

A Research on Effect of Pillow Height on Pressure and Comfort of Human Body's Prone Position

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Abstract. This research has explored the effects of buckwheat pillow at different heights on the body pressure distribution and comfort of women aged 44–64 years. A total of 19 women aged 44–64 years (who are healthy and have no sleep disorder or musculoskeletal disease history) were selected. The quality of sleep and the use of pillow were investigated by questionnaire survey, and subjects were guided to make subjective comfort experience evaluations on the mattresses with moderate hardness with the use of buckwheat pillows at four different heights (the pillow heights were 3 cm, 7 cm, 11 cm and 15 cm, respectively) Laboratory measurement was carried out on body shape index. The body pressure distribution in supine position was also measured. Based on the experiment results the test results of Body Pressure Distribution and Subjective Comfort Evaluation are concluded respectively.

Keywords: Pillow height · Pressure distribution · Subjective comfort · Use experience · Human body's prone position

1 Introduction

About one-third of our time is spent in sleep, so high-quality and adequate sleep is necessary for people, and the living organism maintains the body's homeostasis, immune function and its integrity through sleep. In addition, sleep also regulates the cognitive ability, ability to judge and memory needed in daily life and work [1]. According to Kyle et al, the quality of sleep is directly related to human health and living standards [2]. In sleep, pillow is an important tool to maintain the cervical vertebra's normal physiological curvature and the sleeping pillow supports the head. The right pillow is conducive to maintaining the normal physiological curve of human spine, keeping the body in a natural state and ensuring good rest and sleep of human, but in case of inappropriate pillow selected, the long-term use may cause changes in the

normal physiological curve of cervical spine, affecting the health. Therefore, how to choose a comfortable pillow for good sleep is a vital issue. In the study of bedding comfort, the research of mattress comfort has included the analyses on relationship between the prone position and the body pressure distribution and change in comfort, respectively, but the researches on pillow comfort and function are still limited. This research is aimed at exploring the effects of buckwheat pillows with different heights on the body pressure distribution and comfort of women aged 44–64 years.

1.1 Role of Sleeping Pillow

The quality of sleep at night is closely related to the sleeping posture. Specifically, incorrect cervical posture during sleep increases the biomechanical stress on the cervical spine, which can result in pain and stiffness in cervical spine, headache and pain in scapular or arm, finally leading to poor-quality sleep [3]. In heavy sleep, our neck and shoulder muscles are completely relaxed, and we maintain the normal relationship between the intervertebral structure only by the elasticity of intervertebral ligament and joint capsule. In case of the long-term use of a pillow with inappropriate height, which causes excessive flexion of the cervical spine, the ligaments and joint capsule here will suffer stretch and injury, resulting in cervical instability, joint dislocation, and then developing into cervical spondylosis [4]. If the pillow is too low, head and neck is bound to be over backward with increased lordosis, so the muscles and ligaments in the front of centrum will be too tight. For a long time, there will be fatigue and even chronic injury, accelerating degenerative changes. On the contrary, if the pillow is too high, the head and neck will have excessive antexion, which easily leads to strain of muscles and ligaments in the rear of the cervical spine.

Lavin's research on 41 patients with benign cervical pain also shows that the use of appropriate pillow can significantly reduce the pains in neck and shoulders [5]. Therefore, the selection of a pillow with appropriate height can optimize the body's sleeping posture, thereby improving sleep quality [6]. One of the key factors for a suitable pillow is the ability to support the normal physiological curvature of cervical spine [7].

The main role of pillow during sleep is to support the cervical spine and keep it in a neutral position, so as to minimize the final stage position of cervical spine motion to avoid the loss of cervical curvature and the symptoms of cervical spondylopathy in awakened state [8, 9]. In addition, proper support can increase the area of contact between neck and pillow, allowing a more even distribution of pressure on muscles [10].

Another key feature of a suitable pillow is the ability to reduce head temperature. A pillow that helps reduce core and head temperatures during sleep at night is important for deep sleep [11].

1.2 Research Status and Methods of Sleeping Pillow

In respect of pillow height, the Japanese scholar Minezaki et al. [12] used subjective evaluation method, electromyography test method and X-ray observation method to

research the most comfortable pillow height for 40 20-year-old females, and the most comfortable pillow height most conducive to sleep was recommended to be 5.0 ± 1.0 cm in supine position and 6.8 ± 0.9 cm in lateral position; in terms of shape, Taiwanese scholar Chen HL et al. measured the body sizes of coronal and sagittal planes of the heads, necks and shoulders of 10 males and 10 females with an average age of 21.9 years, and designed two U-shaped pillows suitable for Taiwanese male's and female's heads respectively based on the average [10]; according to the principles and data in anatomy, physiology, pathology and biomechanics in combination with clinical experience, An [13] designed a curve heterologous pillow, applied it clinically, carried out qualitative and quantitative biomechanical analysis, and speculated that the pillow was in line with the natural posture of neck, allowing the best stress state of neck; in terms of comfort, Cheng Xiuguang stated in the Environmental Clothing Science that [14] the performance that bedding should have shall meet the physical needs of human body, such as insulation, hygroscopicity, moisture permeability and ventilation, etc., and bedding shall also be adapted to physical activities, bear reasonable load and allow good skin touch; by studying the relationship between pillow sensory evaluation and compression performance, Japanese scholar Yokura [15] carried out correlation analysis on the relationship between the subjective rating (softness, fitness and general comfort) and the compression work & compression deformation rate of pillow so as to explore the establishment of an objective assessment method of pillow comfort. Pillows with larger contact area and less contact pressure are considered to be softer and more comfortable, and pillows with the same plane shape are assessed with good consistency in terms of pillow hardness and height. Korean scholar [16] Park SJ used 3D scanning to measure adult human's head size, and the head size was classified into four types. When the head rests on the pillow, the pillow height is determined by the relationship between the pillow stiffness and the pressure distribution of head and neck on pillow, and the relationship between pillow height, shape and stiffness is found. It was found through experiment that the rule of choosing a comfortable pillow by subjects can be determined by the relationship between height, shape and stiffness of pillow, and the selected comfortable pillow is significantly correlated with the satisfaction; He [17] summarized the evaluation methods of bedding product comfort, mainly including psychological evaluation method, physiological evaluation method, objective property indicator method and microclimate theory, etc. In this paper, the psychological evaluation method based on psychological scale method and the physiological evaluation method to measure size of human body, state of spine curve and other indicators [18] were adopted to study the relationship between the pillow height the and the pressure and comfort of human body's prone position.

2 Research Subjects and Methods

2.1 Research Subjects

The subjects in this research were 19 women (healthy without history of sleep disorder or musculoskeletal disorders) of 44 to 64 years of age. Subjects were required to

perform subjective comfort experience evaluation on mattresses with moderate hardness (hardness value of 1.56) in respect of pillows with four different heights (with pillow heights of 3 cm, 7 cm, 11 cm and 15 cm, respectively) with the body shape parameters and the body pressure distribution under four pillow heights were measured.

2.2 Research Methods

2.2.1 Experimental Mattress and Pillow

The mattress was brown mattress with hardness value of 1.56, and the pillow was filled with buckwheat. The pillow heights were 3 cm, 7 cm, 11 cm and 15 cm and the length and width were 55 cm × 35 cm.

2.2.2 Subjective Comfort Evaluation Scheme

Subjects experienced the comfort of 4 pillows with different heights. Subjects were free to choose pillow height and posture to use the pillow. The time of experience on each pillow was not less than 3 min. After the completion of experience, the subjective feeling evaluation form was completed with the evaluation results given on 5-level rating basis.

2.2.3 Test Program for Physiological Curvature of Human Head and Neck

In order to study the relationship between the curvature of cervical vertebrae and the pillow height comfortable for subjects, the body size of subjects in the standard anatomical position was measured with the use of Martin Measuring Scale (see Fig. 1) (Table 1).

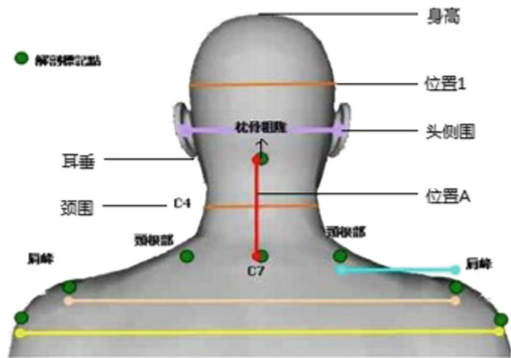


Fig. 1. Human body size test

Table 1. comparison table

解剖标记点	Anatomical mark points
耳垂	Earlobe
颈围	Neck circumference
肩峰	Acromion
颈根部	Neck root
身高	Height
位置1	Position 1
头侧围	Head side circumference
位置A	Position A

2.2.4 Scheme of Body Pressure Distribution Test Under Different Pillow Heights

(1) Test Purpose

The pressure distribution of human body under steady state of pillows with different heights was measured by Tekscan pressure transducer.

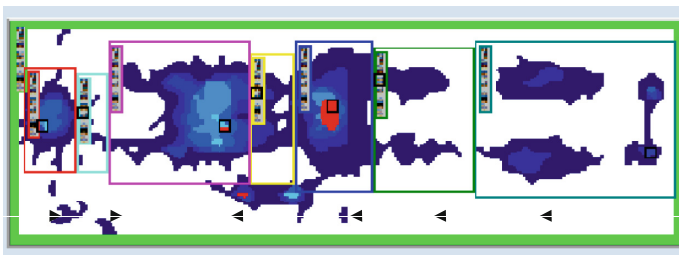
(2) Test Requirements

Subjects lying on the mattress in supine position with their head and neck completely placed on the pillow, feet naturally separated, arms placed on the chest and elbows not touching the mattress as far as possible. The test was started when the subjects lay on back in relaxed state and the pressure data was stabilized. The subjects kept still after the start of test.

(3) Testing Process

After the subjects lay down, the body weight of subjects was calibrated. After the pressure value was stabilized, the 25 s body pressure distribution test was conducted (200 frames in total, 0.125 s/frame with acquisition frequency 8 Hz). In the second half of test (after 100 frames), projections of human neck, waist and thigh on the mattress were pressed with fingers to be used as partition basis, followed by the replacement of pillows with different heights in sequence for testing. The body weight was calibrated before each test.

The body pressure was divided into the following eight areas (see Fig. 2): head, neck, trunk, waist, buttocks, thighs, shanks, feet and body. The five parameters, i.e.

**Fig. 2.** Diagram of human pressure areas

pressure value (F), peak pressure value (PF), pressure intensity value (CP), peak pressure intensity value (PCP) and contact area (CA) of the eight areas were obtained. The effective average of different areas and different parameters in the whole testing process were obtained.

2.3 Data Processing

2.3.1 Raw Pressure Data Derivation

The pressure distribution data, including five parameters, i.e. pressure value (F), peak pressure value (PF), pressure intensity value (CP), peak pressure intensity value (PCP) and contact area (CA), of each subject were obtained through the BPMS Tekscan system software, and the test areas were divided into 8 partitions i.e. head, neck, trunk, waist, buttocks, thighs, shanks, feet and body according to the calibration points in testing.

2.3.2 Data Judgment and Calculation

Scripts written by Python were used to read the raw data. After excluding the outliers caused by the pressure markers during the experiment process, the mean values were selected and summed by selecting effective value range.

2.3.3 Standard Processing of Data

People with different body weights may have different pressure values. Pressure value is proportional to body weight, so standard processing was adopted.

- (1) Pressure value processing: the whole body was set to 100%, with those of other part set to intensity value/body value*100%;
- (2) Peak pressure processing: the maximum of partitions was set to 100%, with those of other parts set to peak pressure value/maximum*100%;
- (3) Pressure intensity value processing: the maximum of partitions was set to 100%, with those of other parts set to pressure intensity value/maximum*100%;
- (4) Peak pressure intensity processing: the maximum of partitions was set to 100%, with those of other parts set to peak intensity pressure/maximum*100%;
- (5) Contact area value processing: the whole body was set to 100%, with those of other part set to contact area value/body value*100%.

2.4 Data Analysis

SPSS software was used to analyze the data. Spearman Rank Correlation was used to compare the relationship between pillow height and subjective comfort and that between pillow height and body measurements; one-way anova, LSD (homogeneity of variance) and Dunnett T3 (heterogeneity of variance) follow-up inspection methods were used for comparing the variance of body pressure distribution under different pillow heights (height of 3 cm, 7 cm, 11 cm and 15 cm, respectively); the relationship between subjective comfort and body pressure distribution was compared by stepwise regression; the significance level was defined as $p < 0.05$.

3 Experimental Results

3.1 Subjective Comfort Evaluation Results

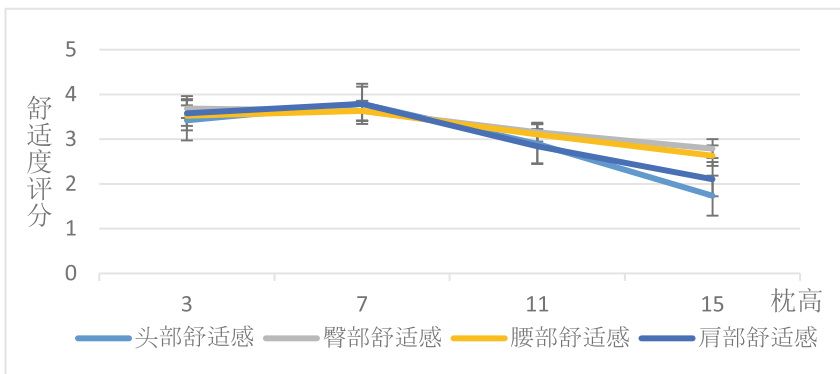
Tables 2 and 3 show the results of the subjective comfort assessment for pillows with different heights (Fig. 3).

Table 2. Scores of pillow's subjective comfort experience (n = 19)

Serial no.	Head and neck comfort	Buttock comfort	Waist comfort	Shoulder comfort	Average
1 (3 cm)	3.4 ± 1.4	3.7 ± 1.2	3.5 ± 1.3	3.6 ± 1.1	3.55 ± 1.2
2 (7 cm)	3.8 ± 0.8	3.6 ± 0.9	3.6 ± 1.1	3.8 ± 1.0	3.7 ± 0.8
3 (11 cm)	2.9 ± 1.1	3.2 ± 1.2	3.1 ± 1.1	2.8 ± 0.9	3.0 ± 0.9
4 (15 cm)	1.7 ± 1.0	2.8 ± 1.2	2.6 ± 1.1	2.1 ± 1.0	2.3 ± 0.9

Table 3. Count of the most comfortable pillow selected by subjects (n = 19)

Most comfortable pillow	1 (3 cm)	2 (7 cm)	3 (11 cm)	4 (15 cm)
Count (Subject)	9	8	2	0



舒适度评分	Comfort score
枕高	Pillow height
头部舒适感	Head comfort
臀部舒适感	Hip comfort
腰部舒适感	Waist comfort
肩部舒适感	Shoulder comfort

Fig. 3. Main comfort evaluation scores and pillow heights

Pillow's subjective comfort evaluation results show that the subjects like 7 cm high Pillow 2 most, which was followed by 3 cm high Pillow 1.

3.2 Body Pressure Test Results Under Different Pillow Heights

All the standardized values in the tables are percentages, i.e., the percentage values standardized based on the maximum value of each subject. Tables 4, 5, 6, 7 and 8 show the results of body pressure distribution test under different pillow heights.

Table 4. Pressure values (F, %) (n = 19)

Item	0 cm	3 cm	7 cm	11 cm	15 cm
F head	7.1 ± 1.4	7.5 ± 1.6	7.2 ± 1.7	7.8 ± 2.3	7.3 ± 2.1
F neck	0.7 ± 0.4	1.9 ± 1.3	2.9 ± 2.2	3.2 ± 3.0	3.7 ± 2.6
F chest	35.8 ± 5.5	34 ± 5.9	31.5 ± 8.6	30.7 ± 8.1	29.9 ± 7.2
F waist	6.4 ± 2.1	6.7 ± 2.1	6.7 ± 1.6	7.0 ± 2.1	7.4 ± 2.7
F buttock	30.8 ± 4.5	30.2 ± 4.4	31.3 ± 5.5	30.8 ± 5.0	31.0 ± 5.6
F thigh	5.5 ± 1.5	5.6 ± 2.0	5.4 ± 1.8	5.5 ± 1.7	5.9 ± 1.4
F shank-foot	12.6 ± 2.2	13.1 ± 2.3	12.8 ± 2.3	12.8 ± 2.1	12.7 ± 2.0

Table 5. Peak pressure values (PF, %) (n = 19)

Item	0 cm	3 cm	7 cm	11 cm	15 cm
PF head	84 ± 14.8	83.3 ± 15.9	77.6 ± 16.8	76.7 ± 16.0	76.4 ± 13.6
PF neck	9 ± 4.1	25.1 ± 15.2	32.5 ± 15.4	34.2 ± 18.8	45.4 ± 25.3
PF chest	60.8 ± 18.3	64.4 ± 14.9	68.1 ± 14.7	64.9 ± 18.7	66.5 ± 15.3
PF waist	34.9 ± 16.3	38.4 ± 15.5	37.6 ± 7.9	36.5 ± 10.8	39.9 ± 16.3
PF buttock	66.5 ± 21.5	73.1 ± 20.5	80.7 ± 17.7	83.2 ± 15.7	84.2 ± 14.7
PF thigh	21.1 ± 6.1	22.1 ± 5.5	20.8 ± 4.4	21.8 ± 5.8	22.6 ± 4.8
PF shank-foot	77.7 ± 15.0	80.7 ± 12.9	80 ± 13.3	82.9 ± 13.7	81.8 ± 24.0

Table 6. Pressure intensity values (CP, %) (n = 19)

Item	0 cm	3 cm	7 cm	11 cm	15 cm
CP body	68.2 ± 7.3	70.1 ± 5.9	67.9 ± 6.9	66.7 ± 6.6	65.3 ± 5.5
CP head	82.3 ± 16.8	83.1 ± 13.8	82.4 ± 16.6	84.6 ± 14.9	83.8 ± 15.7
CP neck	26.1 ± 9.0	42.7 ± 13.2	49.3 ± 14.0	47.7 ± 19.5	56.4 ± 22.3
CP chest	79.7 ± 18.5	80.6 ± 12.9	77.1 ± 16.3	73.8 ± 14.0	71.5 ± 12.5
CP waist	53.4 ± 15.3	59.8 ± 13.2	55.0 ± 9.0	58 ± 12.7	58.6 ± 12.6
CP buttock	89.1 ± 12.0	93.4 ± 10.2	93.1 ± 10.3	93.4 ± 9.9	91.2 ± 11.3
CP thigh	35 ± 7.7	35.6 ± 7.0	33.8 ± 4.8	33.3 ± 5.0	35.4 ± 11.4
CP shank-foot	53.7 ± 15.5	54.7 ± 11.3	52.6 ± 10.4	51.7 ± 10.3	50.6 ± 10.6

With the increase in pillow height, F neck and F waist increased while F chest decreased progressively.

With the increase in pillow height, PF neck and PF buttock had an increasing trend while PF head had a decreasing trend. With pillow height less than 3 cm, the body's

Table 7. Standardized peak pressure intensity values in pressure pad test (PCP, %) (n = 19)

Item	0 cm	3 cm	7 cm	11 cm	15 cm
PCP body	100 ± 0.0	100 ± 0.0	99.9 ± 0.3	98.4 ± 6.9	100 ± 0.0
PCP head	83.9 ± 14.8	82.9 ± 16.9	77.1 ± 17.1	75 ± 17.0	76.4 ± 13.5
PCP neck	11.1 ± 3.2	26.9 ± 14.4	33.2 ± 14.3	34.9 ± 18.2	46.0 ± 24.8
PCP chest	60.7 ± 18.4	64.7 ± 14.7	68.8 ± 13.5	63.7 ± 18.2	67.4 ± 15.3
PCP waist	35 ± 16.3	39.7 ± 14.7	39.3 ± 10.1	36.3 ± 11.4	40.1 ± 16.1
PCP buttock	66.4 ± 21.6	72.4 ± 20.2	80.4 ± 17.8	84.1 ± 16.6	84.4 ± 14.6
PCP thigh	21 ± 6.2	22 ± 5.5	20.6 ± 4.5	21.5 ± 5.9	22.5 ± 4.8
PCP shank-foot	77.6 ± 14.9	80.1 ± 13.36	82.1 ± 11.6	80.8 ± 14.0	86.5 ± 16.9

Table 8. Contact area values (CA, %) (n = 19)

Item	0 cm	3 cm	7 cm	11 cm	15 cm
CA head	6.1 ± 1.6	6.4 ± 1.3	6 ± 1.3	6.1 ± 1.6	5.7 ± 1.7
CA neck	1.8 ± 0.6	2.8 ± 1.3	3.6 ± 1.7	3.8 ± 2.2	4.2 ± 1.8
CA chest	31.2 ± 3.3	29.5 ± 3.7	27.4 ± 4.2	27.5 ± 4.5	27.0 ± 4.1
CA waist	8.1 ± 1.8	7.7 ± 1.7	8.2 ± 1.6	8.0 ± 1.6	8.0 ± 1.9
CA buttock	23.8 ± 4.7	22.9 ± 4.8	23.2 ± 5.9	22.3 ± 5.4	22.4 ± 5.3
CA thigh	10.8 ± 2.8	11 ± 3.1	10.8 ± 3.0	10.9 ± 3.0	11.2 ± 2.8
CA shank-foot	16.8 ± 4.0	17.1 ± 2.5	16.6 ± 2.0	16.7 ± 2.0	16.6 ± 1.9

peak pressure appeared in the head; when the pillow was higher than 7 cm, the body's peak pressure appears in the buttocks.

In the supine lying position, the maximum body's pressure intensity appeared in the buttock area; the increase in pillow height, CP neck increased.

With the increase in pillow height, PCP neck increased, PCP head had decrease trend and PCP buttock and PCP shank-foot had increase trend. When the pillow height was less than 3 cm, the peak pressure intensity appeared in the head; when the pillow was higher than 7 cm, the peak pressure intensity appeared in the buttock and shank-foot areas.

With the increase in pillow height, CA neck increased while CA chest decreased.

3.3 Statistical Analysis Results

3.3.1 Pillow Height and Comfort

Table 9 shows the analysis results of correlation between pillow height and subjective comfort evaluation.

According to the results of Spearman rank correlation analysis, the correlation coefficient between pillow height and shoulder comfort was the highest, i.e. -0.517 , which was followed by head and neck comfort, and the correlation coefficient was -0.494 .

Table 9. Spearman rank correlation analysis of pillow height and subjective comfort (n = 19)

Pillow height	Correlation coefficient r	P value
Head and Neck Comfort	−0.494**	0.000
Hip Comfort	−0.284*	0.013
Waist Comfort	−0.304**	0.008
Shoulder Comfort	−0.517**	0.000

*With $p < 0.05$, the correlation was significant.

**With $p < 0.01$, the correlation was significant.

3.3.2 Most Comfortable Pillow Height and Body Measurements

Table 10 shows the analysis results of correlation between the most comfortable pillow height and the body size.

As shown by the correlation analysis results, the most comfortable pillow height and shoulder width was most relevant, in which the shoulder width had correlation coefficient of 0.463 and the correlation coefficient with shoulder width was 0.523.

3.3.3 Difference in Body Pressure Distributions Under Different Pillow Heights

Differences in body pressure distributions under pillow heights of 0 cm, 3 cm, 7 cm, 11 cm and 15 cm were compared with the use of one-way anova, LSD (homogeneity of variance) and Dunnett T3 (heterogeneity of variance) follow-up inspection.

Table 10. Spearman rank correlation analysis of the most comfortable pillow height and the body measurements

Most comfortable pillow height	Correlation coefficient r	P value
Head circumference	0.240	0.323
Side head circumference	0.024	0.921
Front head circumference	0.101	0.681
Neck circumference	0.216	0.374
From unilateral acromion to earlobe	0.259	0.284
Shoulder width	0.463*	0.046
Unilateral shoulder width	0.523*	0.022
Acromion width	0.183	0.454
Maximal shoulder width between double deltoid muscles	0.022	0.929
Height from neck bottom to head top	−0.057	0.816
From occipital bone tuberosity to C7	−0.112	0.649
Full height of head	0.129	0.597
Position of lower mandible point	0.319	0.184
Age	−0.154	0.528
BMI	0.138	0.574
Height	0.272	0.260
Body weight	0.197	0.418

*With $p < 0.05$, the correlation was significant.

Table 11. Pressure values under different pillow heights (N) (n = 19)

	0 cm	3 cm	7 cm	11 cm	15 cm
F body	586.1 ± 136.7	564.7 ± 153.2	569.5 ± 137.2	590.2 ± 164.8	582.4 ± 166.6
F head	40.9 ± 8.5	41.5 ± 11.0	40.2 ± 9.0	43.7 ± 10.0	40.3 ± 9.7
F neck	4.2 ± 2.7 ^{bcd}	10.3 ± 7.7 ^a	15.9 ± 10.3 ^a	19.2 ± 18.0 ^a	21.3 ± 14.3 ^a
F chest	209.5 ± 56.2	195.0 ± 74.3	181.5 ± 69.3	179.5 ± 59.8	172.5 ± 56.7
F waist	38.2 ± 16.0	38.6 ± 17.0	38.6 ± 17.1	41.5 ± 19.2	43.4 ± 21.1
F buttock	180.4 ± 49.7	169.6 ± 51.9	177.8 ± 51.4	184.1 ± 69.5	182.3 ± 66.7
F thigh	31.9 ± 12.3	31.3 ± 12.0	31.1 ± 12.9	32.8 ± 14.9	34.9 ± 13.8
F shank-foot	74.0 ± 22.6	73.3 ± 20.4	72.3 ± 20.3	75.5 ± 24.6	74.0 ± 25.3

Notes:

^aThe difference with absence of pillow (0 cm) was significant ($P < 0.05$);

^bThe difference with Pillow 1 (3 cm) was significant ($P < 0.05$);

^cThe difference with Pillow 2 (7 cm) was significant ($P < 0.05$);

^dThe difference with Pillow 3 (11 cm) was significant ($P < 0.05$);

^eThe difference with Pillow 4 (15 cm) was significant ($P < 0.05$).

The significance indicators of one-way anova were F neck, CA neck, CP neck, CP chest, PF head, PF neck, PCP head and PCP neck (Tables 11, 12, 13, 14 and 15).

Table 12. Peak pressure values under different pillow heights (N) (n = 19)

	0 cm	3 cm	7 cm	11 cm	15 cm
PF body	12.9 ± 5.7	11.2 ± 3.6	10.4 ± 2.6	10.9 ± 3.5	10.5 ± 3.1
PF head	10.4 ± 3.4 ^e	9.3 ± 3.4	7.9 ± 2.0	8.1 ± 1.8	7.7 ± 1.4 ^a
PF neck	1.1 ± 0.8 ^{bcd}	2.5 ± 1.4 ^a	3.2 ± 1.4 ^a	3.6 ± 2.3 ^a	4.4 ± 2.4 ^a
PF chest	7.0 ± 1.3	6.9 ± 1.6	6.9 ± 1.9	6.9 ± 2.3	6.9 ± 2.9
PF waist	4.2 ± 2.0	4.1 ± 1.6	3.9 ± 1.5	3.9 ± 1.4	4.0 ± 1.6
PF buttock	7.8 ± 2.2	7.7 ± 2.0	8.2 ± 2.4	8.9 ± 3.0	8.6 ± 2.0
PF thigh	2.6 ± 1.0	2.4 ± 0.7	2.1 ± 0.6	2.3 ± 0.7	2.3 ± 0.8
PF shank-foot	10.1 ± 5.4	9.0 ± 3.3	8.2 ± 2.2	9.1 ± 3.4	8.7 ± 3.7

Notes:

^aThe difference with absence of pillow (0 cm) was significant ($P < 0.05$);

^bThe difference with Pillow 1 (3 cm) was significant ($P < 0.05$);

^cThe difference with Pillow 2 (7 cm) was significant ($P < 0.05$);

^dThe difference with Pillow 3 (11 cm) was significant ($P < 0.05$);

^eThe difference with Pillow 4 (15 cm) was significant ($P < 0.05$).

The results showed that the pillow height had a significant effect on change in subjects' neck pressure, and the neck pressure increased while the chest pressure had decrease trend with the increase in pillow height.

The pillow height had a significant effect on the peak pressure of neck, and the peak pressure of head had a decrease trend with the increase in peak pressure of neck.

‘With the increase in pillow height, the neck pressure intensity had an increase trend.

When the pillow was higher than 7 cm, the head peak pressure decreased significantly; relative to absence of pillow, the peak neck pressure intensity with pillow

Table 13. Pressure intensity values under different pillow heights (N/cm²) (n = 19)

	0 cm	3 cm	7 cm	11 cm	15 cm
CP body	0.22 ± 0.07	0.19 ± 0.07	0.19 ± 0.05	0.20 ± 0.06	0.19 ± 0.06
CP head	0.28 ± 0.14	0.23 ± 0.08	0.24 ± 0.10	0.25 ± 0.10	0.25 ± 0.10
CP neck	0.09 ± 0.05 ^{cde}	0.12 ± 0.5 ^e	0.14 ± 0.07 ^a	0.14 ± 0.07 ^a	0.16 ± 0.07 ^{ab}
CP chest	0.24 ± 0.05 ^e	0.22 ± 0.04	0.21 ± 0.05	0.21 ± 0.06	0.21 ± 0.06 ^a
CP waist	0.17 ± 0.06	0.16 ± 0.04	0.16 ± 0.04	0.17 ± 0.05	0.17 ± 0.04
CP buttock	0.28 ± 0.07	0.25 ± 0.04	0.26 ± 0.05	0.27 ± 0.06	0.27 ± 0.06
CP thigh	0.12 ± 0.05	0.10 ± 0.03	0.10 ± 0.03	0.10 ± 0.04	0.11 ± 0.05
CP shank-foot	0.19 ± 0.13	0.15 ± 0.05	0.15 ± 0.06	0.16 ± 0.06	0.15 ± 0.07

Notes:

^aThe difference with absence of pillow (0 cm) was significant (P < 0.05);

^bThe difference with Pillow 1 (3 cm) was significant (P < 0.05);

^cThe difference with Pillow 2 (7 cm) was significant (P < 0.05);

^dThe difference with Pillow 3 (11 cm) was significant (P < 0.05);

^eThe difference with Pillow 4 (15 cm) was significant (P < 0.05); the one-way variance analysis of CP chest was not significant.

Table 14. Peak pressure intensity values under different pillow heights (N/cm²) (n = 19)

	0 cm	3 cm	7 cm	11 cm	15 cm
PCP body	1.12 ± 0.50	0.98 ± 0.31	0.91 ± 0.24	0.95 ± 0.31	0.91 ± 0.27
PCP head	0.90 ± 0.29 ^e	0.80 ± 0.29	0.68 ± 0.17	0.70 ± 0.16	0.67 ± 0.12 ^a
PCP neck	0.12 ± 0.06 ^{bcd}	0.24 ± 0.12 ^a	0.29 ± 0.11 ^a	0.32 ± 0.19 ^a	0.39 ± 0.20 ^a
PCP chest	0.60 ± 0.11	0.61 ± 0.15	0.61 ± 0.15	0.60 ± 0.23	0.61 ± 0.25
PCP waist	0.36 ± 0.18	0.37 ± 0.17	0.36 ± 0.14	0.34 ± 0.13	0.35 ± 0.13
PCP buttock	0.68 ± 0.19	0.67 ± 0.18	0.72 ± 0.22	0.82 ± 0.35	0.75 ± 0.18
PCP thigh	0.22 ± 0.09	0.21 ± 0.62	0.18 ± 0.05	0.20 ± 0.06	0.20 ± 0.07
PCP shank-foot	0.88 ± 0.47	0.78 ± 0.28	0.74 ± 0.20	0.79 ± 0.29	0.78 ± 0.28

^aThe difference with absence of pillow (0 cm) was significant (P < 0.05);

^bThe difference with Pillow 1 (3 cm) was significant (P < 0.05);

^cThe difference with Pillow 2 (7 cm) was significant (P < 0.05);

^dThe difference with Pillow 3 (11 cm) was significant (P < 0.05);

^eThe difference with Pillow 4 (15 cm) was significant (P < 0.05).

increased significantly, and with the increase in pillow height; with pillow height of 11 cm, the peak pressure intensity of buttocks was the highest; the peak pressure intensity of shanks and feet was the highest without pillow.

The head contact area and the chest contact area were highest at the pillow height of 3 cm. Buttock contact area reached the maximum at the pillow height of 7 cm. Neck, waist and thigh contact areas had the trend to increase with increasing pillow height. Relative to the absence of pillow, the use of pillow allows a significant increase in neck contact area.

Table 15. Contact area values under different pillow heights (cm²) (n = 19)

	0 cm	3 cm	7 cm	11 cm	15 cm
CA body	2814.4 ± 707.5	3010.0 ± 703.4	3054.9 ± 742.8	3136.1 ± 781.9	3116.1 ± 774.8
CA head	167.9 ± 50.6	189.1 ± 49.1	183.3 ± 60.9	186.3 ± 53.0	174.1 ± 61.7
CA neck	50.2 ± 20.4 ^{bcdde}	86.0 ± 42.9 ^a	111.3 ± 44.6 ^a	122.4 ± 67.0 ^a	129.9 ± 63.5 ^a
CA chest	873.9 ± 237.5	894.3 ± 262.7	846.5 ± 267.5	863.4 ± 256.6	846.8 ± 258.4
CA waist	229.9 ± 79.5	234.2 ± 77.9	246.8 ± 69.8	248.9 ± 77.0	247.7 ± 78.4
CA buttock	643.7 ± 103.0	663.4 ± 120.7	672.8 ± 110.6	668.0 ± 135.0	668.9 ± 135.3
CA thigh	315.9 ± 128.8	339.8 ± 139.7	346.2 ± 151.3	358.3 ± 161.5	360.0 ± 145.9
CA shank-foot	489.8 ± 187.9	519.2 ± 149.2	510.9 ± 146.4	528.3 ± 155.6	519.8 ± 145.2

^aThe difference with absence of pillow (0 cm) was significant (P < 0.05);

^bThe difference with Pillow 1 (3 cm) was significant (P < 0.05);

^cThe difference with Pillow 2 (7 cm) was significant (P < 0.05);

^dThe difference with Pillow 3 (11 cm) was significant (P < 0.05);

^eThe difference with Pillow 4 (15 cm) was significant (P < 0.05).

4 Analysis and Discussion

4.1 Analysis on Test Results of Body Pressure Distribution

As shown by the results of body pressure distribution test, the neck pressure intensity, contact area and force increase with the increase in pillow height, indicating that the force neck is obviously increased and allowing more effective support to the neck. Chest force, contact area and pressure intensity have a decrease trend with the increase in waist force, indicating the pillow height has adjusted the posture of spine and reduced the pressure on mattress caused by chest curvature hypnosis, so that the waist fits mattress better, allowing more supports; with the increase in pillow height, the peak pressure intensity gradually transfers from the head to the lower limbs, i.e. buttocks, shanks and feet, indicating that the higher pillow will lift the upper body and chest, while buttocks and feet play a role in preventing the body from sliding down.

4.2 Analysis on Subjective Comfort Evaluation Results

- (1) There is a significant negative correlation between subjective comfort score and pillow height, and pillow height has the greatest impact on shoulder and head comforts.
- (2) The most comfortable pillow height has a significant correlation with shoulder width.

5 Conclusions and Recommendations

- (1) Conclusion of pressure test: with the increase in pillow high, pressure intensity, contact area and force of neck are increased, while the pillow can support the neck and adjust the spine posture.
- (2) Correlation conclusion: the pillow height has the greatest impact on the comfort of head and shoulders, the subjective score of comfort has a negative correlation with

the pillow height, and the most comfortable pillow height has a significant correlation with shoulder width. The pillow height of 7 cm shall be the pillow height allowing the most comfortable pressure distribution.

- (3) As shown by the results of comprehensive subjective comfort evaluation and body pressure distribution test, the pillow with lying height of 7 cm is the most comfortable one, providing a reference in selection of pillow.

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