix B) that were 7.39 and 3.89. In many cases, the under-bust level is ignored when constructing a garment. However, the level difference between the bust point and the under-bust appear to be important for desired garment fit.

In general, the bust was not the most prominent point on the front body as seen from the side. A simple calculation using the mean values of the bust prominence to waist (97.01) and the bust prominence to abdomen (85.24) revealed that the waist and the abdomen were respectively 3.08% and 17.3% more prominent than the bust. In terms of frequency, the subjects who had a more prominent bust compared to the waist and the abdomen were 44.2% and 18.2% respectively. However, given the subjects' average girth measurements (Table 22), the bust (1018.69 mm) was still larger than the waist (866.00 mm) and the abdomen (1004.00 mm). Therefore, proper distribution of shaping avoiding the center area will be necessary in front bodice patternmaking.

Two indices for the waist also met the normality assumption. Waist level was located at 57.14% between the back neck point and the crotch point, approximately two thirds of the back torso. IQR was fairly small (2.48), and no outliers were detected (Figure 52 in Appendix B).

Waist inclination showed that based on the vertical reference line, the average proportion of the anterior waist depth was 82.87% of the total waist depth. This number suggested that the anterior waist depth was approximately 4.8 times greater than the posterior waist depth. The middle 50% values were between 76.55 and 89.52 and the total range was 60.73 to 111.14. As the back waist protrusion point was generally positioned to the left of the reference line, index values greater 100 indicated the back waist protrusion point fell to the right of the vertical reference line and signified an absolute anterior waist tilt. Seven subjects (4.2%) had index values greater than 100.

Two indices of the abdomen were normally distributed. The average abdominal protrusion level was defined as one fourth of the distance between the waist and the crotch, positioned 24.55% below the waist. Compared to other indices representing the level of body parts, the abdominal protrusion level had a relatively high standard deviation (11.64) indicating that this level was spread out over a broader range and varied greatly depending on the individual. The minimum value of this index was 0 signifying that the abdominal protrusion level was same as the waist level. Twelve subjects (7.2%) were included in this group and their waist was the most protruding point for the lower body.

In terms of prominence, the abdomen was on average 14.07% more protruding than the waist based on the anterior half of waist depth. The middle 50% values were between 103.53 and 120.99. As with the abdominal protrusion level, 12 subjects (7.2%) had the minimum value, 100, signifying the same prominence of the waist and the abdomen as seen from the side. Given that the abdomen was 15.93% larger than the waist in girth (calculated from Table 22), the abdomen was proportionately protruding around the waist.

Two indices of the hip were not skewed, but the buttocks protrusion level had large kurtosis (1.25). The mean of the buttocks protrusion level was 61.08 and defined the buttocks level as approximately three fifths of the distance between the waist and the crotch. While the IQR was 7.79, the total range was 35.10. Four outliers ranging from 38.67 to

46.10 were detected, and those subjects had a buttock protrusion level higher than the others (Figure 53 in Appendix B).

The buttocks point was in general 43.06% more prominent than the waist based on the posterior half of the waist depth. The middle 50% values ranged from 131.05 to 153.83. These values illustrated the amount to fit the waist on a lower back pattern. Two outliers, 188.23 and 204.60, were detected in the boxplot (Figure 54 in Appendix B).

Seventeen out of 21 indices except the bust point level, waist level, abdominal protrusion level, and abdominal prominence contained outliers. Among the 165 subjects, nine subjects were identified as extreme outliers with one of the indices; four from the acromion inclination, three from the posterior arm point level, and two from the armhole inclination. As those subjects resulted in significantly large deviation from a normal distribution in terms of skewness ($-0.03 \leq S \leq 4.55$) and kurtosis ($3.03 \leq K \leq 30.28$), normality was retested without the nine subjects. Adjusted descriptive statistics were presented in Table 27 (Appendix D). When the extreme outliers were dropped, normality of the three indices greatly improved. However, other indices such as degree of back curvature, degree of upper back curvature, inclination of curvature, and buttocks protrusion level deteriorated. As each subject had a different positioning in the distribution curve depending on an index, dropping subjects based on one index value was not considered legitimate. Those who were defined as an extreme outlier with one index may have represented the central tendency with other index. In addition, the main purpose of this study was not standardization of the body representing women aged 55 and older, but interpretation of their posture. Therefore, the range and variability of the indices were considered as important as the mean and standard deviation. In terms of statistical accuracy for further analysis, each analysis verified its required assumptions individually.

Table 26

Descriptive statistics of indices

	Back curvature				Neck	
	Back protrusion level	Degree of back curvature	Degree of upper back curvature	Inclination of curvature	Neck height	Neck inclination
Mean	55.86	105.19	106.83	7.34	124.53	87.77
SD	5.07	2.49	3.97	6.44	5.31	25.00
1st Qu.	53.05	103.32	104.02	3.07	121.10	70.67
Median	56.25	105.03	106.42	7.16	124.50	85.32
3rd Qu.	58.98	106.28	108.96	11.44	127.03	101.72
Min.	37.61	100.96	100.49	-6.78	113.16	30.90
Max.	69.16	113.97	123.40	28.96	140.23	172.83
Skewness	-.54	**1.02**	**1.08**	.55	.33	.34
Kurtosis	**1.50**	**1.34**	**2.08**	**1.13**	.20	.27
	Shoulder		Armhole			
	Acromial level	Acromial inclination	Anterior arm indentation level	Posterior arm indentation level	Armhole inclination	
Mean	92.16	127.80	72.57	72.49	151.57	
SD	3.30	105.53	6.15	3.69	46.49	
1st Qu.	90.38	75.13	68.56	70.55	122.02	
Median	92.64	99.51	71.76	72.56	147.55	
3rd Qu.	94.67	144.79	74.91	74.55	173.17	
Min.	84.88	32.09	57.72	58.69	52.72	
Max.	101.06	995.10	93.28	87.78	335.59	
Skewness	.01	**4.55**	.84	-.03	**1.19**	
Kurtosis	-.41	**30.28**	.99	**3.92**	**3.03**	
	Bust				Waist	
	Bust point level	Under-bust level	Bust prominence to waist	Bust prominence to abdomen	Waist level	Waist inclination
Mean	47.00	29.20	97.01	85.24	57.14	82.87
SD	6.25	7.47	17.50	14.28	2.47	9.56
1st Qu.	42.46	24.68	85.45	76.14	55.29	76.55
Median	48.28	29.93	97.52	84.56	57.37	82.01
3rd Qu.	51.66	34.67	108.50	95.38	58.77	89.52
Min.	31.12	3.86	57.42	57.27	50.33	60.73
Max.	62.36	47.10	152.24	128.86	63.52	111.14
Skewness	-.29	-.50	.23	.23	-.17	.38
Kurtosis	-.40	.46	-.05	-.30	-.21	.24
	Abdomen		Hip			

	Abdominal protrusion level	Abdominal prominence	Buttocks protrusion level	Buttocks prominence
Mean	24.55	114.07	61.08	143.06
SD	11.64	11.16	6.28	15.87
1st Qu.	17.59	103.53	58.03	131.05
Median	28.25	112.97	61.84	140.72
3rd Qu.	32.83	120.99	65.82	153.83
Min.	0.00	100.00	38.67	108.35
Max.	45.83	142.33	73.77	204.59
Skewness	-.85	.57	-.85	.66
Kurtosis	-.30	-.41	**1.25**	.80

Validation of Developed Indices

The indices representing one body part were developed using two criteria; variations in the X-axis representing the height dimension and variations in the Y-axis representing the depth dimension. As variations in each axis were less likely to correspond to each other, each index based on the respective criteria was expected to have a minimal correlation within a body part, but they comprehensively illustrated the posture from the sagittal plane. Therefore, the purpose of index evaluation was to demonstrate that theoretically established indices had distinctive or uncorrelated aspects to explain the posture. If indices under one particular body part were highly correlated, it may have implied either redundancy or unexpected implications to understand the body. The relationship between the indices in the individual body part was tested using correlation analysis and principal component analysis.

Inter-index Correlations per Body Part

To investigate the associations between the indices, Pearson's correlation coefficients (*r*) were examined. In Table 29, each body part was highlighted in gray, and r values greater than .40 was interpreted as a moderate correlation and indicated in bold.

Although a correlation coefficient provided a numerical measure as to the size of association between the indices, its pattern could not be identified by the number. Especially, while the data had many outliers, a correlation could be highly influenced by outliers. Therefore, as a graphical representation of the relationship, a scatterplot matrix per body part was reviewed (See Appendix E). The scatterplots effectively displayed that there was no strong relationship between the indices when they were developed from different criteria. However, there was an exception. On the scatterplot for back curvature, the degree of upper back curvature and the inclination of back curvature had a positive linear association, and its r value (.687, $p \leq .01$) reinforced the relationship.

The two indices of the abdomen showed a moderate positive association by its r value (.581, $p \leq .01$). However, while correlation analysis described linear relationships between variables, the association between the indices did not resemble a straight line on the scatterplot; instead, it was slightly curvilinear. As the abdominal protrusion level increased at a constant rate, the abdominal prominence increased at a greater rate and its variability also increased. Therefore, its r value was not appropriate to determine its linear relationship.

The scatterplots and r values provided evidence that the indices in general were not strongly associated each other.

Principal Components of Indices per Body Part

To confirm independency of each index within a body part, principal component analysis was conducted using a varimax rotation. The purpose of the rotation was to simplify the structure of components by which a relationship between a component and an index could be clearly identified. In terms of the number of components, the number of criteria per body part was entered. Then, eigenvalues of each component were reviewed. Eigenvalues greater 1 were considered appropriate to generate a component. Analogous to degree of back curvature, arm point level, bust level, and bust prominence were specified by two indices each. Thus, one component each was assigned for those criteria. The results of principal component analysis are illustrated in Table 28.

Eigenvalues for all the components were greater than 1 suggesting that each criterion had a different contribution to the corresponding body part. The greater the eigenvalue, the better the component explained the variation in that particular body part. For example, the component 1 of back curvature representing two indices of degree of curvature had a larger eigenvalue (1.69) and captured more variation (42.16%) in the back curvature compared to the other components.

Component loadings indicated a correlation coefficient between an index and the assigned component. The value of loadings also suggested that each criterion clearly constructed a different component except the armhole. In terms of the armhole, two components were divided in an unintended manner. The two original criteria for the three indices were the arm indentation level and armhole inclination. However, the anterior arm indentation level was more associated with the armhole inclination instead of the posterior arm indentation level and grouped together.

When principal component analysis was applied to two indices representing one body part, a varimax rotation with a fixed number of components generated the ideal eigenvalue and variance, 1 and 50% respectively. These values were unusual, however, as it verified that each index created a different component. In addition, the Cronbach's alpha measured the extent to which the indices comprising the individual body part hung together to be combined to one component. Using .70 as a standard, the indices except for the abdomen showed low internal consistency, and they were not suited for a component. Despite the high alpha value, the loadings of the abdomen indicated that each index was assigned to a different components with high correlation respectively.

Table 28

Principal component analysis of indices

Indices	Component loadings			Eigen Value	Variance Explained	Cronbach alpha
	PC1	PC2	PC3			
Back curvature						.44
Degree of curvature	.964			1.69	42.16%	
Degree of upper back curvature	.828					
Inclination of curvature		.962		1.22	30.42%	
Back protrusion level			.993	1.02	25.59%	
Neck						.30
Neck inclination	.976			1.00	50.00%	
Neck height		.976		1.00	50.00%	
Shoulder						.02
Acromial inclination	.997			1.00	50.00%	
Acromial level		.997		1.00	50.00%	
Armhole						-.10
Armhole inclination	.885			1.29	43.07%	
Anterior arm indentation level	-.710					
Posterior arm indentation level		.930		1.18	39.31%	
Bust						.49
Bust prominence to waist	.956			1.85	46.12%	
Bust prominence to abdomen	.956					
Bust point level		.952		1.81	45.29%	
Under-bust level		.944				
Waist						-.06
Waist inclination	1.000			1.00	50.0%	
Waist level		1.000		1.00	50.0%	
Abdomen						.74
Abdominal protrusion level	.952			1.00	50.0%	
Abdominal prominence		.952		1.00	50.0%	
Hip						.32
Buttocks prominence	.990			1.00	50.0%	
Buttocks protrusion level		.990		1.00	50.0%	

Note. PC: principal component

Interrelationship of the Indices across the Body Parts

The correlation coefficients (*r*) in Table 29 suggest that a total of 16 cases pairwise had statistically significant positive associations. The r values greater than .40 at a significance level less than .05 are indicated in bold. The posture in the back is related to the neck that is associated to the waist. In addition, the values of the bust tend to accompany the values of the waist and the abdomen that are also connected to the values of the buttocks. Although the back curvature is not directly correlated to other torso regions except the neck, posture of one body part continuously influences the adjoining body part.

Table 29

Inter-Index Correlations

	Indices	1	2	3	4	5	6	7	8	9	10	11
1	Back protrusion level	1										
2	Degree of back curvature	-.265**	1									
3	Degree of upper back curvature	-.086	**.829****	1								
4	Inclination of back curvature	-.145	.390**	**.687****	1							
5	Neck height	-.261**	.359**	**.463****	**.507****	1						
6	Neck inclination	-.062	.164*	.311**	**.464****	**.427****	1					
7	Acromial level	.289**	.127	.138	.042	-.1	-.002	1				
8	Acromial inclination	-.134	.345**	.296**	.166*	.187*	.204**	.164*	1			
9	Anterior arm indentation level	.038	-.161*	-.069	-.003	.01	.286**	.087	0	1		
10	Posterior arm indentation level	.286**	-.135	-.051	-.035	-.029	-.069	.061	.043	.259**	1	
11	Armhole inclination	.163*	.086	.237**	.301**	.133	.123	.086	-.234**	-.319**	.114	1
12	Bust point level	.181*	-.082	-.131	-.243**	-.083	-.014	.298**	.068	.272**	.275**	-.012
13	Under-bust level	.266**	-.192*	-.180*	-.228**	-.098	.127	.223**	-.017	.384**	.310**	.075
14	Bust prominence to waist	.046	-.292**	-.188*	.097	-.006	.271**	-.061	-.034	-.009	-.06	.009
15	Bust prominence to abdomen	.149	-.287**	-.144	.170*	-.081	.182*	.035	-.07	-.056	.016	.058
16	Waist level	.341**	-.145	-.048	.011	-.107	-.019	.132	-.058	.222**	.387**	.163*
17	Waist inclination	.027	-.061	-.202**	-.374**	.003	**.599****	-.024	.051	.235**	-.035	-.12
18	Abdominal protrusion level	-.230**	.037	-.032	-.048	.183*	.125	-.196*	.012	-.08	-.113	-.028
19	Abdominal prominence	-.160*	-.052	-.087	-.099	.143	.228**	-.182*	.061	.096	-.138	-.083
20	Buttocks protrusion level	-.052	-.254**	-.348**	-.377**	.02	.192*	-.288**	.027	.036	-.034	-.164*
21	Buttocks prominence	-.029	-.052	-.194*	-.229**	-.02	.324**	-.045	.027	.102	-.076	-.12

Note. $^*p < 0.05$; $^{**} p < 0.01$; $^{***} p < 0.001$

Table 29

Inter-Index Correlations (continued)

	Indices	12	13	14	15	16	17	18	19	20	21
1	Back protrusion level										
2	Degree of back curvature										
3	Degree of upper back curvature										
4	Inclination of back curvature										
5	Neck height										
6	Neck inclination										
7	Acromial level										
8	Acromial inclination										
9	Anterior arm indentation level										
10	Posterior arm indentation level										
11	Armhole inclination										
12	Bust point level	1									
13	Under-bust level	**.812****	1								
14	Bust prominence to waist	-.131	-.181*	1							
15	Bust prominence to abdomen	-.126	-.208**	**.842****	1						
16	Waist level	**.422****	**.563****	-.186*	-.068	1					
17	Waist inclination	.160*	.257**	.047	-.045	-.06	1				
18	Abdominal protrusion level	-.046	-.128	.269**	-.054	-.306**	.115	1			
19	Abdominal prominence	-.04	.018	**.411****	-.139	-.240**	.189*	**.581****	1		
20	Buttocks protrusion level	.085	.111	.226**	.003	-.212**	**.429****	.361**	**.439****	1	
21	Buttocks prominence	.09	.104	.368**	.267**	-.245**	**.506****	.204**	.232**	.281**	1

Note. *$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

The correlations provided evidence of association, but did not imply a causal relationship as to whether changing the value of one index influenced the value of the other index. Therefore, to investigate a consistent change between the indices, a set of linear regressions were applied.

As with the correlations, regression analysis requires a linear relationship. Thus, scatterplots were constructed based on the r values greater than .40 (see Appendix F). Among the 16 pairs, three pairs didn't meet the assumption; the bust prominence to waist and the abdomen prominence (r = .411), the abdominal protrusion level and the abdominal prominence (r = .581), and the abdominal prominence and the buttocks protrusion level (r = .439). Although the area covered by the plots could have been converted to a straight line, the plots were scattered widely around the line, and the regression line was not suitable to estimate the relationship. For example, when the values of abdominal prominence were close to 100, the majority values of the buttocks protrusion level were widely scattered approximately between 50 and 70. This range also held true for the abdominal prominence level of 110.

Along with the linearity, regression analysis requires assumptions of normality of residuals and homoscedasticity of variance. Therefore, both assumptions were tested as to the rest 13 pairs. For the normality of the residuals, a normal Predicted Probability (P-P) plots were examined (Appendix G). The plots of the all 13 pairs followed the diagonal normality line suggesting that the assumption was met. For the homoscedasticity of variance, the scatterplots of residuals were reviewed (Appendix G). The plots of the all 13 pairs were equally distributed above and below 0, and right and left of 0 which indicated that the assumption was met.

As regression analysis identifies predicted changes, an independent variable and a dependent variable need to be carefully determined. This study supposed that back curvature may have influenced postural variations in the torso. Therefore, the initial independent variable was assigned to the degree of back curvature, and the dependent variable was the indices that had a significant correlation with the independent variable. The following independent variable was assigned to either the previous dependent variable or the adjoining body part. The results of the regressions are presented in Table 30.

Table 30

Regression analysis of the indices

Independent variables	Dependent variables	B	SE B	β	t	R^2	F
Degree of back curvature	Degree of upper back curvature	1.322	.070	.829	18.940***	.688	358.727***
Degree of upper back curvature	Inclination of back curvature	1.114	.092	.687	12.063***	.472	145.523***
Degree of upper back curvature	Neck height	.620	.093	.463	6.668***	.214	44.462***
Inclination of back curvature	Neck height	.419	.056	.507	7.509***	.257	56.392***
Inclination of back curvature	Neck inclination	1.804	.270	.464	6.695***	.216	44.822***
Neck height	Neck inclination	2.012	.333	.427	6.037***	.183	36.440***
Neck inclination	Waist inclination	.229	.024	.599	9.550***	.359	91.207***
Bust point level	Under-bust level	.969	.055	.812	17.733***	.659	314.466***
Bust point level	Waist level	.167	.028	.422	5.939***	.178	35.269***
Under-bust level	Waist level	.186	.021	.563	8.690***	.317	75.517***
Bust prominence to waist	Bust prominence to abdomen	.687	.034	.842	19.935***	.709	397.423***
Waist inclination	Buttocks protrusion level	.282	.047	.429	6.056***	.184	36.679***
Waist inclination	Buttocks prominence	.841	.112	.506	7.497***	.256	56.207***

Note. *** $p < 0.001$

The F values showed that all the regressions were valid at the significance level of .001. The t values indicated that all the explanatory indices positively predicted the response indices. Three sequential regression models were found. (Figure 55)

In the first model, the degree of back curvature explained 68.8% of the variation in the degree of upper back curvature. There was a predicted increase of 1.32 points in the upper back curvature for a one-point increase in the back curvature. This suggested that as the back curved, changing the degree of upper back curvature was greater.

The degree of upper back curvature was informative in predicting the inclination of back curvature as well as the neck height, accounting for 47.2% and 21.4% of the variance respectively. The more curve in the upper back, the more forward inclined the back, the greater the vertical distance between the front neck point and the back neck point. However, the neck height was more effectively estimated by the inclination of back curvature (β = .507, $p < .001$) compared to the degree of upper back curvature (β = 463, $p < .001$), and 25.7% of the variance was explained by the inclination of back curvature.

Besides the neck height, the inclination of back curvature also predicted the change in the neck inclination (R^2 = .216, F = 44.822, $p < .001$). As both indices shared the back neck point, which directly affected the inclination in the back and the neck, the neck inclination was more associated with the inclination of back curvature (β = 464, $p < .001$) than the neck height (β = .427, $p < .001$).

In addition, the more the neck inclined forward, the more the waist was anteriorly positioned (β = .599, $p < .001$) and that in turn affected the values of both indices representing the buttocks. As the waist was inclined forward in a gradual manner, the buttocks protrusion level moved up and the prominence increased at a consistent rate respectively.

In the second model, the associations between the level of the bust point, under-bust, and the waist are illustrated. The under-bust level was predicted to change .969 points for one-point increase in the bust point level. That suggested that the vertical distance between the bust point and the under-bust appeared almost consistent. However, when a subject's bust point level was further above or below the average, the distance may have either increased or decreased. The bust point level explained 65.9% of the variance in the under-bust level. The average waist level was expected to increase as both the bust point level and the under-bust level increased. Between the two explanatory indices, the under-bust level was more informative in estimating the waist level (β = .563, $p < .001$) than the bust point level (β = .422, $p < .001$).

The third model predicted a consistent change between the bust prominence to the waist and the bust prominence to the abdomen.

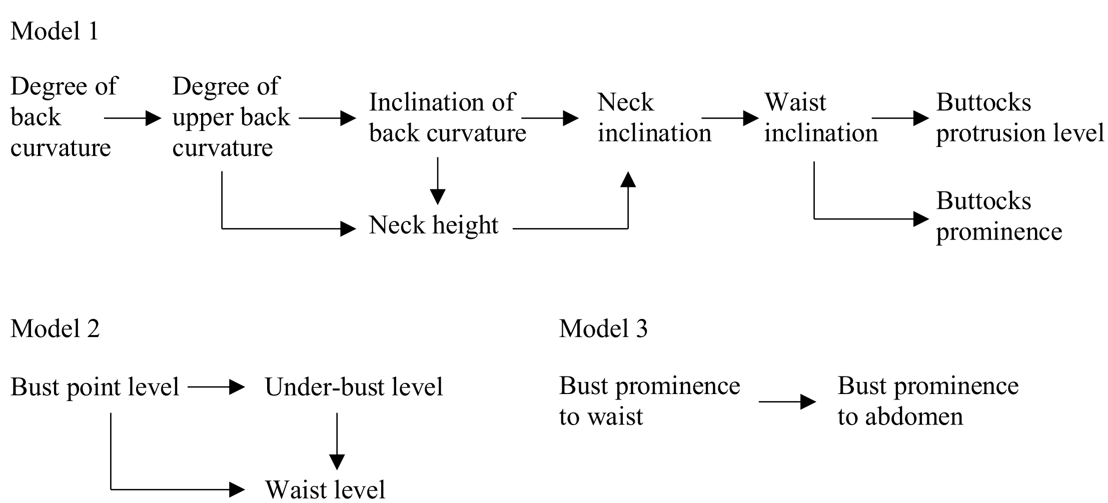


Figure 55. Sequential Regression Models

The inter-index correlations and regressions verified that each body part was tightly connected. Changes in one particular body part are linked variations in the other body parts. The variations occurred simultaneously across the body. The back curvature influenced the posture in the neck, the waist, and the buttocks in various dimensions. Therefore, clothing to accommodate the back curvature will require overall consideration of body measurements, shaping, and balance in the torso. Although the statistical significance may not directly linked with ideal solutions for desired garment fit, objective understanding of the posture will be necessary, and the results clearly support the interrelationship of each body part.

Back Curvature Classification and Body Variations in the Torso

While the interrelationship between indices illustrates a general tendency of body variations, this section specifies how variations of each body part significantly differ depending on the classified back curvature. To identify patterns of variations, the subjects' back curvature was classified using both standard deviation and cluster analysis, then the results of cluster analysis were further investigated for comparisons of body variations.

Classification by Standard Deviation

As the first classification for back curvature, three indices representing respective criteria were divided into three groups based on 0.5 standard deviation above and below the mean. For the criterion of degree of curvature, the degree of overall back curvature was applied. Descriptive statistics of the nine index groups are presented in Table 31.

Theoretically, Group 2 was expected to contain 38.2% of the subjects, however, slightly more subjects were assigned to this group with a smaller standard deviation signifying that the distribution of all three indices tended to be centrally converged. The range and standard deviation of Group 1 and Group 3 demonstrated that the further away from the mean, the greater the variations in the back curvature.

Table 31

Descriptions of index classification

	Back protrusion level			Degree of back curvature			Inclination of curvature		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
F	43	74	48	57	69	39	50	68	47
%	26.1	44.8	29.1	34.5	41.8	23.6	30.3	41.2	28.5
M	49.50	55.96	61.4	102.79	105.22	108.63	0.36	7.17	14.99
SD	3.70	1.53	2.6	0.78	0.63	2.07	3.00	1.78	4.55
Min.	37.61	53.36	58.40	101.81	104.00	106.49	-6.78	4.30	10.54
Max.	53.21	58.31	69.16	103.93	106.32	113.97	4.07	10.40	28.96
Range	15.60	4.95	10.76	2.12	2.32	7.48	10.85	6.10	18.42

Note. F = frequency, % = percentage

The nine index groups were combined together to categorize the back curvature and a total of 27 subgroups were generated (Table 32). Expectedly, the combination of Group 2 (2-2-2) had a largest number of subjects (10.9%), however, there was no distinct tendency in terms of frequency. The subjects were distributed throughout the subgroups ranging from one subject to 18 subjects.

Table 32

Classification of back curvature by standard deviation

		Degree of back curvature	Inclination of curvature								
			Group 1			Group 2			Group 3		
				F	%		F	%		F	%
Back protrusion level	Group 1	Group 1	1 – 1 – 1	9	5.5	1 – 1 – 2	4	2.4	1 – 1 – 3	1	0.6
		Group 2	1 – 2 – 1	4	2.4	1 – 2 – 2	8	4.9	1 – 2 – 3	10	6.1
		Group 3	1 – 3 – 1	3	1.8	1 – 3 – 2	2	1.2	1 – 3 – 3	2	1.2
	Group 2	Group 1	2 – 1 – 1	8	4.9	2 – 1 – 2	13	7.9	2 – 1 – 3	2	1.2
		Group 2	2 – 2 – 1	3	1.8	2 – 2 – 2	18	10.9	2 – 2 – 3	7	4.2
		Group 3	2 – 3 – 1	3	1.8	2 – 3 – 2	10	6.1	2 – 3 – 3	10	6.1
	Group 3	Group 1	3 – 1 – 1	9	5.5	3 – 1 – 2	5	3.0	3 – 1 – 3	6	3.6
		Group 2	3 – 2 – 1	8	4.9	3 – 2 – 2	5	3.0	3 – 2 – 3	6	3.6
		Group 3	3 – 3 – 1	3	1.8	3 – 3 – 2	3	1.8	3 – 3 – 3	3	1.8

Note. F = frequency, % = percentage

The standard deviation method divided the subjects based on index values, and the range of index values did not overlap between the subgroups. Therefore, each subgroup represented independent and distinct features of back curvature that provided an ideal condition for comparisons of other body parts. However, as the number of subjects in each subgroup was too small to obtain statistically significant results, K-means clustering to create a fewer subgroups was performed.

Classification by Clustering

Cluster analysis comprehensively evaluated the indices and grouped the subjects based on similarities, whereas the classified groups did not correspond to a clear distinction of index values as did the standard deviation method. However, clustering effectively showed the representative structure of the data, thus the use of cluster analysis was considered appropriate for further analysis. All four indices of back curvature were included for classification.

K-means cluster analysis required entering the number of clusters. Two criteria to determine the number of clusters were whether each index was distinctively partitioned by the clusters and whether each cluster had a sufficient number of subjects for statistical analysis. After entering two to five clusters, the back curvature was classified in three groups. To identify statistical significant mean differences between the clusters, one-way ANOVA per index was applied. Then, using post hoc comparisons, differences between the clusters were indicated by A, B, or C in order of mean (Table 33). The boxplots illustrate the graphical configuration of clusters per index (Appendix H).

Applying post hoc analysis required testing homogeneity of variances, because different types of post hoc tests had to be utilized depending on the result. The assumption of equal variances was examined by the Levene's test at a significance level of 0.5. Then, the Bonferroni test was applied when equal variances were assumed, and the Dunnett's T3 was performed when equal variances were not assumed. The results of the Levene's test are presented in Table 34 (Appendix J).

Table 33

Cluster means and standard deviation of back curvature

Back curvature	Classification			F
	Cluster 1 (N=24)	Cluster 2 (N=87)	Cluster 3 (N=54)	
Back protrusion level	57.01 (4.83) B	53.65 (4.44) A	58.92 (4.39) B	23.99***
Degree of curvature	107.47 (3.02) C	105.41 (2.21) B	103.82 (1.72) A	23.80***
Degree of upper back curvature	112.68 (4.33) C	107.00 (2.60) B	103.94 (2.35) A	89.92***
Inclination of curvature	17.50 (5.20) C	8.27 (3.20) B	1.32 (3.84) A	159.85***

Note. A, B, C = significant mean differences by Bonferroni or Dunnett T3 depending on equal variances test (Levene's test)
*** $p < 0.001$

Cluster 1 explained 14.5% of the subjects. The back protrusion point was located on a relatively higher level. This group showed the greatest degree of curvature and the most forward inclined back among the three clusters. The upper back curvature was more noticeable than the back as a whole. Overall, cluster 1 displayed the most prominent back curvature with large variations and corresponded to the group 2-3-3 among the subgroups in Table 32.

Cluster 2 represented more than half of the subjects (52.7%). The back protrusion level was positioned relatively lower than the other clusters. The degree of curvature was close to the sample mean, and the upper back was slightly curvier than the back as a whole. The inclination of back curvature was also close to the sample mean. Overall, cluster 2 was the middle group and showed a moderate back curvature. The group 2-2-2 in Table 32 matched this cluster.

Cluster 3 accounted for 32.7% of the subjects. The back protrusion level was relatively high as with the cluster 1. This cluster showed the least degree of curvature with an even curve across the back, and the back was the most balanced. Overall, this group had a flat and upright back posture with smaller variations. The group 3-1-1- in Table 32 corresponded with this cluster.

Although the three clusters did not feature the respective subgroups in Table 32, they enveloped the complete range of index values, and each cluster presented distinctive characteristics. See Appendix I for the representative posture as to the three clusters.

Torso Variations by Back Curvature Clusters

Interaction of the clusters with other torso regions were examined using one-way ANOVA. Once a statistically significant mean difference was found to exist, through the Levenes' test (see Appendix J), either Bonferroni or Dunnett's T3 was employed for post hoc comparisons. The results are specified in Table 35 and graphically illustrated in Appendix K.

Eleven out of 17 indices indicated that the mean for at least one cluster was different from the other clusters. However, the Bonferroni test suggested that the mean of the posterior arm point level was not different between the clusters, thus torso variations were explored for the remaining 10 indices.

As the back curvature directly affected the neck posture, all three clusters had significantly different mean values for both the neck height and the neck inclination. Cluster 1 showed the greatest distance between the front neck point and the back neck point, and the largest anterior neck tilt. Cluster 3 had the smallest neck height and a relatively balanced neck position.

Both indices for the shoulder also differed between the clusters. In terms of the acromial level, cluster 2 with the moderate back curvature had a greater shoulder slope than the other clusters. Although cluster 1 with the prominent and forward back curvature was expected to have the most sloped shoulder, their acromial level was not statistically different from cluster 3. This may have been due to the placement of the side neck point. The acromion level was calculated based on the side neck point, and the side neck point may have been located at a lower level with the anteriorly tilted round back. The acromial inclination increased according to the back curvature. Therefore, cluster 1 had less sloped and forward inclined shoulders; cluster 2 had sloped but slightly forward shoulders; whereas cluster 3 had less sloped and balanced shoulders.

In terms of the armhole, cluster 1 showed an anteriorly tilted armhole. There was no significant difference found for the arm point level.

The back curvature affected the bust point level and under-bust level. Mean differences existed only between cluster 1 and cluster 3. For cluster 3, the bust level was approximately in the mid-level between the front neck point and the waist level, whereas it was located lower for cluster 1. The distance between the bust point and the under-bust was almost the same for all three clusters.

In terms of the waist, all three clusters had a more anteriorly proportioned waist based on the reference line, however, the waist of cluster 1 was significantly less inclined to the front.

For cluster 1, the buttocks protrusion level was significantly lower and its prominence was less.

Table 35

Mean and standard deviation of indices by clusters of back curvature

Body parts	Indices	M	Classification			F
			Cluster 1 (N=24)	Cluster 2 (N=87)	Cluster 3 (N=54)	
Neck	Neck height	124.53 (5.31)	128.93 (6.35) C	125.18 (4.29) B	121.53 (4.62) A	21.984***
	Neck inclination	87.77 (25.00)	103.47 (28.53) C	90.24 (23.86) B	76.82 20.34) A	11.686***
Shoulder	Acromial level	92.16 (3.30)	94.16 (2.78) B	91.64 (3.17) A	93.51 (3.25) B	9.280***
	Acromial inclination	127.80 (105.53)	173.26 (189.17) B	133.23 (92.22) AB	98.85 (57.37) A	4.564*

Armhole	Anterior arm indentation level	72.57 (6.15)	71.33 (7.44) A	72.32 (6.57) A	73.07 (4.68) A	.815
	Posterior arm indentation level	72.49 (3.69)	73.05 (4.45) A	71.82 (3.26) A	73.33 (3.82) A	3.212*
	Armhole inclination	151.57 (46.49)	187.36 (65.49) B	146.13 (33.41) A	144.44 (48.33) A	9.174***
Bust	Bust point level	47.00 (6.25)	43.91 (6.23) A	46.57 (6.45) AB	49.05 (5.25) B	6.441**
	Under-bust level	29.20 (7.47)	26.27 (8.01) A	28.31 (7.55) AB	31.95 (6.27) B	6.551**
	Bust prominence to waist	97.01 (17.50)	95.78 (15.95) A	97.38 (16.97) A	96.97 (16.20) A	.078
	Bust prominence to abdomen	85.24 (14.28)	86.64 (13.77) A	84.91 (14.18) A	85.14 (14.90) A	.138
Waist	Waist level	57.14 (2.47)	57.63 (2.56) A	56.78 (2.43) A	57.49 (2.45) A	1.950
	Waist inclination	82.87 (9.56)	76.66 (6.44) A	82.48 (9.23) B	86.25 (9.86) B	9.370***
Abdomen	Abdominal protrusion level	24.55 (11.64)	21.27 (14.09) A	26.51 (10.64) A	22.86 (11.64) A	2.812
	Abdominal prominence	114.07 (11.16)	110.95 (11.24) A	115.04 (11.64) A	113.89 (10.24) A	1.279
Hip	Buttocks protrusion level	61.08 (6.28)	56.11 (8.68) A	61.51 (5.51) B	62.57 (5.14) B	10.292***
	Buttocks prominence	143.06 (15.87)	135.47 (15.34) A	142.82 (14.22) AB	146.81 (17.57) B	4.443*

Note. A, B, C = significant mean differences by Bonferroni or Dunnett T3 depending on an equal variances test (Levene's test), standard deviation in parentheses
*$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

In many cases, each body part had a different configuration depending on the back curvature with clear distinction for cluster 1 and cluster 3. Although the previous regressions verified the general interrelationships across the torso regions, the cluster analysis provided more detailed and specific implications in terms of the influence of back curvature on postural variations in the torso.

The boxplots (Appendix K) demonstrated that for the torso regions, each cluster generally had great variations and there were overlaps between the clusters. However, for the indices representing back curvature (Appendix H), especially the degree of upper back curvature and the inclination of curvature, showed clear partitions between the clusters in terms of the middle 50% values. Therefore, each classified back curvature and its corresponding dimensional variations in the torso should be individually applied to pattern development.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

This study started from a series of questions: What causes fit issues related to age? What are the universal and progressive physical changes that occur with age? What are the consequences of spinal curvature for posture in the torso? and What are the implications of back curvature and postural variations in the torso for desired garment fit? To explore these questions, three research objectives were set up and 165 female body scans aged 55 and older were investigated for eight torso regions. The three research objectives were (1) develop a measuring method for back curvature and posture in the torso and its validation, (2) identify interrelationships between back curvature and posture in the torso, and (3) interpret torso variations based on back curvature classification.

Conclusions

A total of 21 indices representing eight torso regions were developed using 34 linear measurements. Two criteria for index development were variations to the sagittal plane and those to the transverse plane. Each criterion was verified for independency within a body part. Correlation and regression analysis between the indices showed interactions and predicted changes among the indices and confirmed sequential influence of back curvature on posture in the torso. In general, degree of upper back curvature and inclination of curvature were more informative than back protrusion level and degree of overall back curvature in predicting variations in the torso. Depending on the back curvature classification, the torso exhibited diverse dimensional configurations. The classified groups correlated strongly to changes in the neck, acromial level, bust point and under-bust level, buttocks protrusion level, and overall inclination of the torso. Neck height, acromial level, and anterior inclinations in the neck, acromion, and armhole increased according to the back curvature, whereas the levels of the bust point, under-bust, and buttocks protrusion, anterior inclination of the waist, and buttocks prominence decreased. Given that the vertical reference line was established based on an ideal standing posture, there was significant distinction between the group with a prominent and forward inclined back and the group with a relatively flat and upright back. The former showed greater deviation from the ideal posture and had more variations in terms of index values. Although some of the indices remained unaffected by the back curvature classification, respective index values will provide meaningful information for garment fit.

The results of the study justified and articulated all three research objectives. However, there is more to explore in the future. First, for generalizing the results as to posture of older women, the age distribution of the data was somewhat younger in which the average age was 60.01 and the majority (88.5%) were Caucasian. While posture may change in a continuous fashion with increasing age regardless of ethnicity, the findings from the data may not represent older women's universal tendency. Data including diverse demographics are required. Second, although each statistical analysis verified its required assumptions for an accurate outcome, the data itself did not ideally meet the normality assumption and contained many outliers. To suggest more reliable information about the population, a larger sample is required. Third, this study analyzed linear relationships between the indices, however, some relationships may have been better elucidated by non-linear patterns. For example, abdominal protrusion level and abdominal prominence showed a high correlation (r =.581, $p \leq .01$), whereas on the scatterplot the regression line did not steadily increase or decrease. Linear regressions may have missed some of the body relationships. The body might change progressively with increasing age, but not at a constant rate, and thus some indices may have been correlated with other indices in an exponential curve. Therefore, transforming the data using log functions or other statistical approaches will need to be explored. Again, a larger sample may have been required to identify more precise patterns. Fourth, variations in the armhole need to be explored in more depth. For the purpose of identifying the shape of the armhole, especially the location of the most indented points, the arm was cut from the scans. While the cut line was based on the landmarks of the acromion and the break-point between the arm and the torso, the latter reference point was not always clear on scans. Therefore, the accuracy of the data needs to be verified with test garments and fit evaluations. In addition, the alignment of the front and back arm indentation points from the frontal plane need to be examined in relation to the back curvature. Lastly, this study used secondary data. It provided huge efficiency in the data collection process, however, landmarks on the scans could not be confirmed by palpation. Some landmarks appeared slightly set aside from the intended placement, however body fat and muscles may have directed the placement of the original landmarks. As an "eye test" was not reliable to prove the correct body location, the original landmarks on the scans were kept throughout the data collection.

People use garments to improve their appearance, project their self-image, and create positive impressions to others (Kang, Sklar, & Johnson, 2011). Therefore, garments are related to the wearer's body image and perceptions of aging. Birtwistle and Tsim (2005) defined the term 'cognitively young' for those who feel younger than their chronological age and argued that the chronological-cognitive age gap affected the clothing selection among mature women. People aged 51-86 perceived their age 10.3 years younger than their actual age (Szmigin & Carrigan, 2000), and women aged 66-101 felt 19.24 years younger (Nam et al., 2007). Therefore, providing desired garment fit may significantly enhance the wearer's self-image.

Apart from these psychological aspects, people experience physical changes with age that greatly affect garment fit. Variations in fabric choices and styles may provide tentative solutions, however they do not address the fundamental challenges. Changes in posture which in turn cause changes in body dimensions occur progressively, interactively, and simultaneously across the body. The degree of postural changes occurs gradually and garments require adjustment and compromise. Therefore, understanding the typical postures of older women and providing proper garment fit are important.

Garments are suspended from the shoulder and the waist, contour the chest and the upper back in the upper body and the abdomen and the hip in the lower body, and drape down to the bottom. How fealty a garment drapes on the body begins with how well the patterns of the garment address the wearer's posture which in turn determines the garment fit. A body form differs across a single size (Carufel, 2017), and posture encompasses the forms in different body regions. Thus, posture is an overarching characteristic to represent the body, and pattern development should take the wearer's posture into account. Pattern companies mass-market to consumers based on body build and posture, and their basic patterns show slightly different shapes to accommodate their consumers' physical characteristics (Liechty, Pottberg, & Rasband, 1992). Best practices in patternmaking should start with an assumption of the wearer's posture for desired garment fit, thus the results of this study will provide significant implications for garment design for older women.

Future Recommendations

To accurately verify the influence of age-related physical characteristics on garment fit and to provide more practical suggestions, theoretical and conceptual understanding from this study will need to be empirically corroborated through pattern development and wear tests. As three-dimensional body scans were utilized in this study, pattern digitizing using a Computer-Aided Design (CAD) method and fit assessment using a virtual fitting method are appropriate for the next step.

Understanding typical posture is essential, but fit is a moving target. Garments are worn on a dynamic body. Knowledge of how a garment moves and feels on the body is critical for the wearer's physiological comfort and satisfaction (DeLong et al., 1993). Therefore, it is important to explore how each body region interacts in movement and affects the fit in a garment. Typical posture may cause typical movements. For evaluation of fit during movement, a mixed-method approach may be suitable for more sophisticated information. Although fit can be visually inspected and needs to be quantified for patternmaking, it requires physical, physiological, and psychological considerations. Individual interviews and observation will provide diverse and in-depth perspectives on the body/garment relationship.

This study developed 21 indices for a lateral body based on theoretical criteria, however, the number of indices may increase when including frontal balance or decrease when selectively applied to a certain type of garment. Although all the 21 indices can be utilized for pattern development, for practical applications, only essential indices characterizing the wearer's posture should be identified depending on garment types and effectively integrated in garment design.

Current ASTM (2010) standards subdivide figure types of women aged 55 and older into seven different categories; junior, junior petite, miss petite, misses, misses tall, half-size, and womens. While the common terms for body shapes communicate the proportions and maturity in this age group, they were not developed for posture. An identical body shape accommodates different body forms (Carufel, 2017) and posture typified by combined body forms may feature certain figure types. Thus, relationships between posture and body shapes need to be investigated. In addition, posture was analyzed targeting older women in this study, however, postural variations may occur for various reasons at any age. Garment development starting from posture may create more desirable garment fit and this should be verified by test garments and fit assessment.

This study only contained female subjects. As women have more complex body structure that requires more sophisticated garment design, they are expected to have more fit issues than men. Men's bodies may display similar aspects with increasing age, however, body shapes and basic measurements for garment design are different, thus men's posture and garment fit also needs to be studied.

Typical posture may extend beyond a standing posture. Older people with physical impairments may have a sedentary lifestyle such as spending a large amount of time in wheelchairs and they undergo additional anatomical changes over time due to their seated posture. A sedentary body may hasten progressive spinal curvature and increases in torso girth (Sau-Fun et al., 2011). In addition, while garments in the market based on common patternmaking and sizing use measurements from a standing position and aim at ambulatory bodies, garments for people who are more sedentary should consider measurements from a seated position for better fit and mobility. Therefore, posture should be studied from a broad perspective and participatory approaches through interacting with the wearer are necessary.

This study focused on illustration of posture but did not address the potentials of using clothing to hide postural changes. While a fitted garment may accentuate the wearer's posture, many points of the body can be camouflaged in a garment that is suspended from the shoulder. Design attributes, such as collar masking a neck curve or upper back curvature or a side seam hiding a pelvic tilt or waist inclination, are helpful to camouflage posture. Thus, along with understanding of the wearer's posture, various design attributes that may compensate the changing posture need to be explored.

Emphasizing the integration of research and practice, Bye (2010) presented a framework for clothing and textile design scholarship in which three approaches of (1) problem-based design research, (2) research through practice, and (3) creative practice were illustrated. Problem-based design research commences with a clearly identified problem and includes critical literature review and a methodical approach to the analysis and evaluation. Research through practice begins with a problem or question raised by practice and involves a broader contextual review about the issue. Creative practice is related to desire to express individual inspiration through a design work. Each approach contributes to the body of knowledge in the apparel design discipline from various perspectives, thus original scholarship requires a combined process of these approaches (Bye, 2010). This study applied the problem-based design research approach, thus conceptual understanding of this study needs to be put into practice and evaluated by the wearer. In this process, best practices should be creatively explored, broadly implemented, and efficiently integrated for better design solutions. The fundamental goal of this study is to satisfy the wearer. Thus, research followed by practice is a key component of advancing our understanding of fit.

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Appendix A

Boxplots for Body Measurements

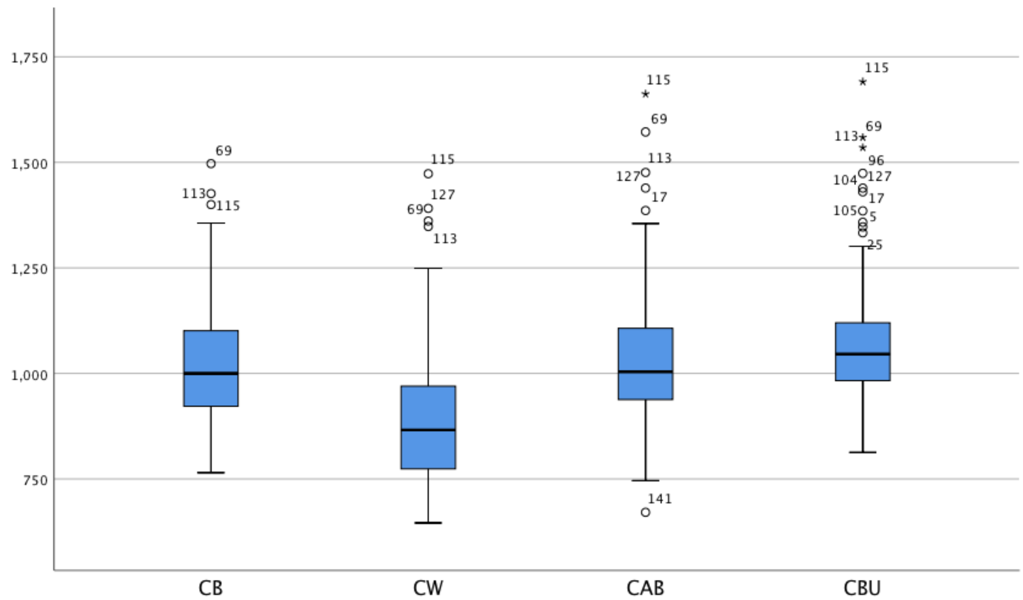


Figure 33. Boxplots for basic girth measurements of bust circumference (CB), waist circumference (CW), abdominal circumference (CAB), and buttocks circumference (CBU)

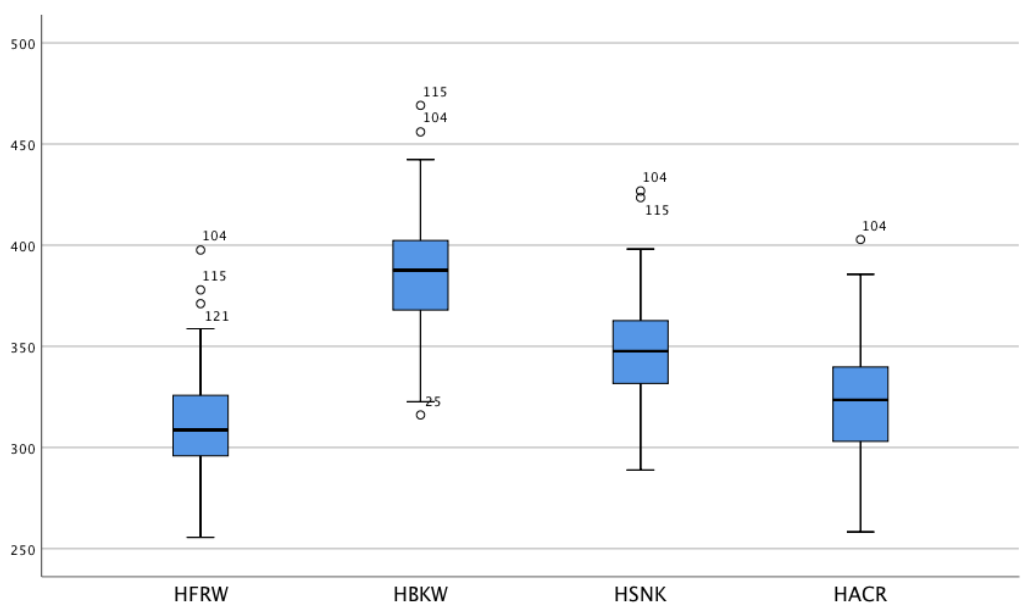


Figure 34. Boxplots for height measurements of front waist height (HFRW), back waist height (HBKW), side neck height (HSNK), and acromion height (HACR)

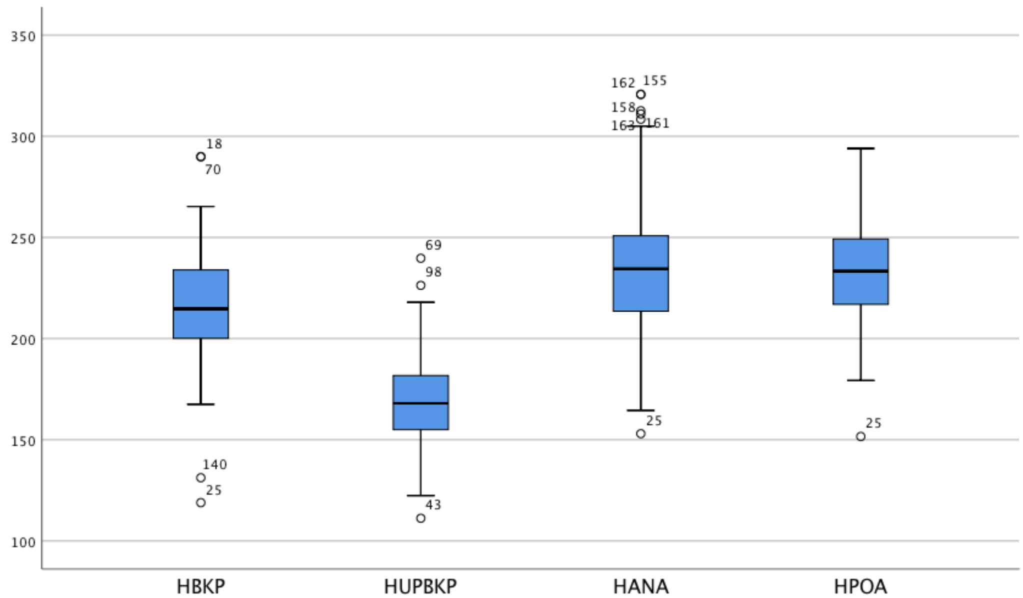


Figure 35. Boxplots for height measurements of back protrusion height (HBKP), upper back protrusion height (HUPBKP), anterior arm point height (HANA), and posterior arm point height (HPOA)

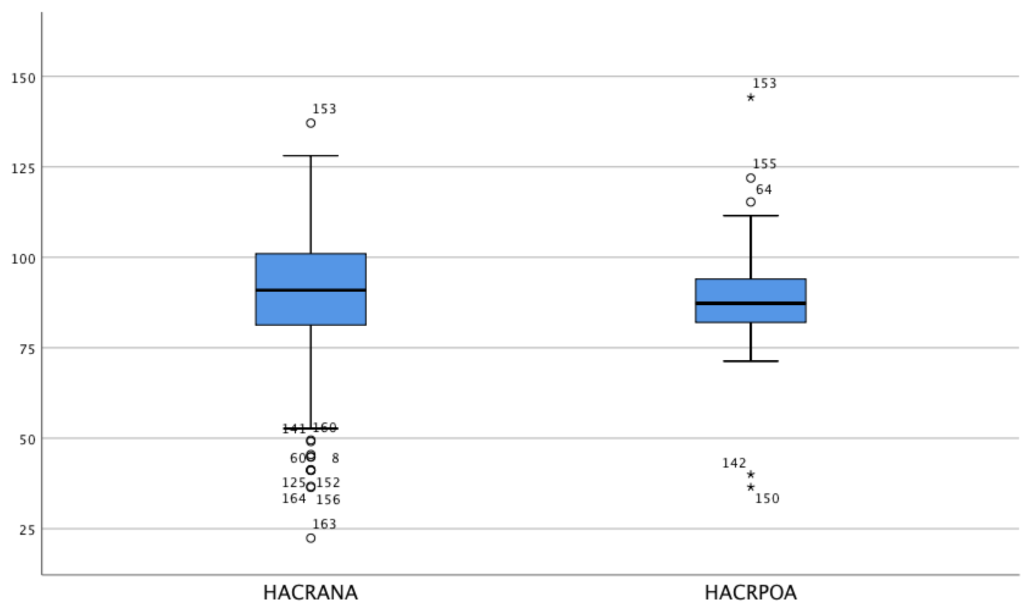


Figure 36. Boxplots for height measurements of anterior upper arm height (HACRANA) and posterior upper arm height (HACRPOA)

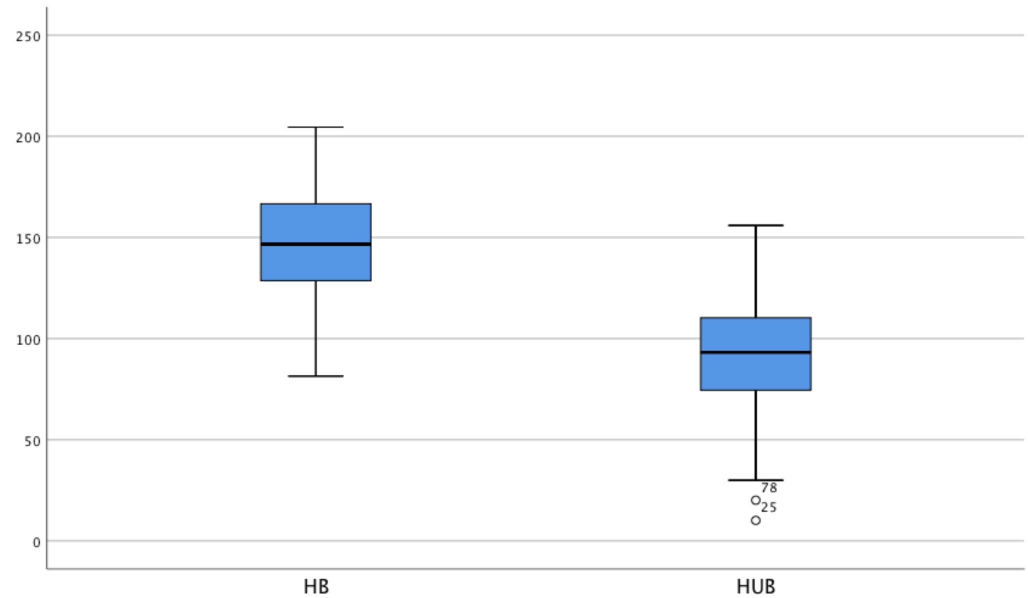


Figure 37. Boxplots for height measurements of anterior bust point height (HB) and under-bust height (HUB)

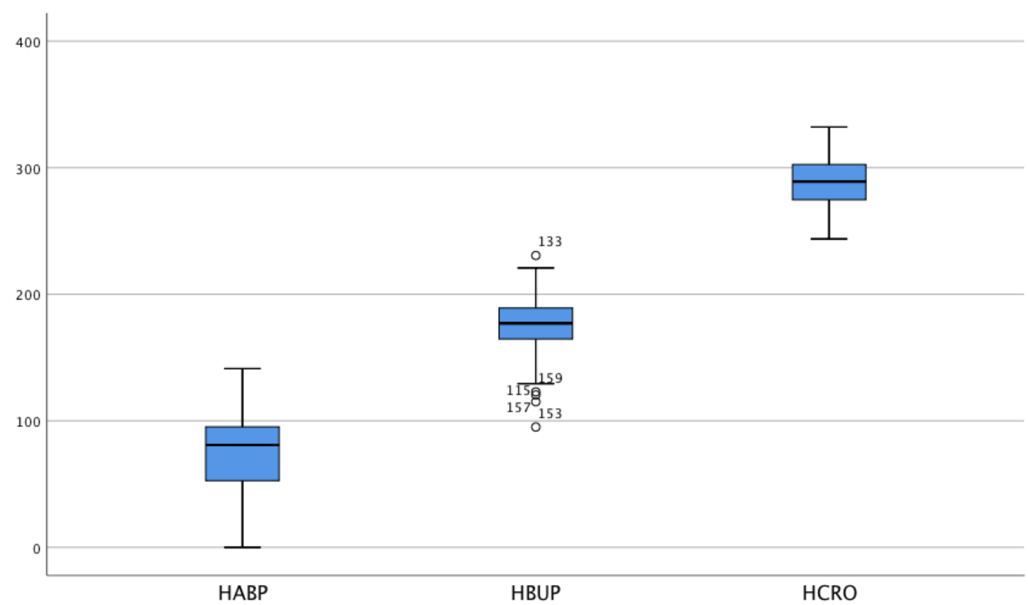


Figure 38. Boxplots for height measurements of abdominal protrusion height (HABP), buttocks protrusion height (HBUP), and crotch height (HCRO)

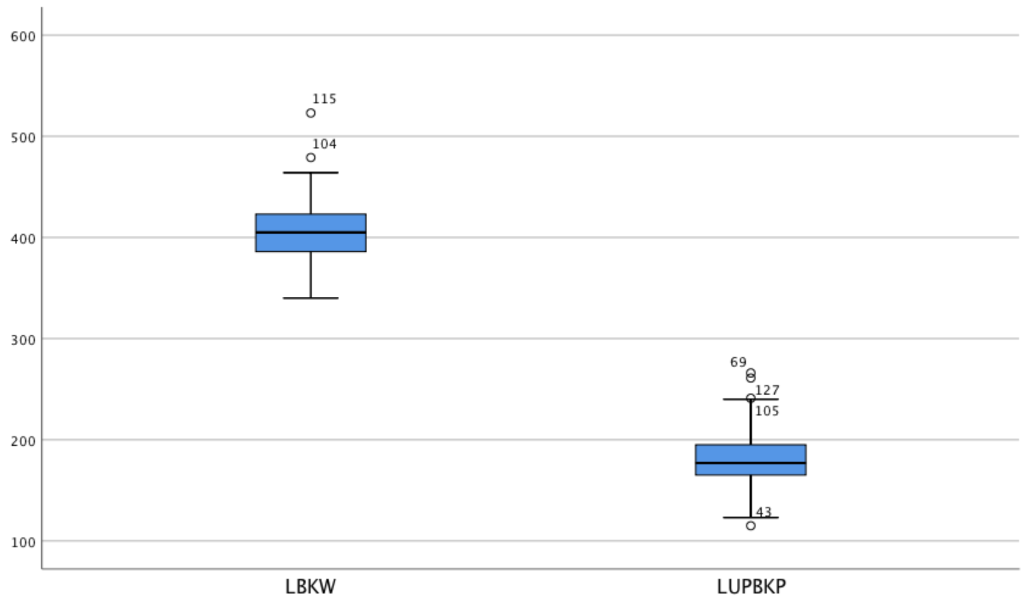


Figure 39. Boxplots for length measurements of back waist length (LBKW) and upper back protrusion length (LUPBKP)

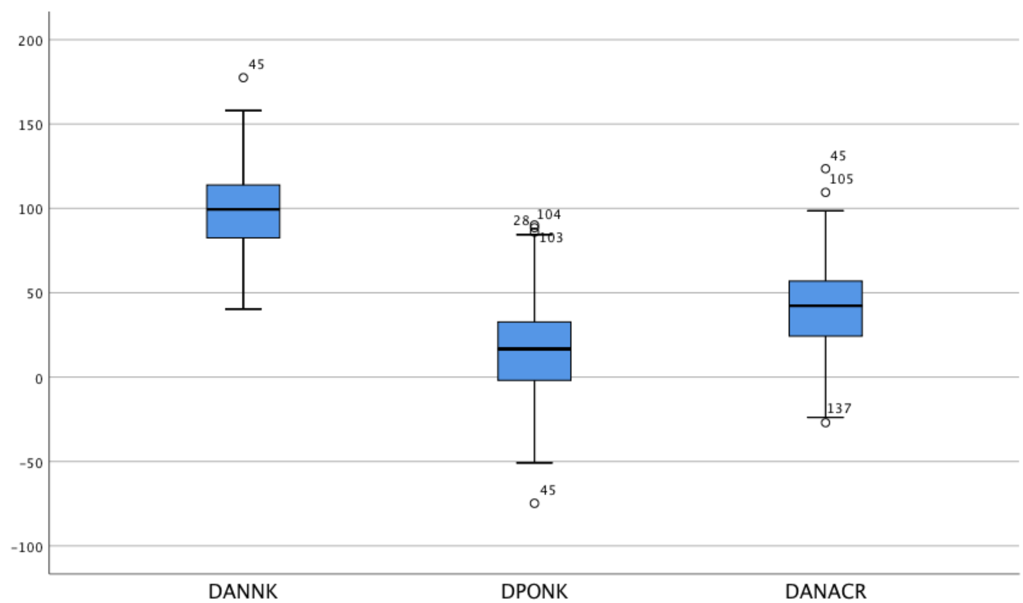


Figure 40. Boxplots for depth measurements of anterior neck depth (DANNK), posterior neck depth (DPONK), and anterior acromion depth (DANACR)

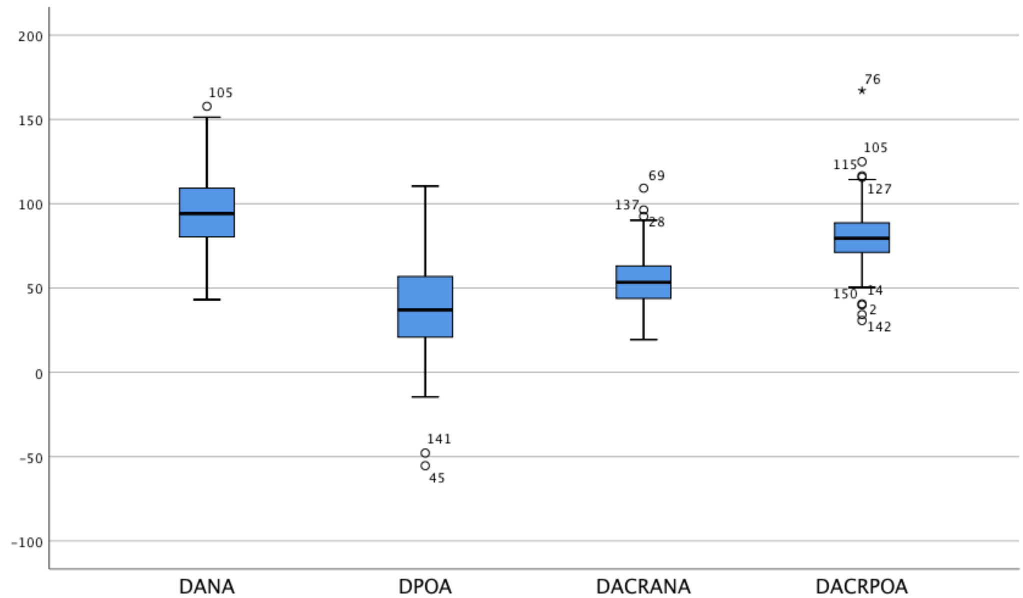


Figure 41. Boxplots for depth measurements of anterior arm point depth (DANA), posterior arm point depth (DPOA), anterior armhole depth (DACRANA), and posterior armhole depth (DACRPOA)

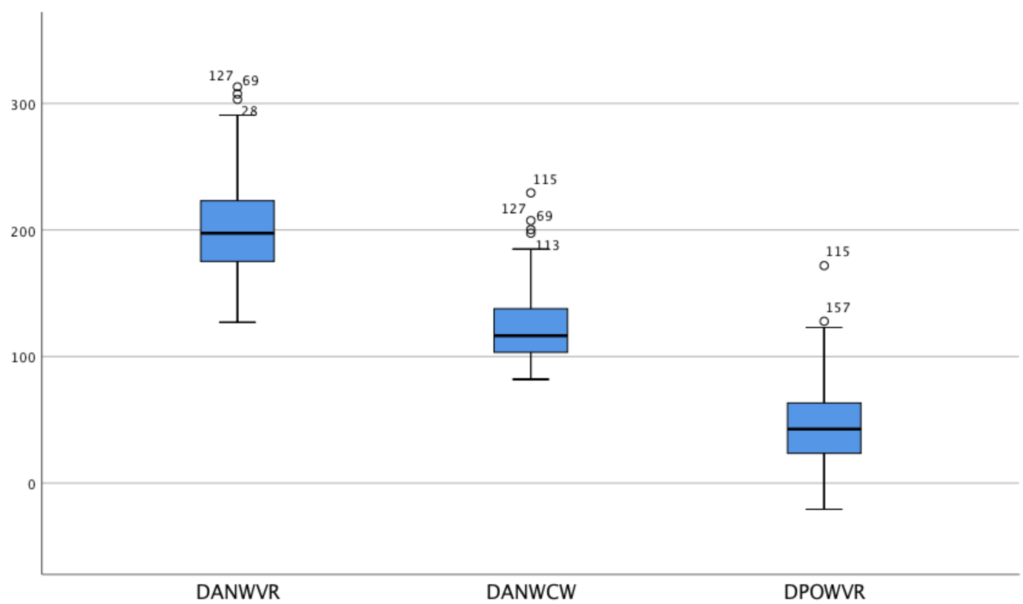


Figure 42. Boxplots for depth measurements of anterior waist depth (DANWVR), center waist depth (DANWCW), and posterior waist depth (DPOWVR)

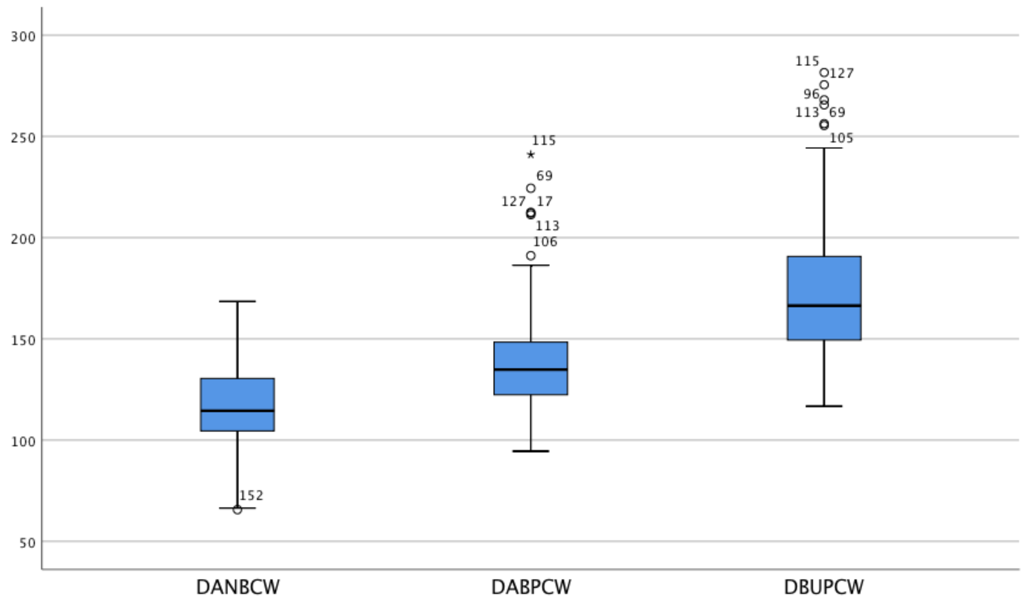


Figure 43. Boxplots for depth measurements of anterior bust-center waist depth (DANBCW), abdominal protrusion-center waist depth (DABPCW), and buttocks protrusion-center waist depth (DBUPCW)

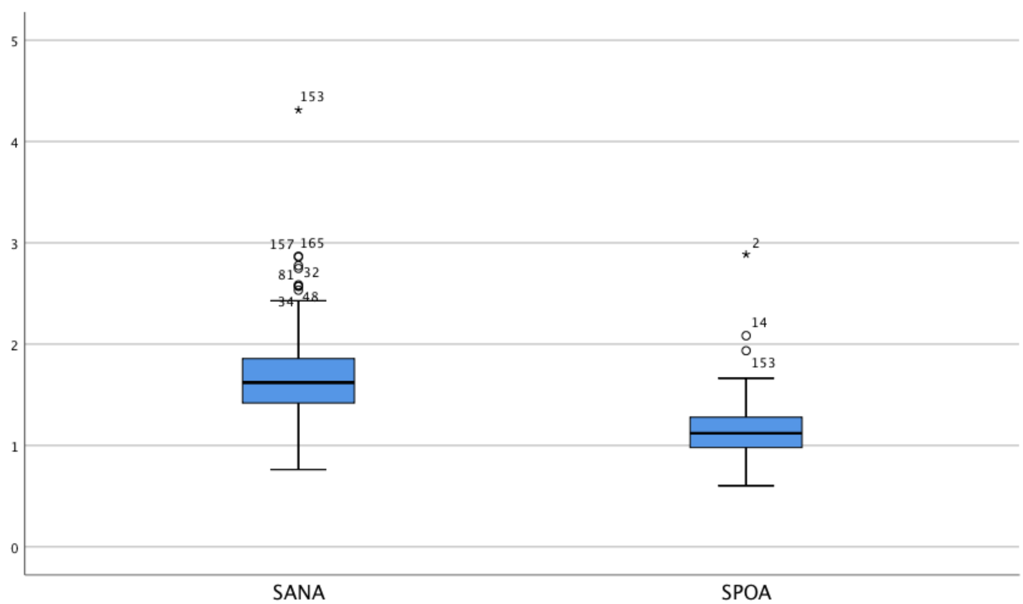


Figure 44. Boxplots for slope measurements of anterior upper arm slope (SANA) and posterior upper arm slope (SPOA)

Appendix B

Boxplots for Indices

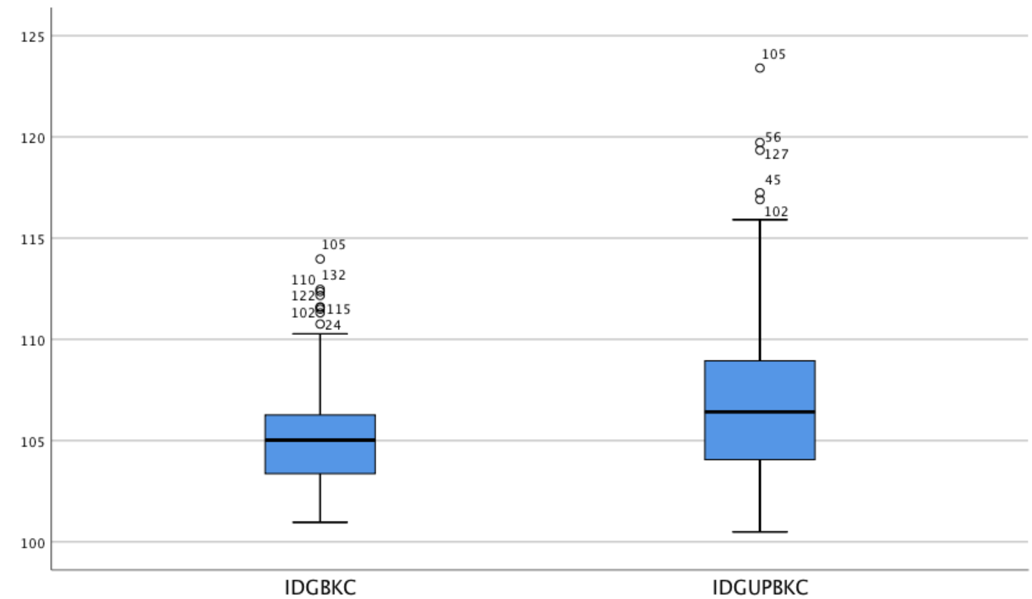


Figure 45. Boxplots for indices of degree of back curvature (IDGBKC) and degree of upper back curvature (IDGUPBKC)

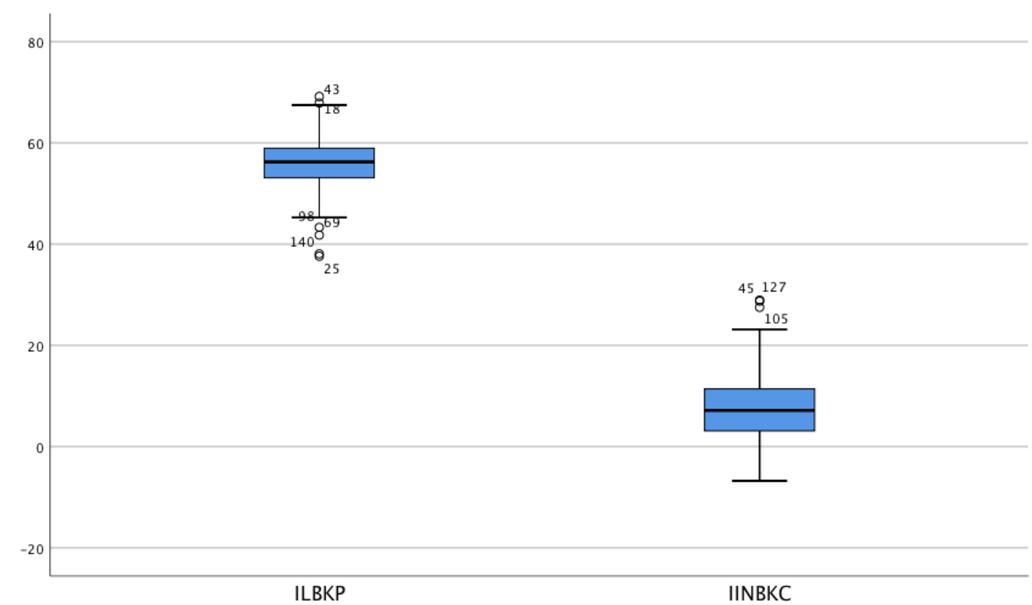


Figure 46. Boxplots for indices of back protrusion level (ILBKP) and inclination of back curvature (IINBKC)

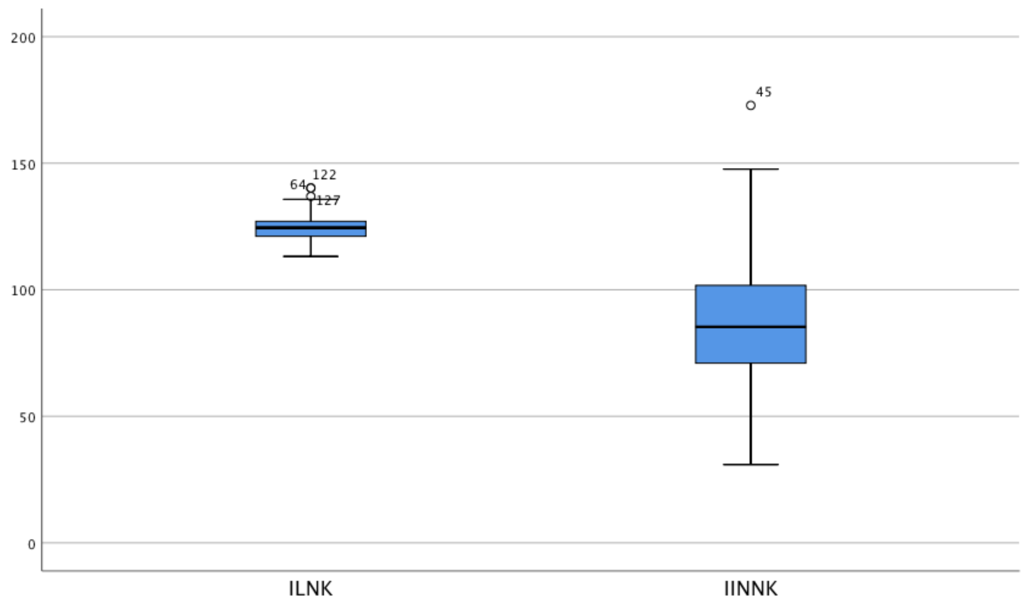


Figure 47. Boxplots for indices of neck height (ILNK) and neck inclination (IINNK)

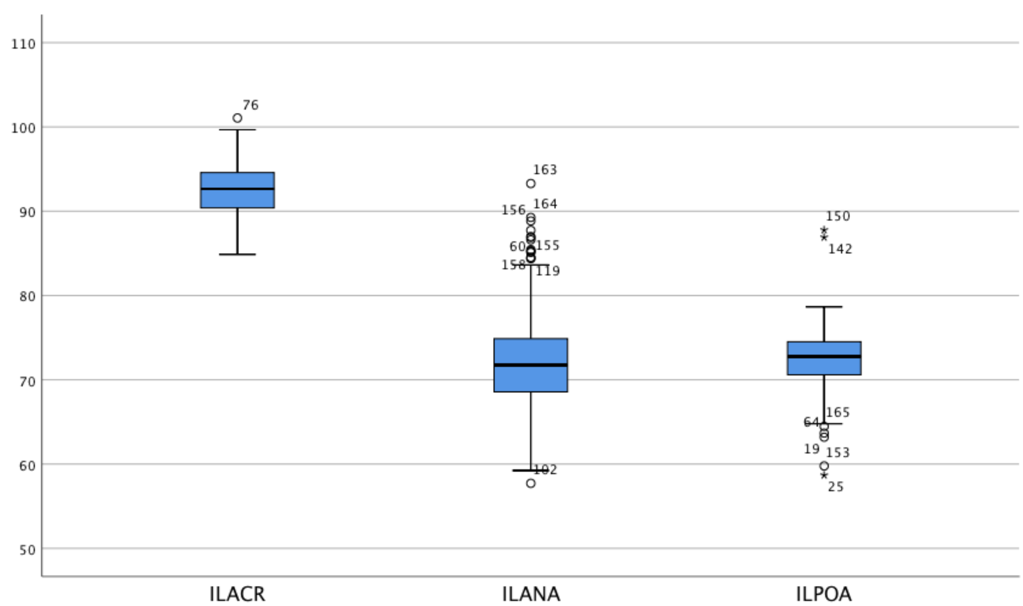


Figure 48. Boxplots for indices of acromial level (ILACR), anterior arm indentation level (ILANA), and posterior arm indentation level (ILPOA)

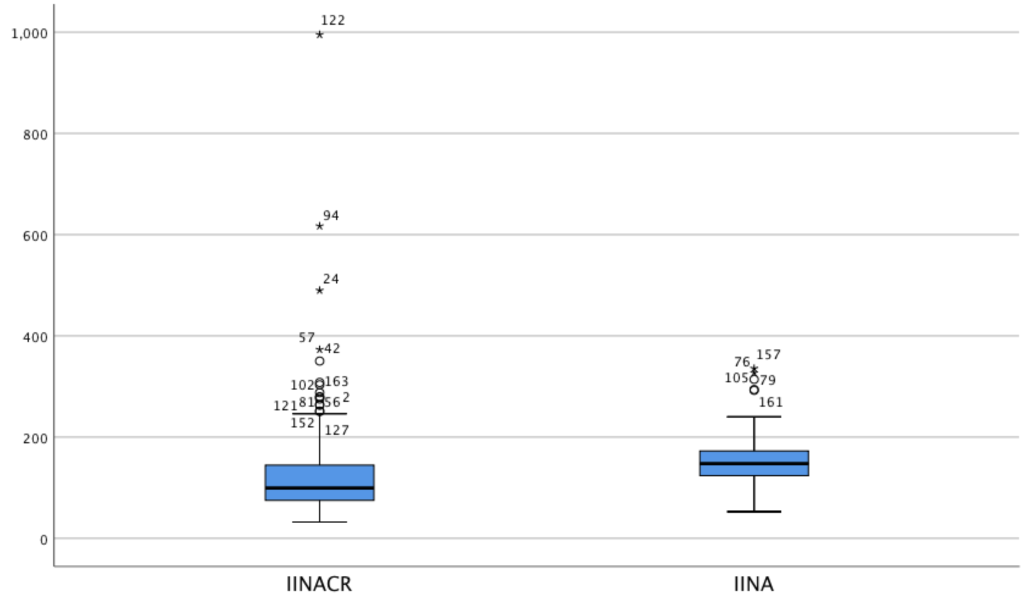


Figure 49. Boxplots for indices of acromial inclination (IINACR) and armhole inclination (IINA)

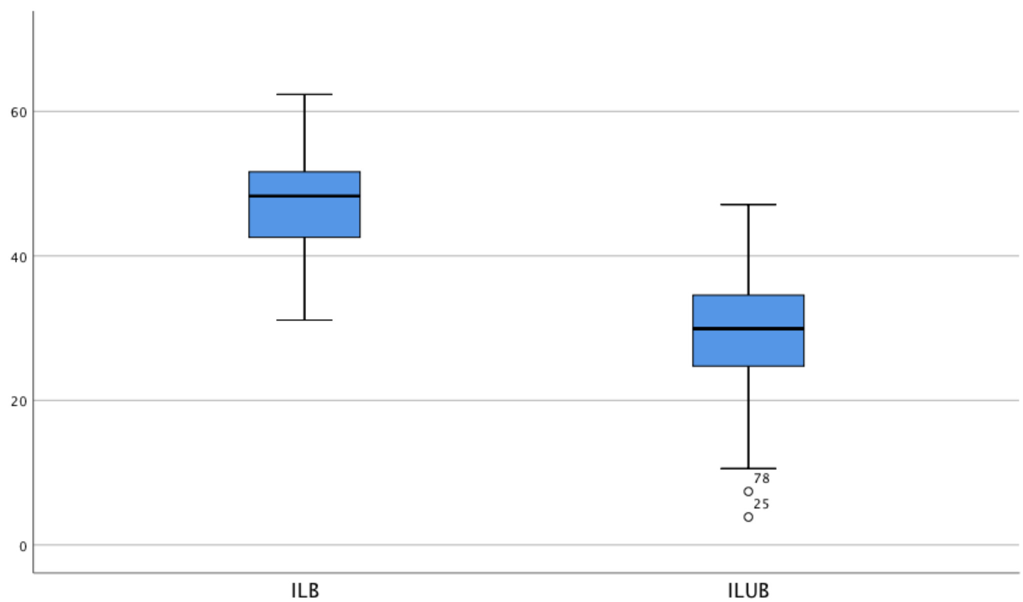


Figure 50. Boxplots for indices of bust pint level (ILB) and under-bust level (ILUB)

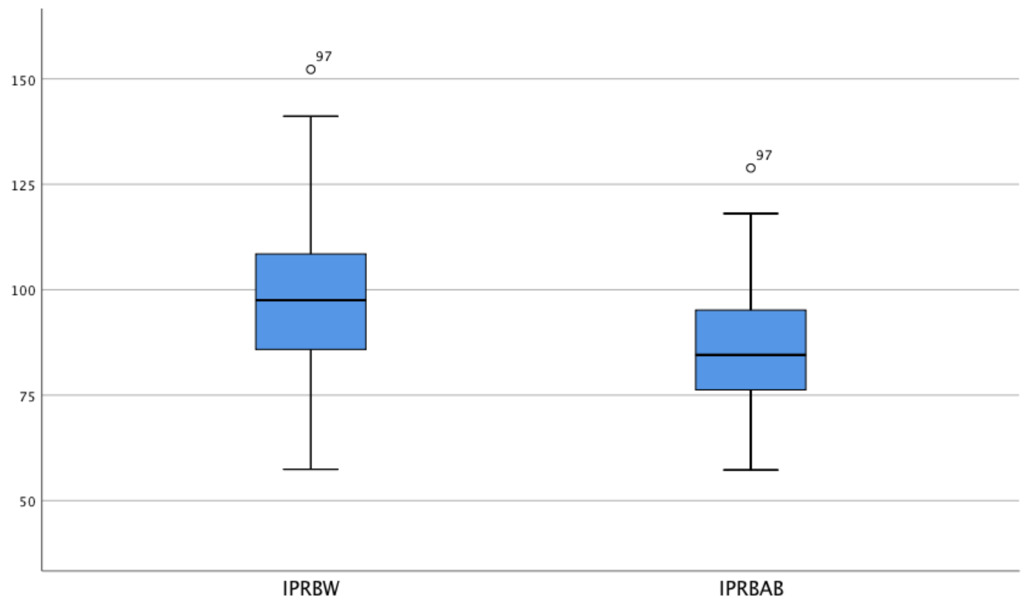


Figure 51. Boxplots for indices of bust prominence to waist (IPRBW) and bust prominence to abdomen (IPRBAB)

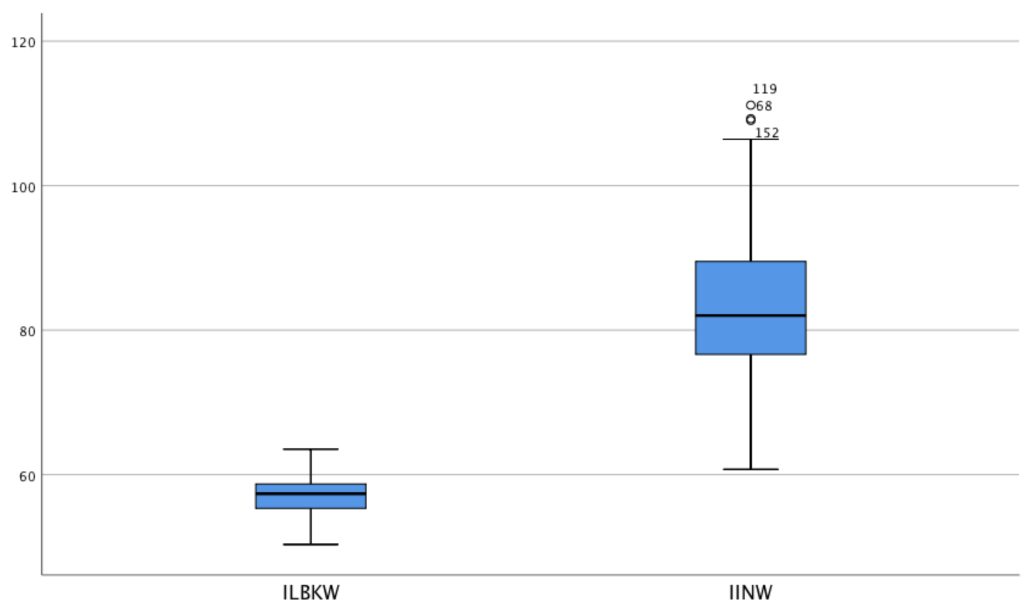


Figure 52. Boxplots for indices of waist level (ILBKW) and waist inclination (IINW)

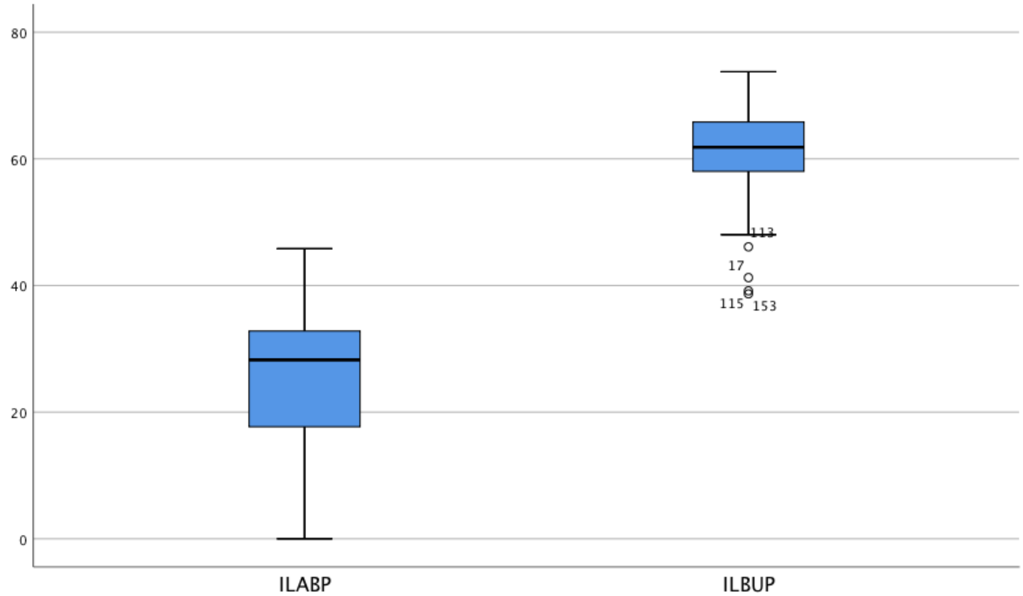


Figure 53. Boxplots for indices of abdominal protrusion level (ILABP) and buttocks protrusion level (ILBUP)

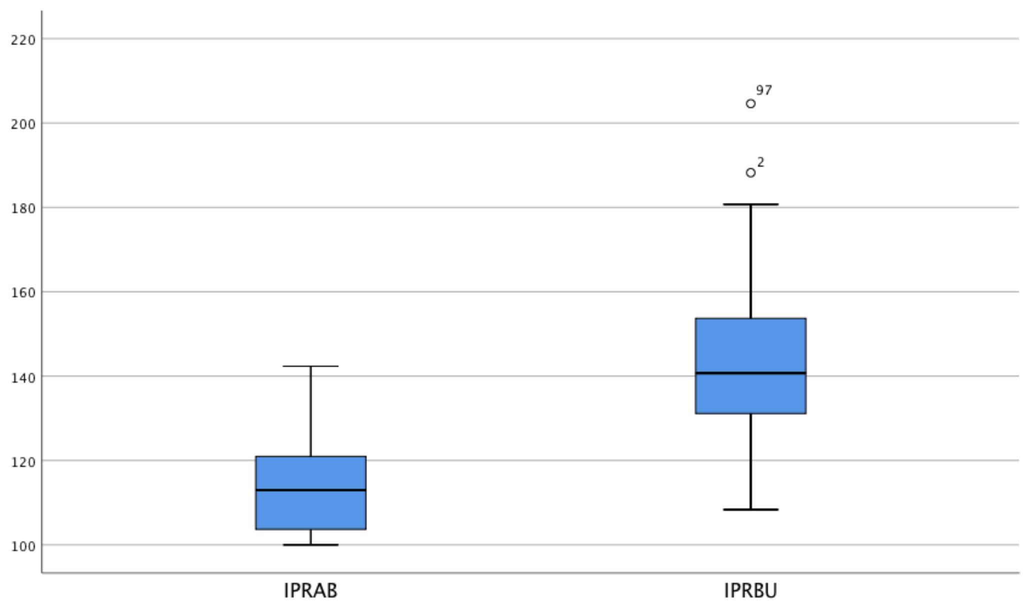
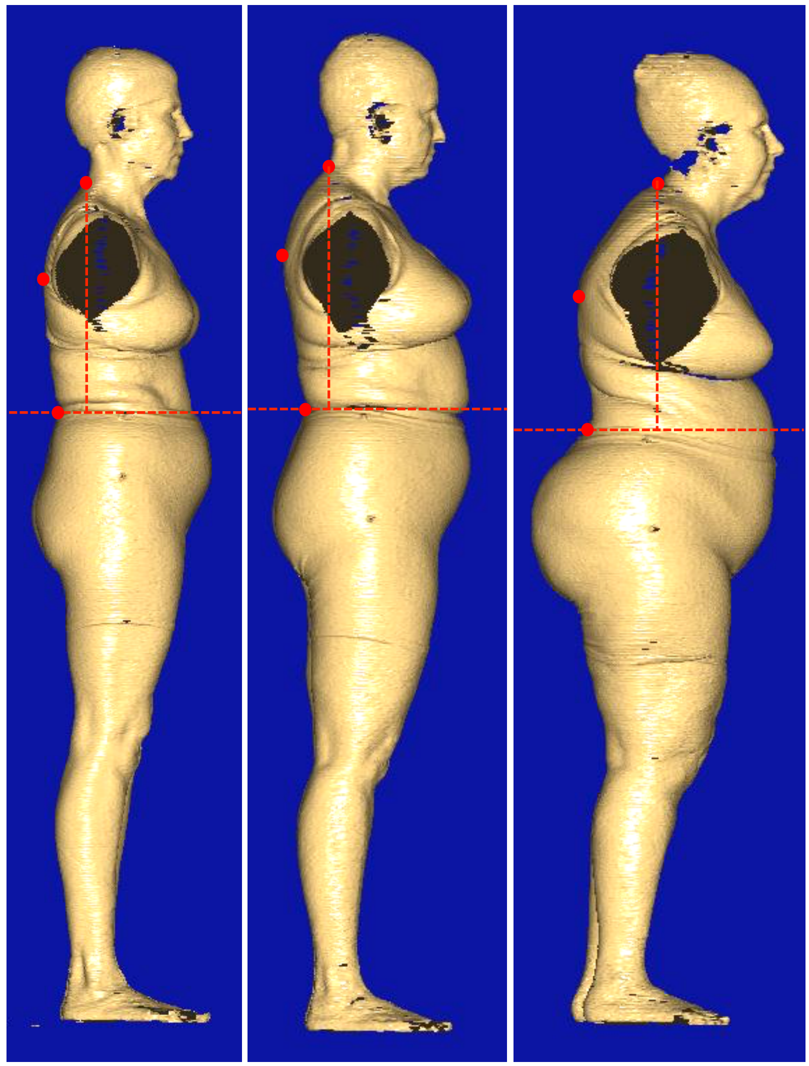


Figure 54. Boxplots for indices of abdominal prominence (IPRAB) and buttocks prominence (IPRBU)

Appendix C

Scans for Index Descriptions

Scans for Back Curvature

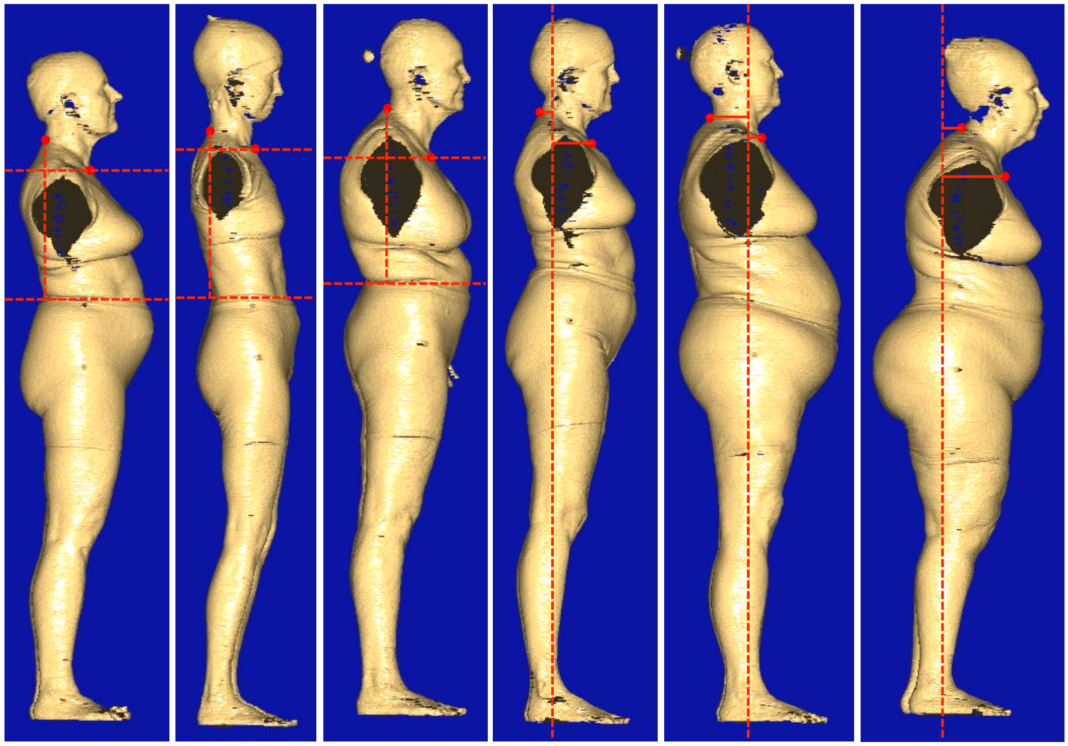


1 2 3

Indices	1	2	3
Back protrusion level (55.86)	**55.81**	58.57	**49.76**
Degree of back curvature (105.03)	**105.23**	**105.35**	**113.97**
Degree of upper back curvature (106.42)	107.23	108.13	**123.40**
Inclination of curvature (7.34)	12.23	**7.28**	**27.50**

Note. The numbers in parentheses refer to the average index values.

Scans for Neck

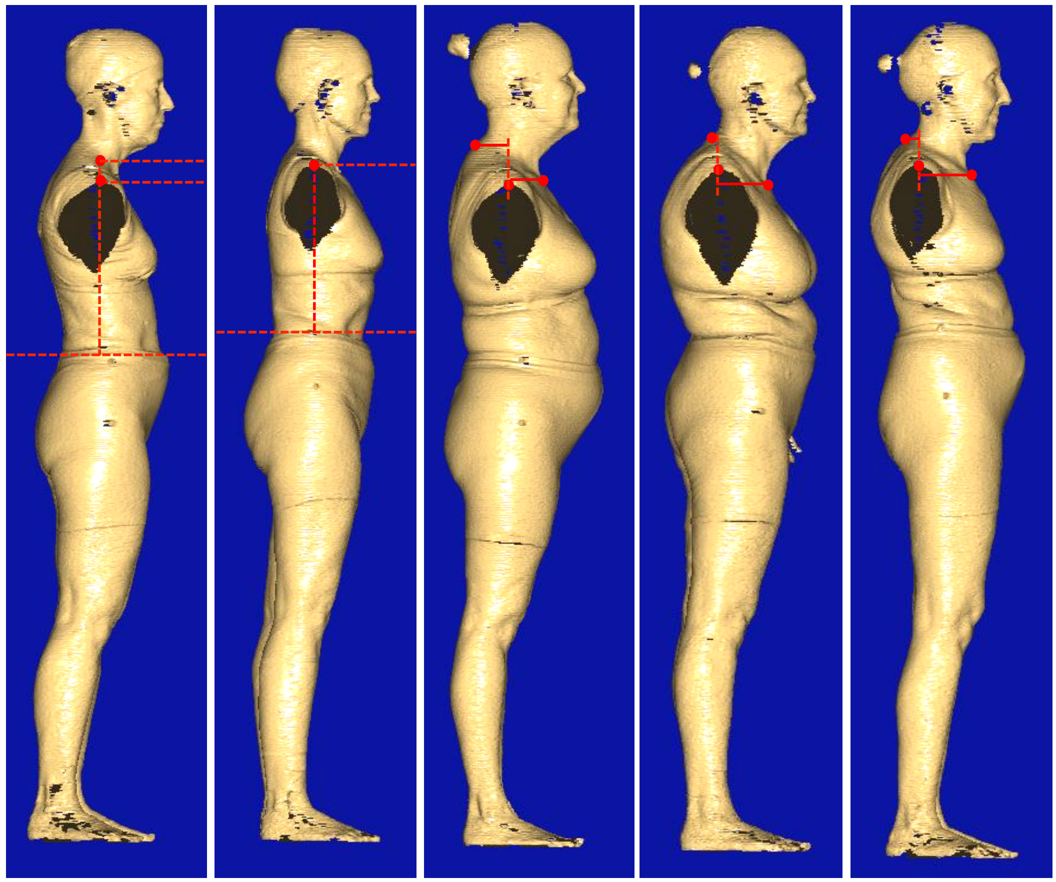


1 2 3 4 5 6

Indices	1	2	3	4	5	6
Neck height (124.53)	**124.50**	**113.16**	**140.17**	128.60	114.69	134.27
Neck inclination (87.77)	67.00	76.41	99.55	**87.91**	**31.50**	**147.65**

Note. The numbers in parentheses refer to the average index values.

Scans for Acromion

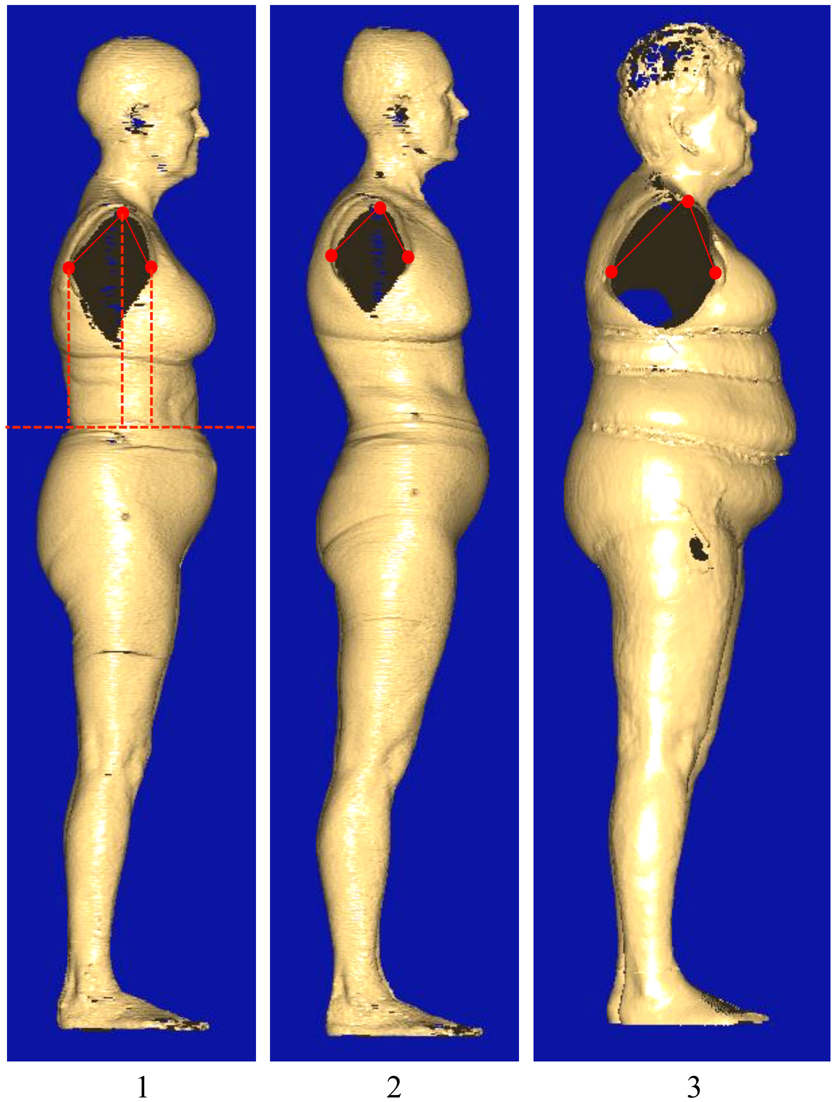


1 2 3 4 5

Indices	1	2	3	4	5
Acromial level (92.16)	**92.13**	**101.06**	87.87	97.14	92.68
Acromial inclination (99.51)	42.40	95.89	**99.51**	**995.10**	**616.99**

Note. The numbers in parentheses refer to the average index values.

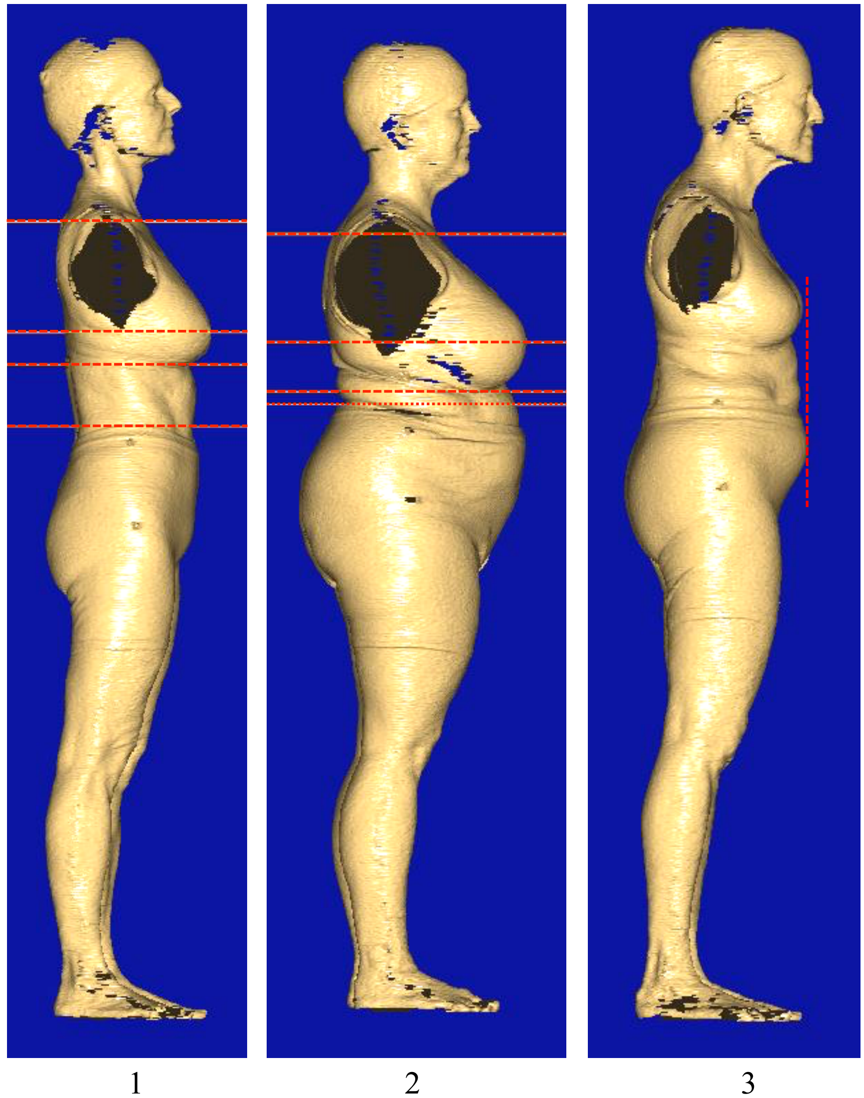
Scans for Armhole



Indices	1	2	3
Anterior arm indentation level (72.57)	**72.54**	74.29	68.55
Posterior arm indentation level (72.49)	**73.08**	75.63	76.46
Armhole inclination (147.55)	127.15	**147.55**	**335.59**

Note. The numbers in parentheses refer to the average index values.

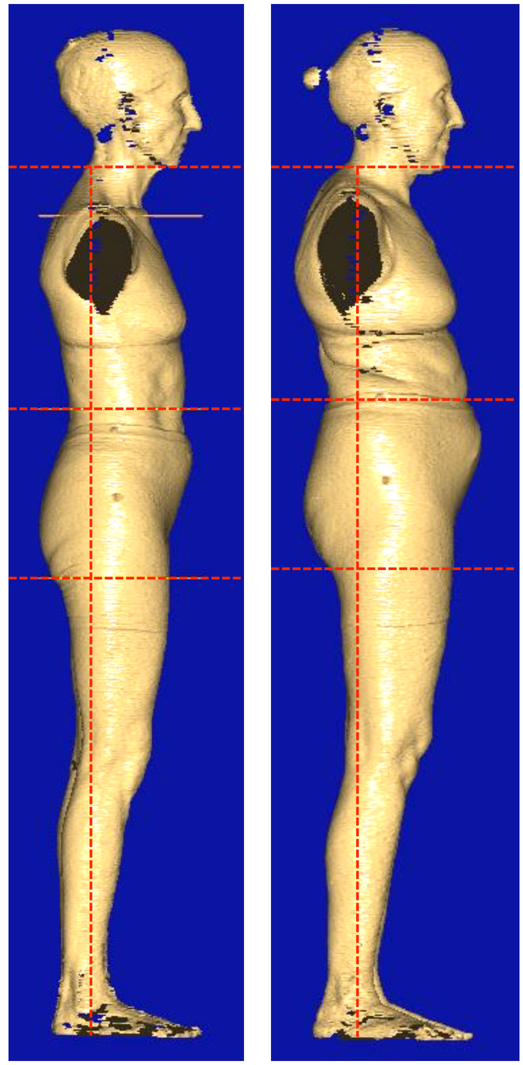
Scans for Bust



Indices	1	2	3
Bust point level (47.00)	**47.06**	36.43	48.28
Under-bust level(29.20)	**29.43**	**7.39**	24.61
Bust prominence to waist (97.01)	129.68	111.14	**96.97**
Bust prominence to abdomen (85.24)	116.69	99.41	**87.28**

Note. The numbers in parentheses refer to the average index values.

Scans for Waist

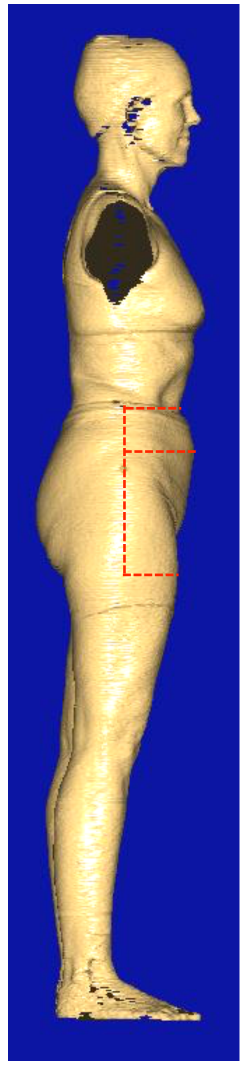


1 2

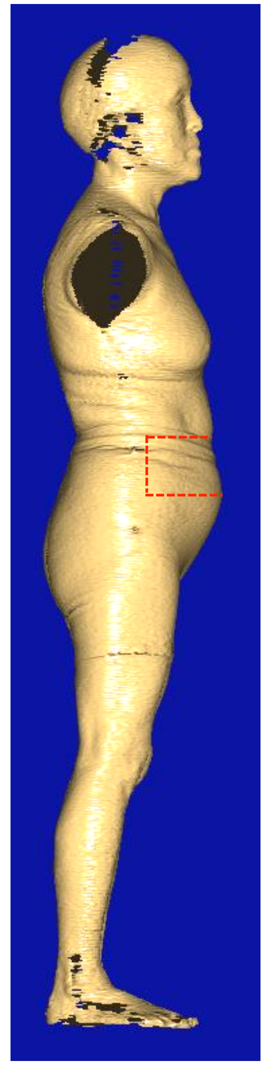
Indices	1	2
Waist level (57.14)	**57.55**	53.98
Waist inclination (82.87)	85.80	**82.40**

Note. The numbers in parentheses refer to the average index values.

Scans for Abdomen



1

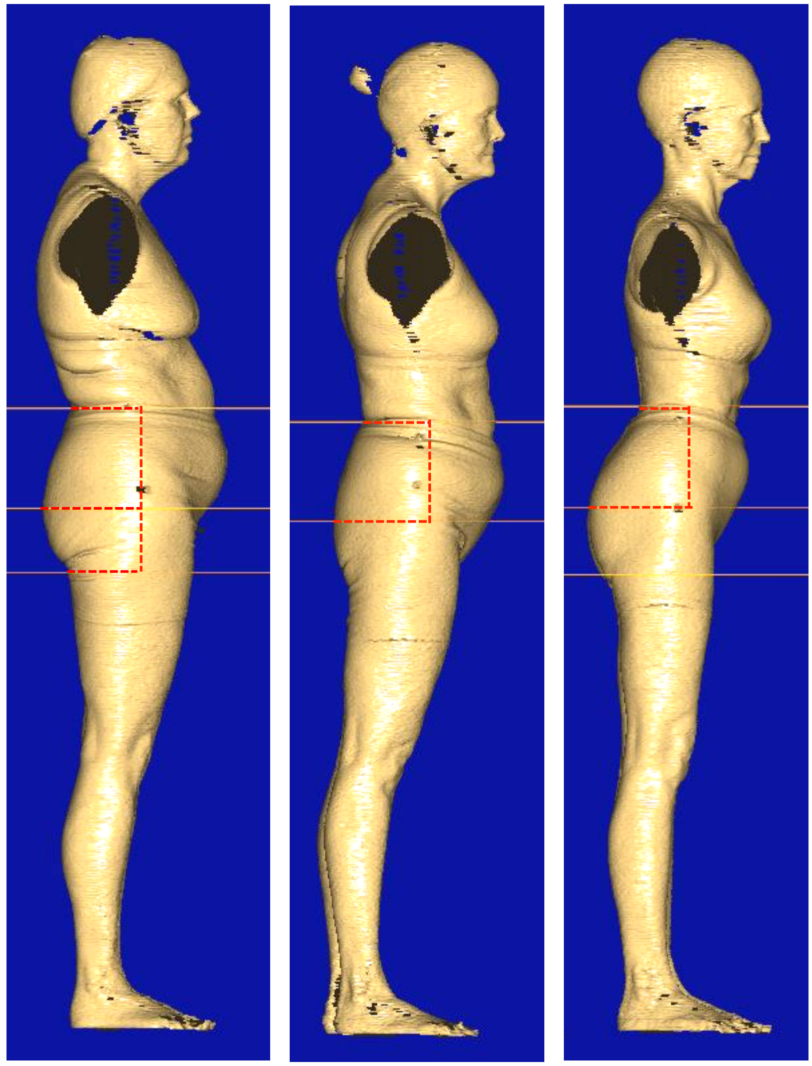


2

Indices	1	2
Abdominal protrusion level (24.55)	**24.91**	37.53
Abdominal prominence (114.07)	125.65	**114.17**

Note. The numbers in parentheses refer to the average index values.

Scans for Hip



1 2 3

Indices	1	2	3
Buttocks protrusion level (61.84)	**60.88**	58.66	60.66
Buttocks prominence (143.06)	142.39	**143.28**	**204.59**

Note. The numbers in parentheses refer to the average index values.

Appendix D

Table 27

Adjusted descriptive statistics of indices except nine extreme outliers (N = 156)

	Back curvature				Neck	
	Back protrusion level	Degree of back curvature	Degree of upper back curvature	Inclination of curvature	Neck height	Neck inclination
Mean	55.99	105.15	106.79	7.26	124.53	87.72
SD	4.88	2.41	3.95	6.44	5.26	25.41
1st Qu.	53.25	103.40	104.00	3.14	121.14	70.50
Median	56.27	105.02	106.38	6.96	124.51	85.10
3rd Qu.	58.99	106.21	108.88	11.31	127.04	101.73
Minimum	38.07	100.96	100.49	-6.78	113.16	30.90
Maximum	69.16	113.97	123.40	28.96	140.23	172.83
Skewness	-.37	**1.04**	**1.14**	.58	.21	.35
Kurtosis	**1.21**	**1.64**	**2.34**	**1.28**	-.15	.22

	Acromion		Armhole		
	Acromial level	Acromial inclination	Anterior indentation level	Posterior indentation level	Armhole inclination
Mean	92.51	116.61	72.73	72.33	150.21
SD	3.19	62.74	6.18	3.17	42.43
1st Qu.	90.39	75.12	68.57	70.46	121.14
Median	92.50	99.39	71.76	72.72	147.95
3rd Qu.	94.54	138.83	74.94	74.44	172.41
Minimum	84.88	32.09	57.72	59.78	52.72
Maximum	99.66	350.20	93.28	78.65	314.05
Skewness	-.10	**1.47**	.88	-.72	.81
Kurtosis	-.45	**1.97**	.90	**1.35**	**1.93**

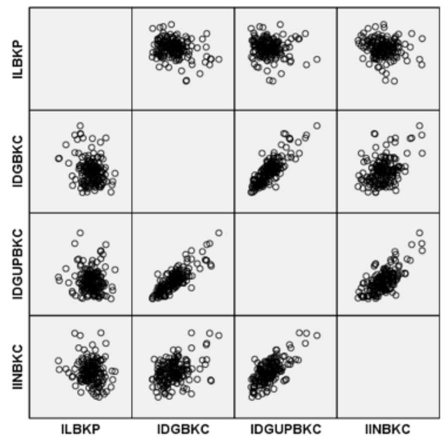
	Bust				Waist	
	Bust point level	Under-bust level	Bust prominence to waist	Bust prominence to abdomen	Waist level	Waist inclination
Mean	46.96	29.16	97.31	85.48	57.13	82.89
SD	6.07	7.14	17.10	14.07	2.37	9.67
1st Qu.	42.69	24.64	86.13	76.30	55.35	76.31
Median	48.21	29.87	98.16	85.68	57.33	81.96
3rd Qu.	51.57	34.10	108.50	95.49	58.70	89.73
Minimum	31.45	7.39	57.42	57.27	51.17	60.73
Maximum	62.36	47.10	152.24	128.86	63.23	111.14
Skewness	-.28	-.37	.14	.23	-.18	.42
Kurtosis	-.41	.09	-.01	-.25	-.42	.18

	Abdomen		Hip	
	Abdominal protrusion level	Abdominal prominence	Buttocks protrusion level	Buttocks prominence
Mean	24.76	114.12	61.08	143.49
SD	11.67	11.30	6.32	15.68
1st Qu.	17.53	103.46	58.03	131.24
Median	28.46	112.96	61.68	141.14
3rd Qu.	33.32	121.10	65.77	156.90
Minimum	0.00	100.00	38.67	108.35
Maximum	45.83	142.33	73.77	204.59
Skewness	-.85	.58	-.84	.71
Kurtosis	-.28	-.44	**1.30**	.94

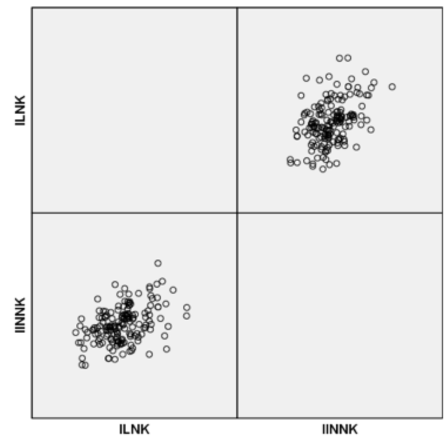
APPENDIX E

Scatterplot Matrix per Body Part

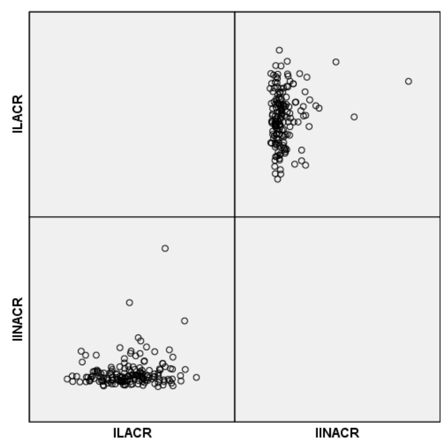
Back curvature



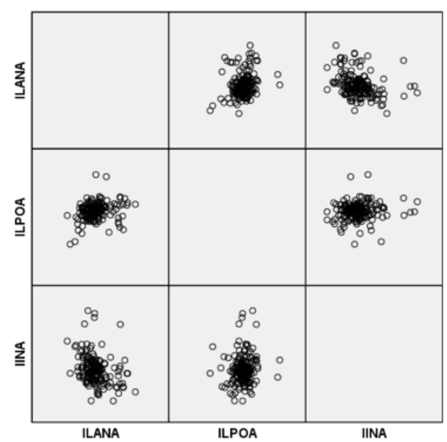
Neck



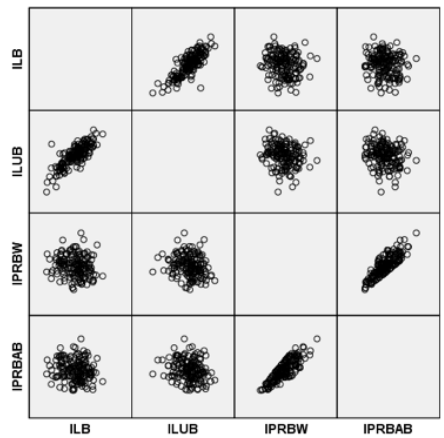
Acromion



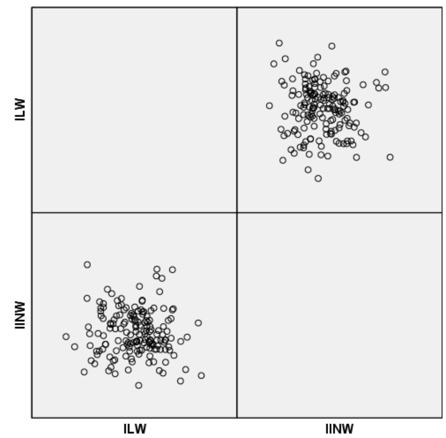
Armhole



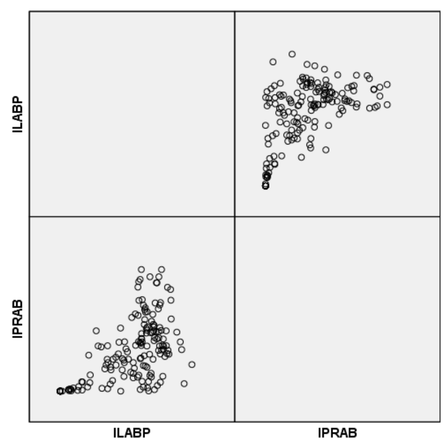
Bust



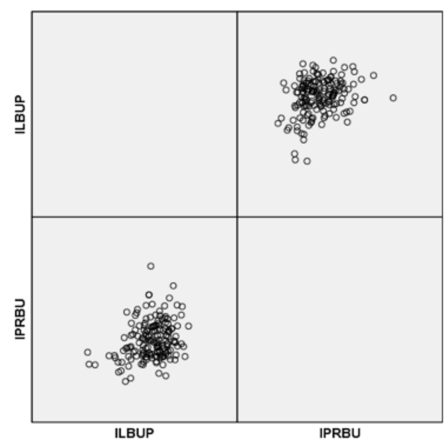
Waist



Abdomen

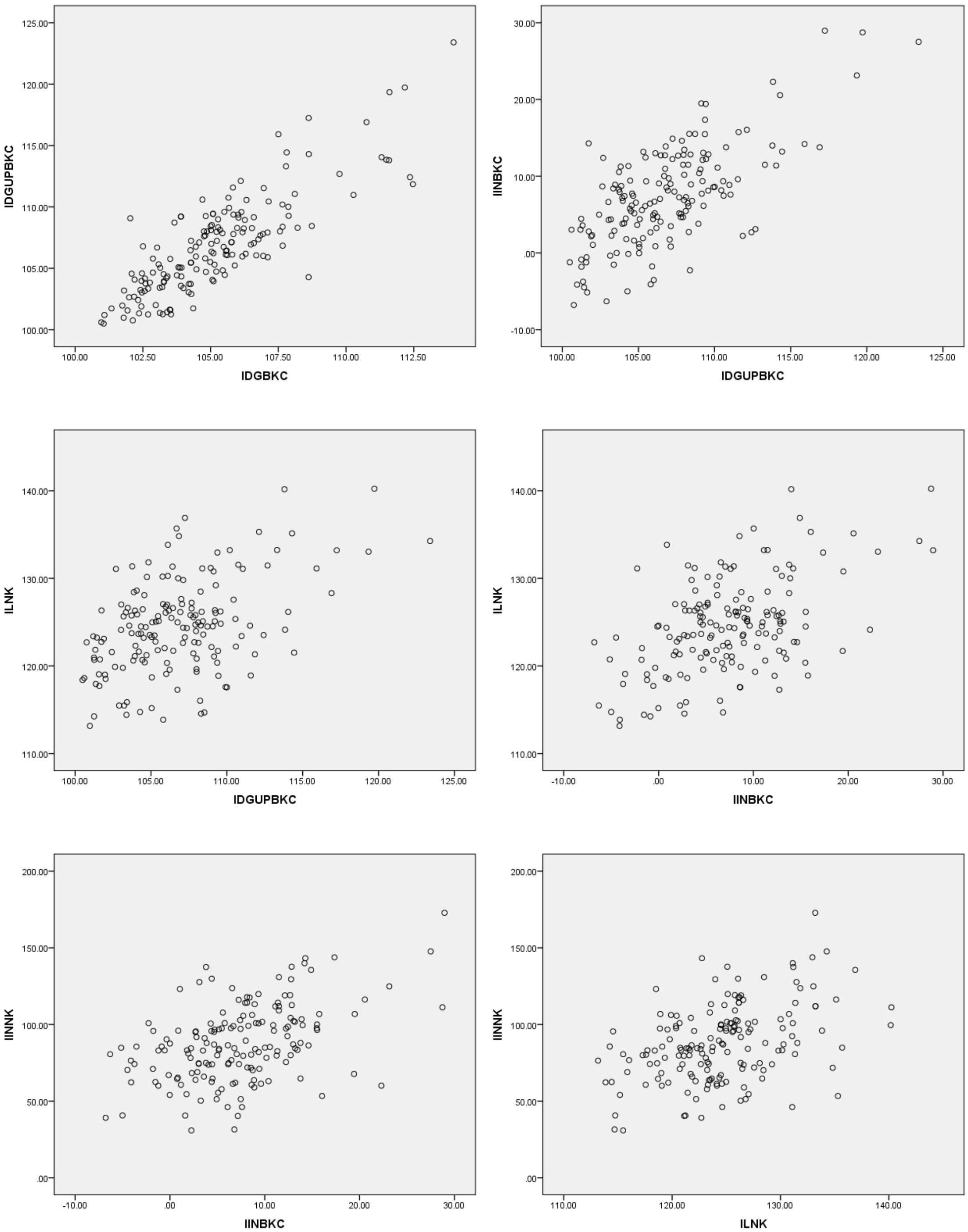


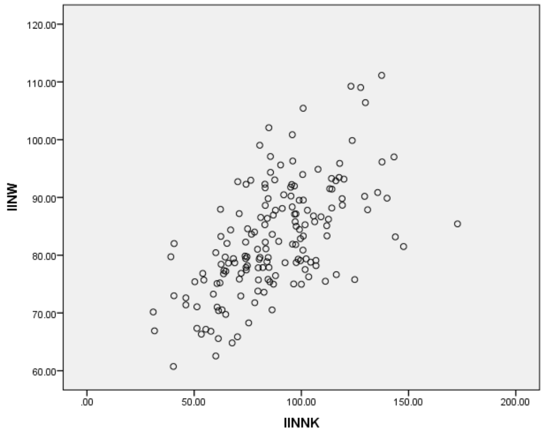
Hip



APPENDIX F

Scatterplots for Regression




IINW
IINNK
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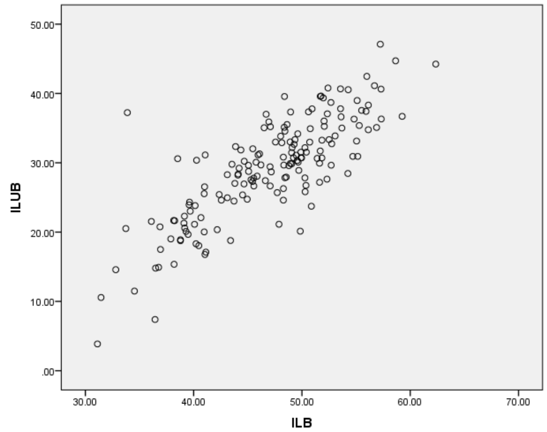
110.00
100.00
90.00
80.00
70.00
60.00
.00
50.00
100.00
150.00
200.00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ILB
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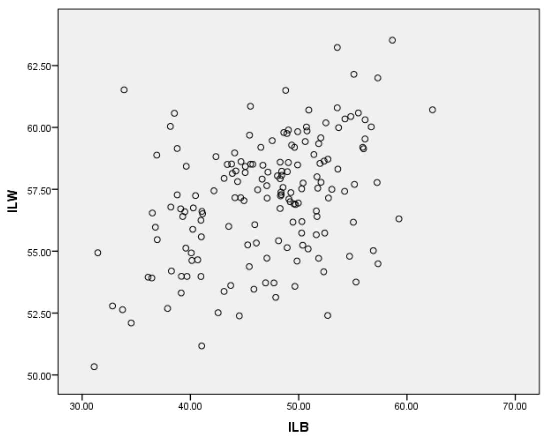
40.00
30.00
20.00
10.00
.00
30.00
40.00
50.00
60.00
70.00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ILB
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57.50
55.00
52.50
50.00
30.00
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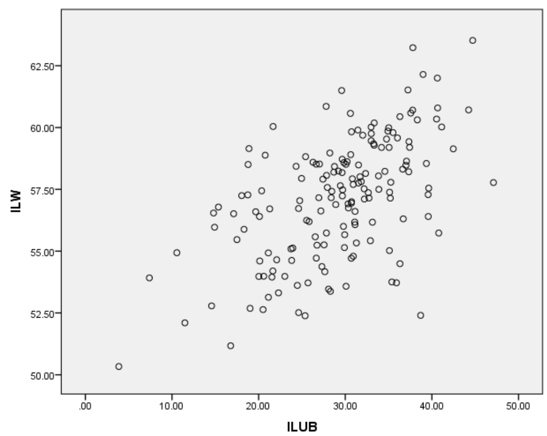
50.00
60.00
70.00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ILUB
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55.00
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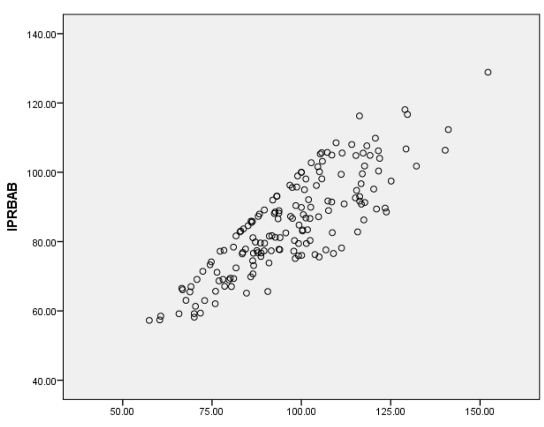
10.00
20.00
30.00
40.00
50.00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100.00
125.00
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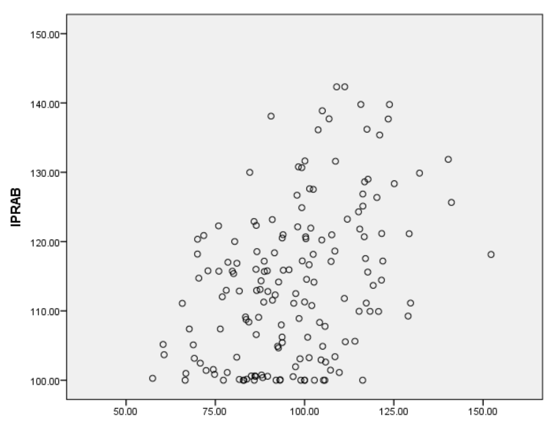
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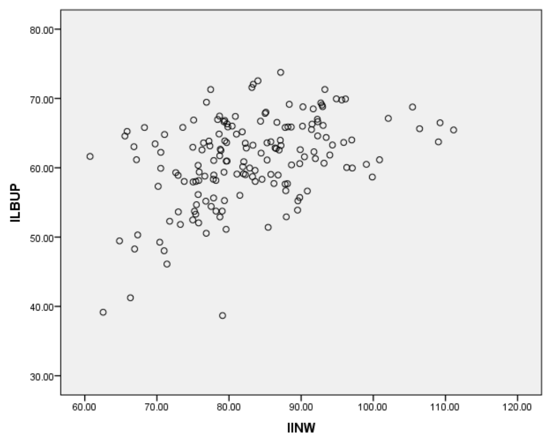
100.00
125.00
150.00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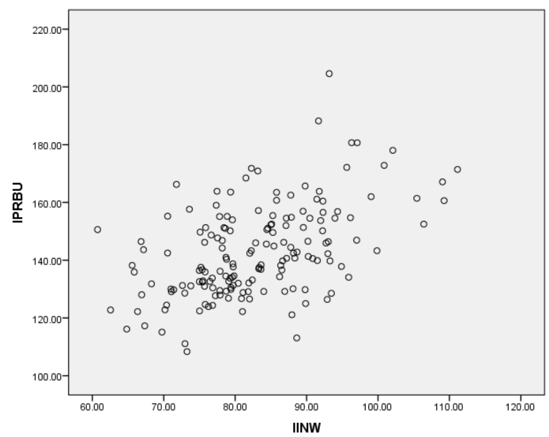
80.00
90.00
100.00
110.00
120.00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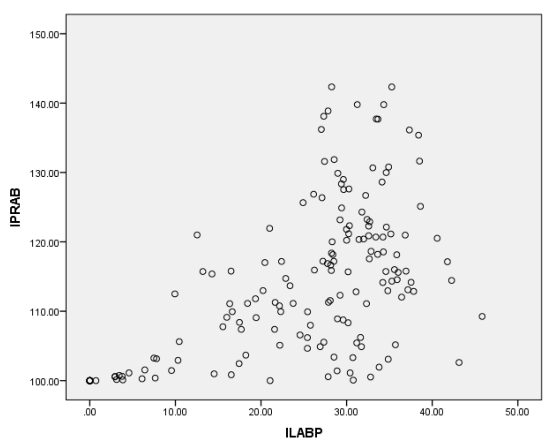
100.00
110.00
120.00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ILABP
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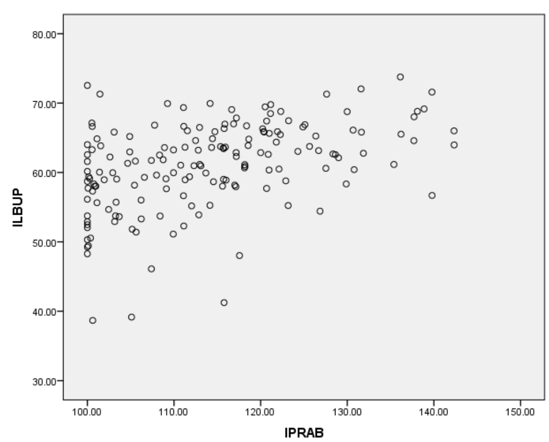
50.00


ILBUP
IPRAB
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50.00
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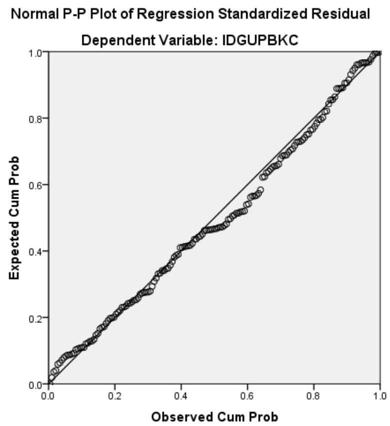
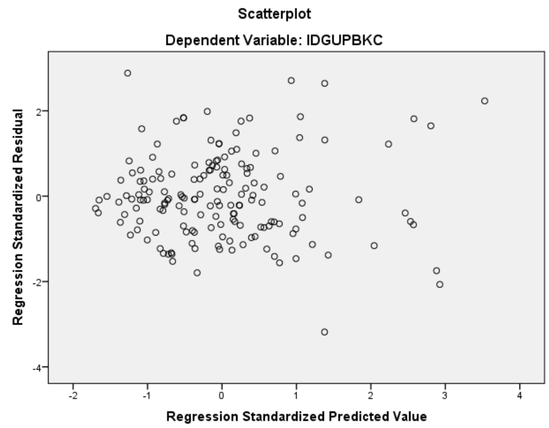
70.00
80.00
100.00
110.00
120.00
130.00
140.00
150.00

APPENDIX G

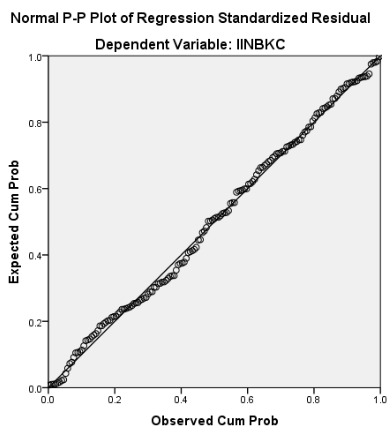
Normality Probability Plot and Homoscedasticity of Variance

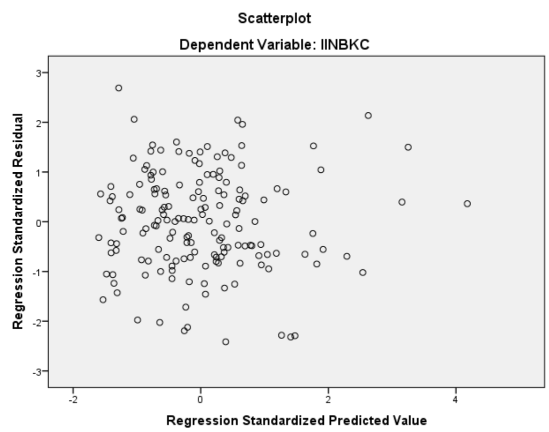
Degree of back curvature and degree of upper back curvature



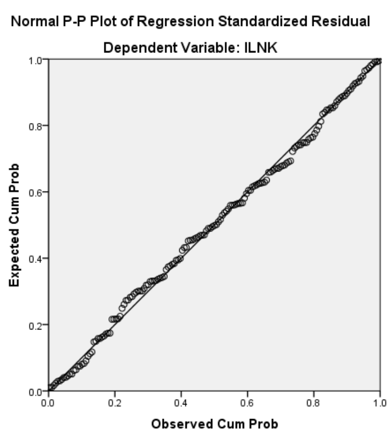


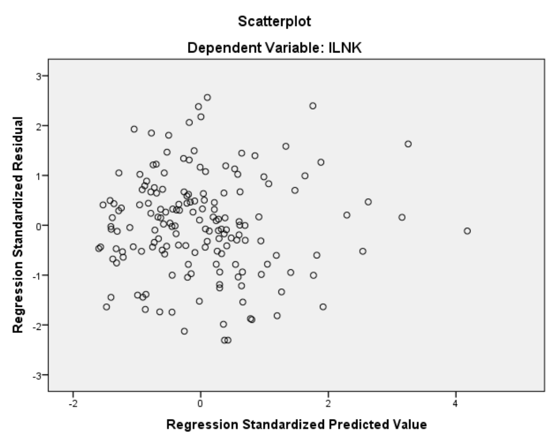
Degree of upper back curvature and inclination of back curvature



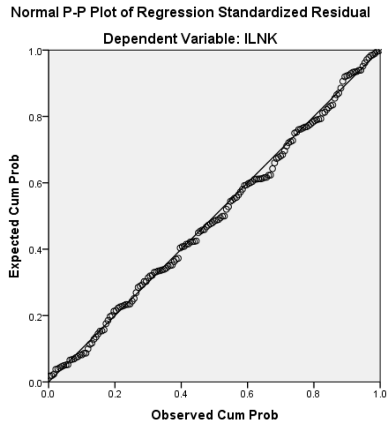


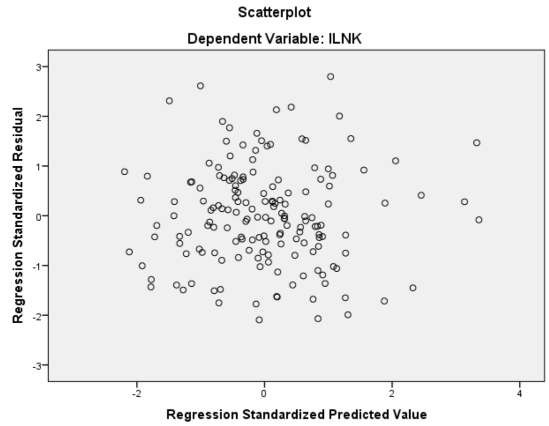
Degree of upper back curvature and neck height



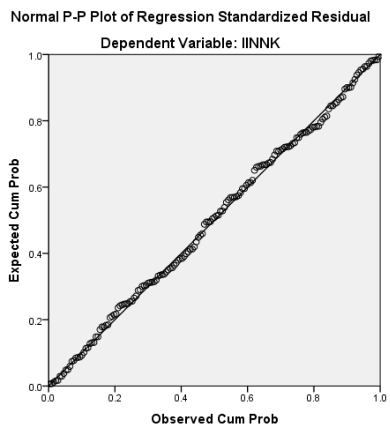


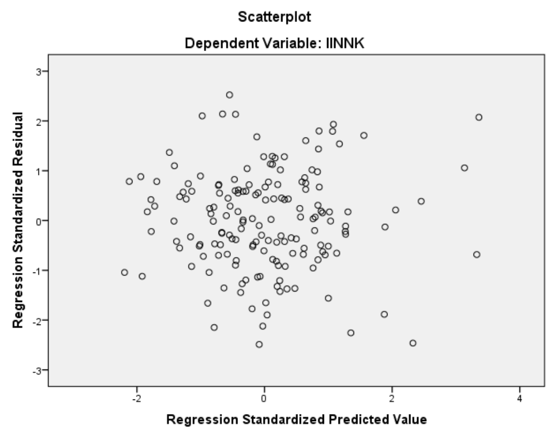
Inclination of back curvature and neck height



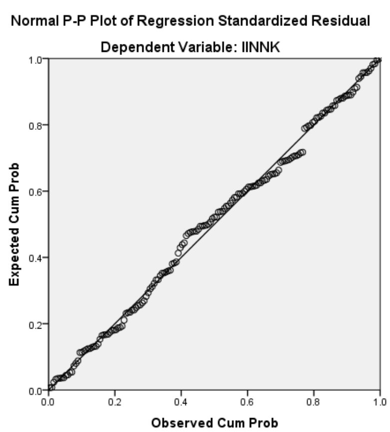


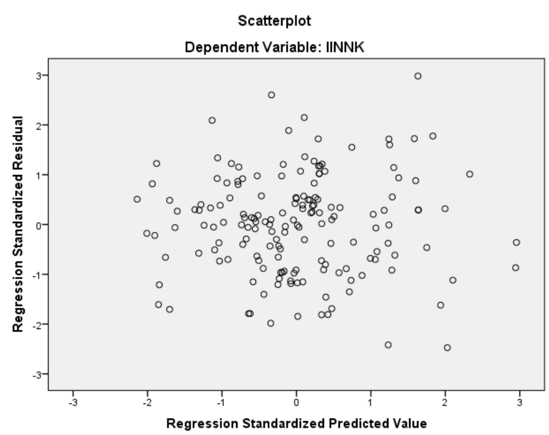
Inclination of back curvature and neck inclination



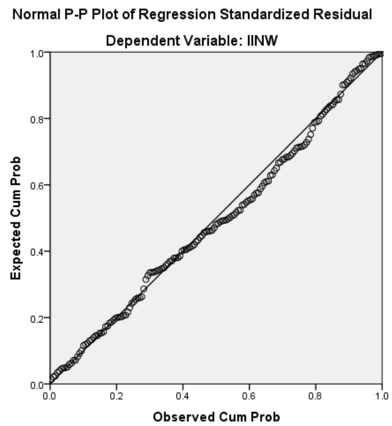


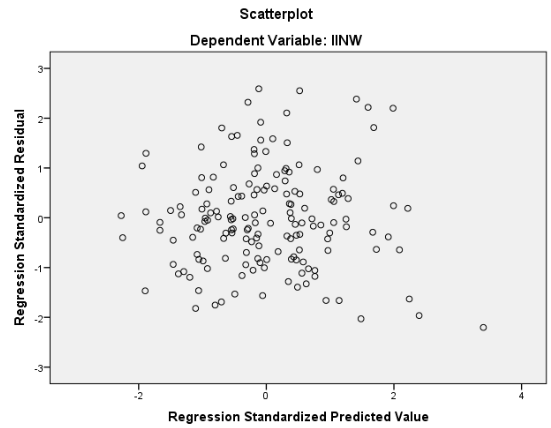
Neck height and neck inclination



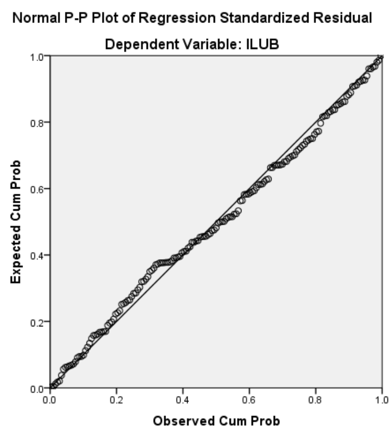


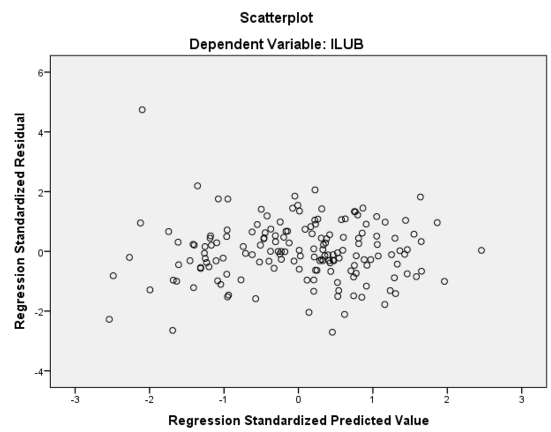
Neck inclination and waist inclination



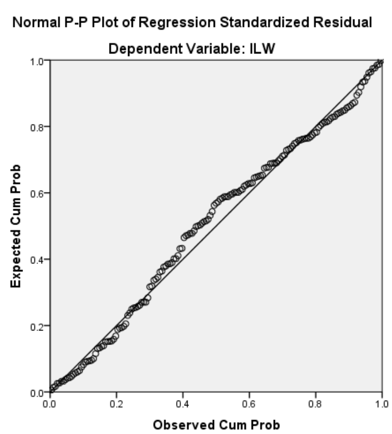


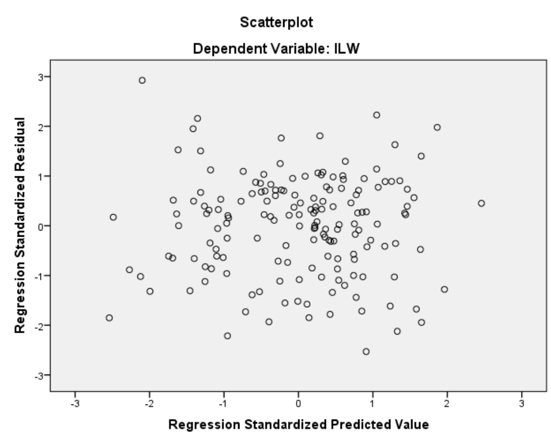
Bust point level and under-bust level



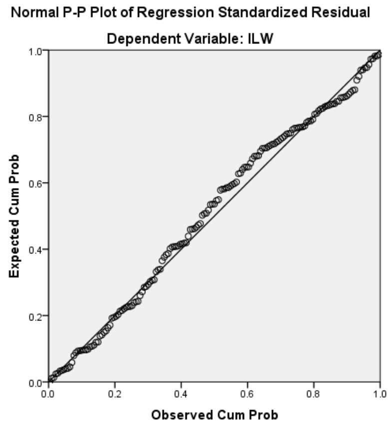


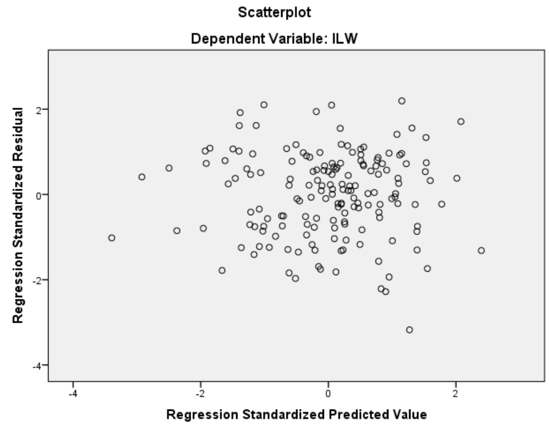
Bust point level and waist level



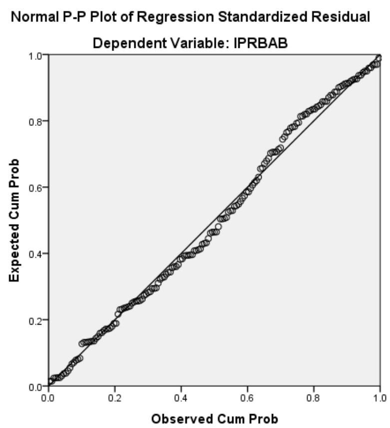


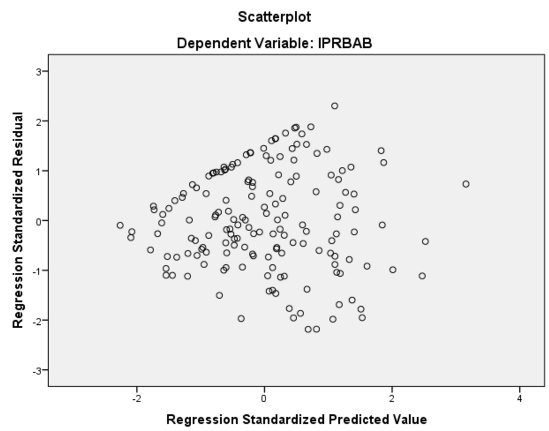
Under-bust level and waist level



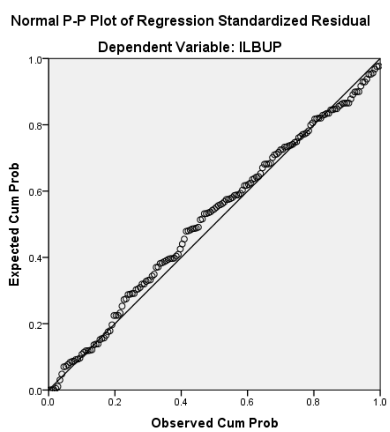


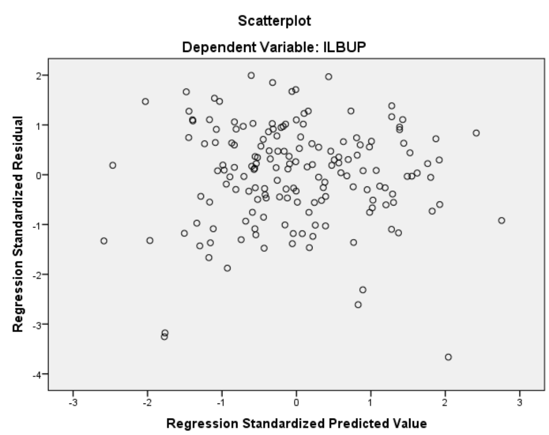
Bust prominence to waist and bust prominence to abdomen



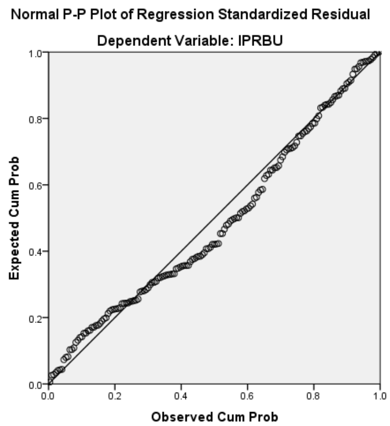


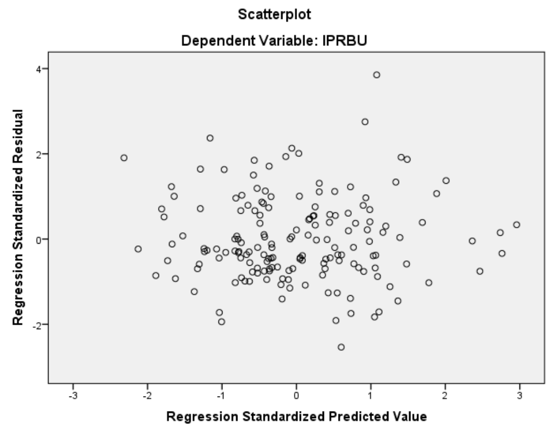
Waist inclination and buttocks protrusion level





Waist inclination and buttocks prominence

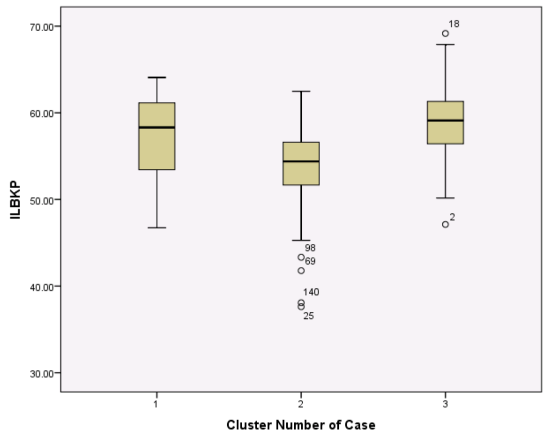




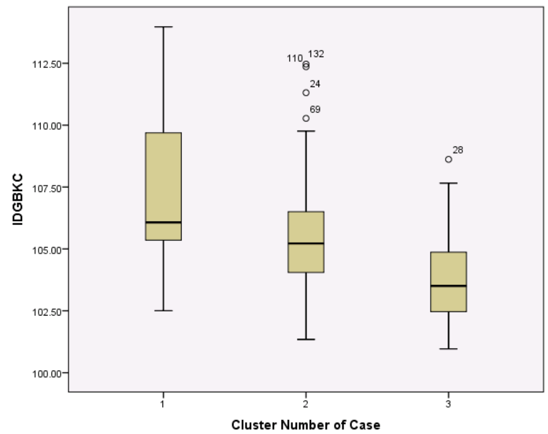
Appendix H

Clustering of Back Curvature

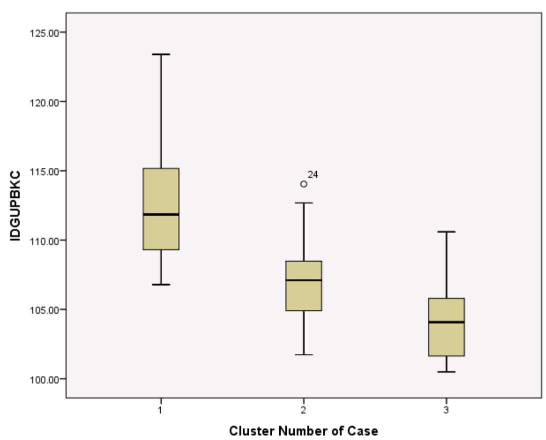
Back protrusion level



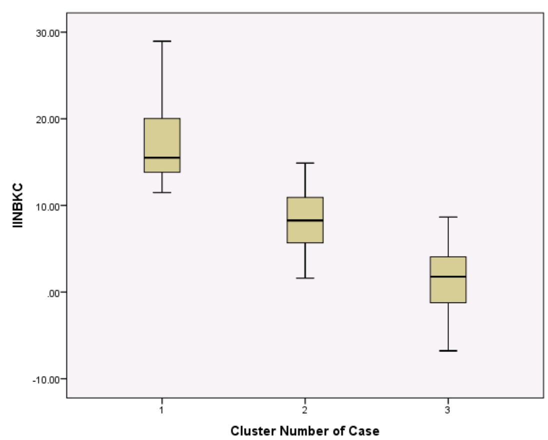
Degree of back curvature



Degree of upper back curvature



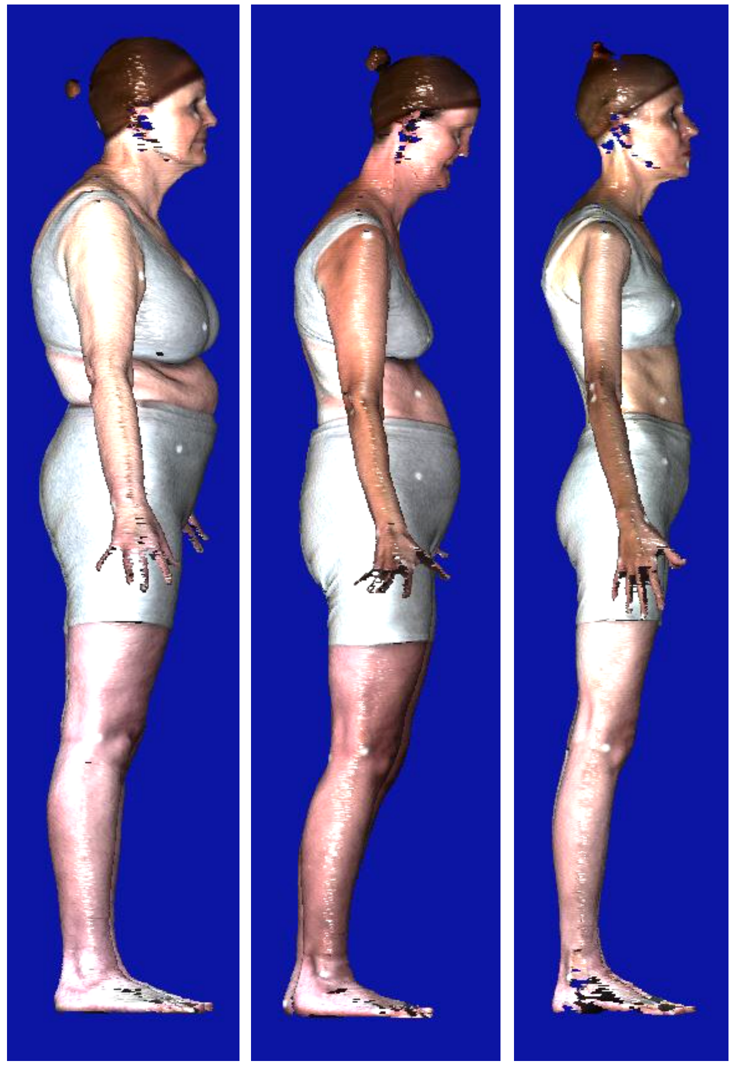
Inclination of back curvature



Appendix I

Scans for Back Curvature Classification

Back Curvature Cluster 1

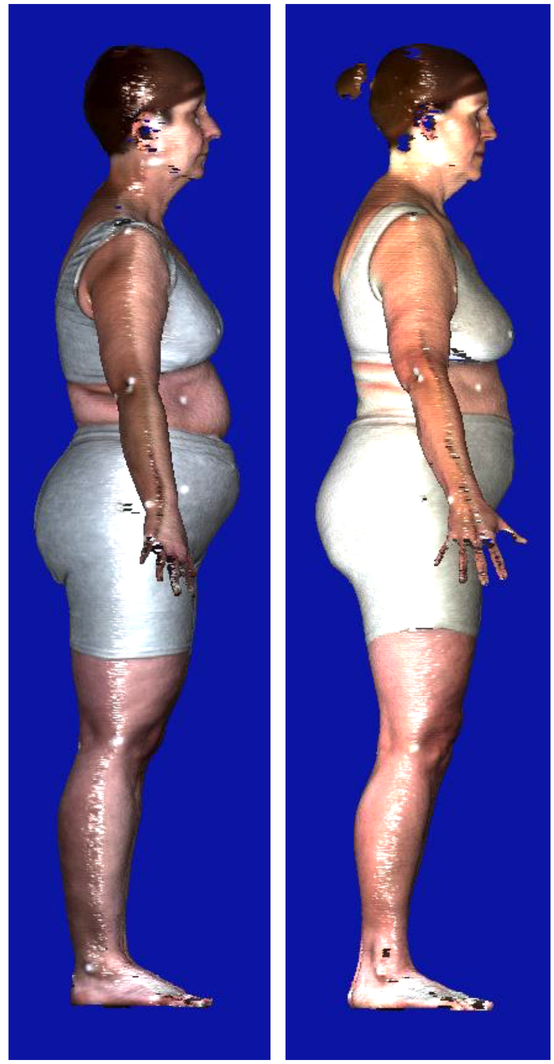


1 2 3

Indices	1	2	3
Back protrusion level (57.01)	**51.32**	62.44	**56.15**
Degree of back curvature (107.47)	111.59	**107.50**	109.76
Degree of upper back curvature (112.68)	**113.80**	115.91	**112.68**
Inclination of curvature (17.50)	**14.00**	**14.19**	3.10

Note. The numbers in parentheses refer to the average index values.

Back Curvature Cluster 2

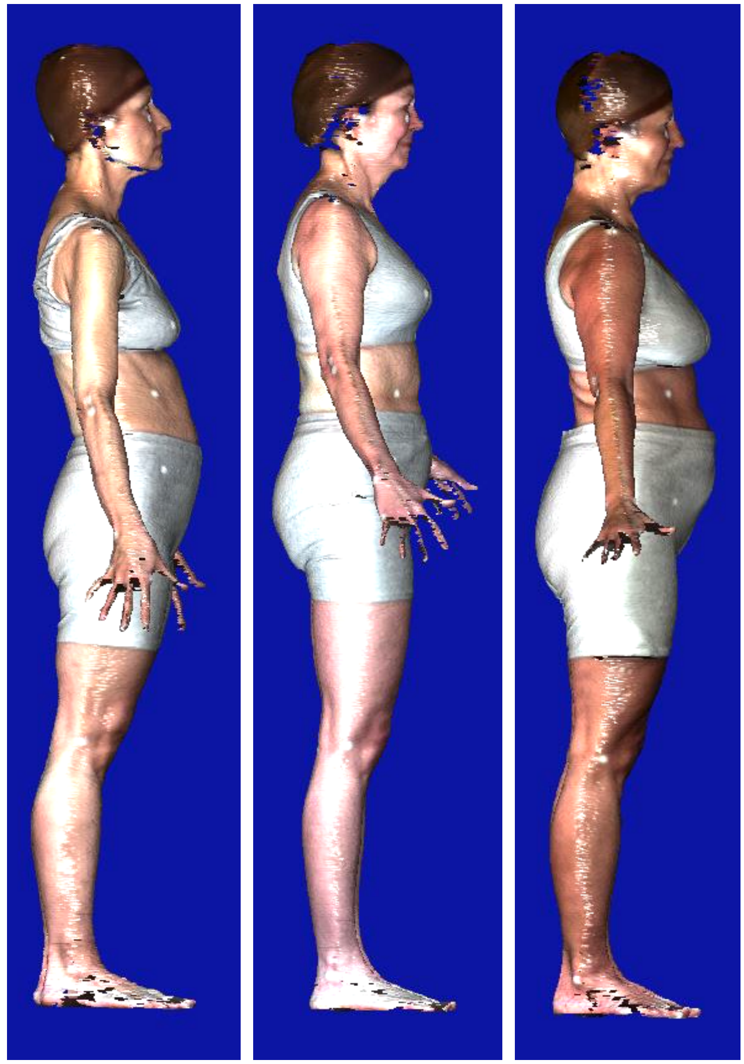


1 2

Indices	1	2
Back protrusion level (53.65)	**53.01**	56.10
Degree of back curvature (105.41)	**105.23**	104.58
Degree of upper back curvature (107.00)	**106.99**	**107.10**
Inclination of curvature (8.27)	9.73	**8.99**

Note. The numbers in parentheses refer to the average index values.

Back Curvature Cluster 3


1 2 3

Indices	1	2	3
Back protrusion level (58.92)	**59.28**	56.74	64.60
Degree of back curvature (103.82)	**103.40**	103.27	103.12
Degree of upper back curvature (103.94)	101.43	**104.52**	101.36
Inclination of curvature (1.32)	-4.49	5.44	**-3.74**

Note. The numbers in parentheses refer to the average index values.

Appendix J

Results of Levene's Test

Table 34

Homogeneity of Variances for Back Curvature Indices

	Levene Statistics	df1	df2	*p*	Post hoc test
Back protrusion level	.556	2	162	.575	Bonferroni
Degree of back curvature	5.556	2	162	.005	Dunnett's T3
Degree of upper back curvature	9.425	2	162	.000	Dunnett's T3
Inclination of back curvature	5.071	2	162	.007	Dunnett's T3

Table 36

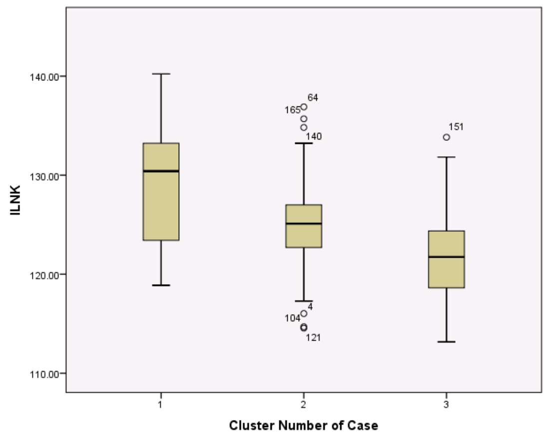
Homogeneity of Variances for Torso indices

	Levene Statistics	df1	df2	*p*	Post hoc test
Neck height	5.774	2	162	.004	Dunnett's T3
Neck inclination	1.400	2	162	.250	Bonferroni
Acromial level	.270	2	162	.764	Bonferroni
Acromial inclination	6.118	2	162	.003	Dunnett's T3
Anterior arm indentation level	3.004	2	162	.052	Bonferroni
Posterior arm indentation level	.824	2	162	.441	Bonferroni
Armhole inclination	6.374	2	162	.002	Dunnett's T3
Bust point level	2.401	2	162	.094	Bonferroni
Under-bust level	1.488	2	162	.229	Bonferroni
Bust prominence to waist	.589	2	162	.556	Bonferroni
Bust prominence to abdomen	.326	2	162	.722	Bonferroni
Waist level	.045	2	162	.956	Bonferroni
Waist inclination	3.489	2	162	.033	Dunnett's T3
Abdomen protrusion level	4.207	2	162	.017	Dunnett's T3
Abdomen prominence	.507	2	162	.603	Bonferroni
Buttocks protrusion level	4.131	2	162	.018	Dunnett's T3
Buttocks prominence	2.022	2	162	.136	Bonferroni

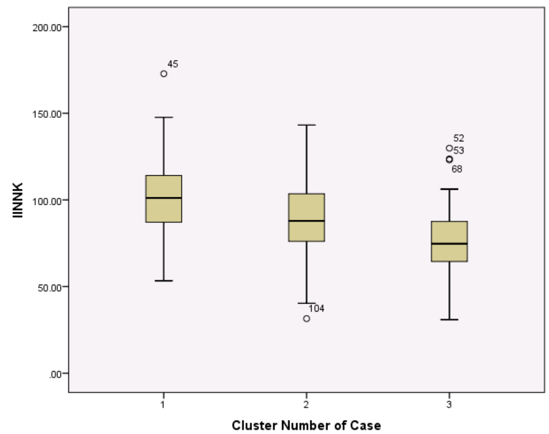
Appendix K

Range of Torso Variations based on Back Curvature Clustering

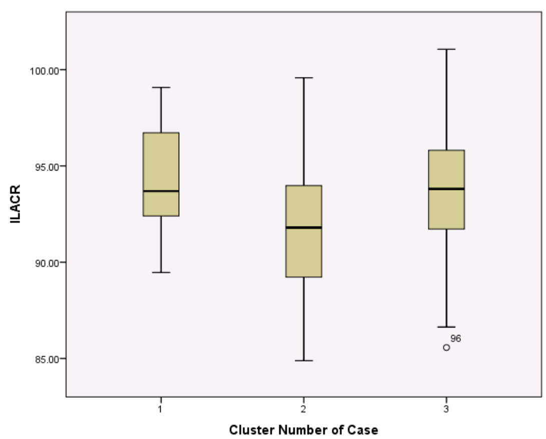
Neck height



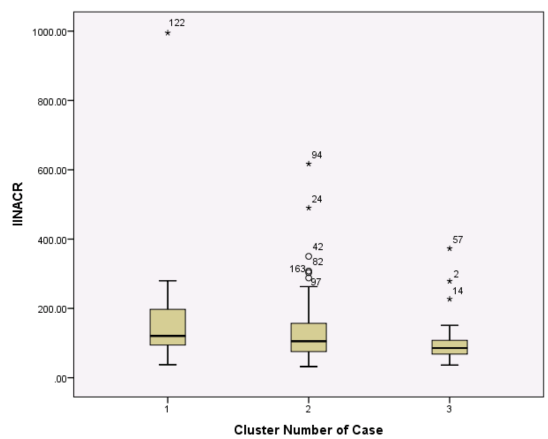
Neck inclination



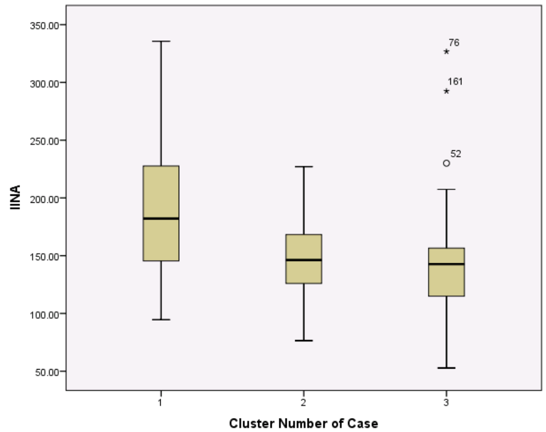
Acromial level



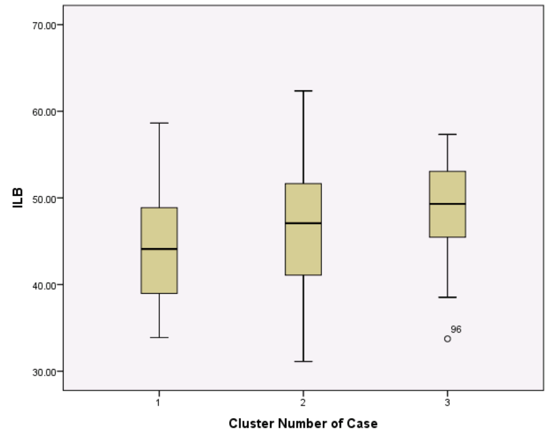
Acromial inclination



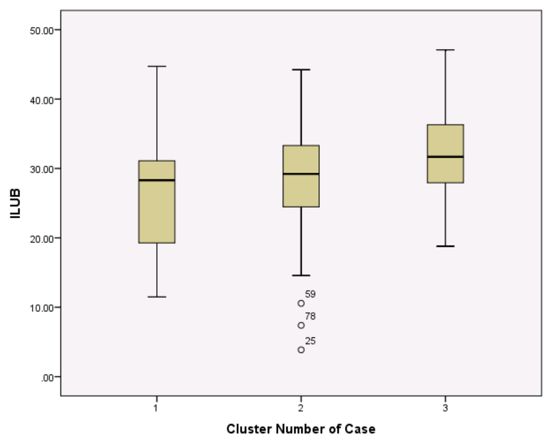
Armhole inclination



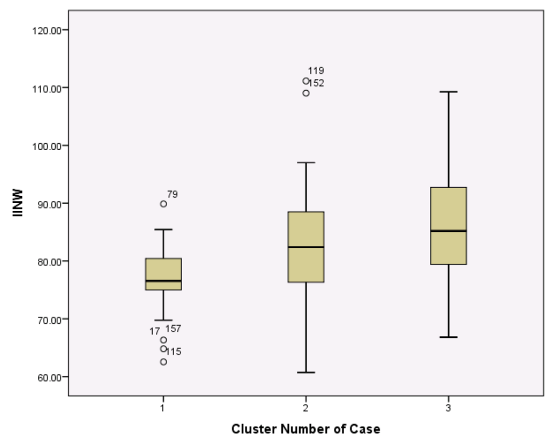
Bust point level



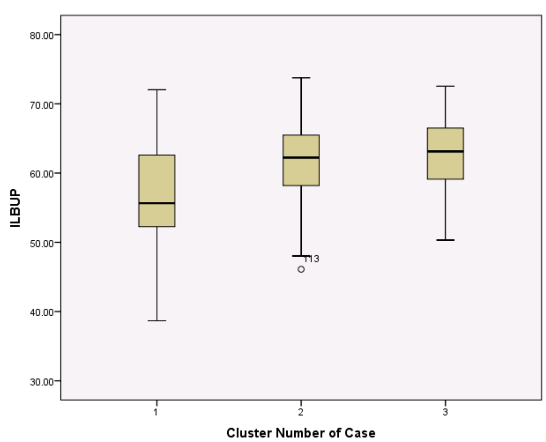
Under-bust level



Waist inclination



Buttocks protrusion level



Buttocks prominence