RESEARCH ON THE INFLUENCE OF PILLOW MATERIAL ON SLEEPING COMFORT

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ABSTRACT

Introduction: *This research chose seven pillow materials and studied the influence of pillow materials on sleeping comfort which can improve sleep quality during epidemic period.*

Materials and methods: *The pressure distribution was measured and recorded using the Tekscan body pressure measurement system (BPMS). Then subjective comfort evaluation, variance and correlation analysis, and cervical spine positioning point methods were adopted to analyze the influence of pillow core materials on sleeping comfort.*

Results: *In the supine position, the peck pressure was concentrated on the subjects' head spot. When subjects used the memory sponge and latex pillows, the overall contact area was larger, the peck and average pressure was lowest. The overall comfort value of the memory sponge pillow and the latex pillow was high. In lateral position, the peck pressure point in Chinese medicine and buckwheat skin pillows was concentrated on the face; the other material pillows were concentrated on the arm. In the case that the subjects used latex pillow and buckwheat skin pillow, the deformation of the spine was small, and the overall comfort evaluation was high.*

Conclusion: *The subjects had higher comfort value with the use of memory sponge and latex pillow but lower comfort value with the use of Chinese medicine pillow and inflatable pillow in supine position. In the same way, the subjects had higher comfort evaluation of latex and buckwheat-skin pillow in lateral position. Using a buckwheat-skin pillow increased the neck contact area, which could alleviate cervical pain. The study results can guide people with different sleeping habits, posture and with spinal diseases to choose suitable pillow materials.*

Keywords: *Pillow Material, body pressure distribution test, subjective evaluation, sleeping comfort.*

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Introduction

Novel corona-virus pneumonia (COVID-19) related blockade measures has had an important impact on people's daily life, including sleep patterns and sleep quality. For example, lack of sleep, irregular sleep time and late sleep are already becoming to common problems. Pillow is a part of the bedding that functions to support the neck to maintain the cervical spine's standard physiological curve and help people sleep. Pillow performance is an essential factor affecting sleep quality, including pillows' height, length, width, material, and shape. Simultaneously, the pillow performance varies with the individual, such as sleeping posture, weight, and personal habits, so the evaluation index of pillow comfort is also different. The pillow is generally composed of two parts: the pillow core and the pillowcase. The pillow core is the filling material to keep the pillow at a certain height. There is a variety of filling materials on the market, from commonly used chemical fiber, feathers, latex to modern technology production materials such as memory sponge, porous vacuum cotton, slow rebound sponge, and traditional

buckwheat and Chinese medicine, which are widely used in China. The diversity of pillow materials has different hardness, permeability, and elasticity, which greatly influences sleep posture and sleep quality. This experiment chose the chemical fiber, buckwheat-skin, latex, memory sponge, inflatable pillow, Chinese medicine, and pearl cotton as pillow core materials. The body pressure distribution of the head, neck, shoulder, arm, and back was measured with a body pressure distribution instrument when the subjects were lying on different pillows in supine and lateral positions.

After that, the subjects used each pillows in 3 days and completed the subjective comfort evaluation. This paper used variance and correlation analysis, spine positioning point analysis methods to study the effect of pillow core material on sleep comfort in supine and lateral positions.

Research status

Pillow performance includes pillow size, material, and shape. The research on pillow performance is as follows.

Research on pillow material and comfort evaluation method

A Japanese scholar explored the establishment of an objective assessment method for pillow comfort and analyzed the correlation between the subjective rating and the compression deformation rate of the pillow[1]. The Visual Analog Scale (VAS), Sleep Questionnaire, Sickness Impact Profile (SIP) and pillow satisfaction survey methods were used as subjective evaluation method[2].

Person used the test of pillows with different heights and different materials; it is considered that the rigid pillow core material can relieve users' neck pain and discomfort[3]. Susan studied the relationship between pillow material and cervical affection and sleep quality in a lateral lying position. The test used four materials, including polyester fiber, foam, feather, and latex, and the results showed that the latex pillow could relieve cervical affection and improve sleep quality; the feather pillow had a poor effect on cervical affection[4]. Huimin Hu explored the buckwheat pillow at different heights on the body pressure distribution and confirmed that the pillow height has the most significant impact on the comfort of the head and shoulders. The research found that the pillow height of 7cm had the most comfortable pressure distribution[5].

Research on pillow size

Pillow size includes pillow height, pillow length and pillow width. Pillow height is an essential factor affecting sleep comfort. If the pillow is too high, the cervical spine can not maintain the normal curvature, which will not only increase the burden of the cervical spine but also cause stiff neck[6]; If the pillow height is too low, the pillow will cause user head congestion, and the jaw lift upward, which is easy to cause snore[7]. The choice of pillow height was related to shoulder width and the height of the pillow in the supine position should be lower than that in the lateral position[8, 9]. Su Youxin suggested that the height of the pillow should be (15.10±1.67) cm in lateral position by measuring the subject's distance from the face to the acromion[10].

Moreover, this height also can avoid cervical scoliosis and keep the spinous process of cervical, thoracic and lumbar vertebrae in a horizontal line[11]. Huang Jiyan used the photoelastic experiment, three dimensional finite element calculation and two dimensional plane finite element dynamic model calculation methods and found that the lateral sleeper's pillow height should be 14-15cm[12]. Xu Linhai studied the relationship between the size of shoulder width and occipital height by measuring the shoulder zygomatic distance and shoulder width, concluded that the optimal pillow height = 0.167×shoulder width + 4.6 cm[13].

Pillow length is another crucial size for pillows. If the pillow is too short, the pillow cannot support the user's neck when turning over, which will affect the safety and comfort of sleeping. The length of the pillow should be 15cm longer than user shoulder width, which the pillow length of an adult should be between 50-70 cm[14, 15]. The pillow's width affects whether the human head is reasonably supported and the head is stable. Researcher suggested that the pillow width should be more than 30 cm[7, 14].

Research on pillow shape

The different shapes of the pillow will directly affect the user's pressure point and sleep comfort. Shan Junping used investigation and research methods to develop traction pillow and cervical health pillow. The cervical vertebra traction pillow is oval shape which can use the head weight's natural suspension to recover the cervical spine's physiological flexion. The cervical shape pillow can adjust cervical physiological flexion; the concave shape pillow can make patients feel comfortable when using a long time[16]. He Yanmei and his

team selected flat, cubic, S-shaped sleeping pillows and used questionnaires, objective soft hardness, and contact pressure methods and found that the S-shaped pillow was the more comfortable shape among the other three pillow shape[17].

Ph.D.Liu Shuo Fang studied the optimal shape of the pillow based on the analytic hierarchy process (AHP), and four different shape pillows with cotton core were selected in the experiment. The results showed that standard pillow(455x297x110cm), cervical pillow (length 455, cylindrical shape=55), and shoulder pillow (658x238x50cm) had a higher evaluation and overall comfort.

Therefore, the performance of the pillow has an essential impact on sleep comfort. Simultaneously, the pillow comfort test is limited to the pillow's soft hardness, air permeability, and elasticity, but also can judge the needs of different users according to different sleeping habits and preferences based on the pressure distribution and subjective evaluation of users.

Materials and methods

Participants

The experiment selected 20 subjects including 10 male and 10 female, age between 22 to 30, the information of subjects shown in Table 1.

	Test items	Mean (n=20)	Range (n=20)	SD (n=20)
1	Weight (Kg)	53.9	45.2~66.4	8.58
2	Height (cm)	168.2	161.9~175.7	6.04
3	Shoulder width (cm)	37.9	32.2~42.0	7.38

Table 1: The information of subjects.
Note: SD is the standard deviation.

Experimental material

Seven pillowcases of length 50 cm, width 35cm and height 8cm were used in the experiment.

The inner pillowcases were filled with seven materials:

- Chemical fiber;
- Buckwheat skin;
- Latex;
- Memory sponge;
- Inflatable pillow;
- Chinese medicine;
- Pearl cotton.

The height of the filled pillows were 8cm. The information of mattress is shown in Table 2.

Pillow Material	Material Performance
(1) Chemical Fiber	Ordinary man-made fiber pillow core, polyester is the most commonly used synthetic fiber filling which is thin, like silk.
(2) Buckwheat Skin	The natural buckwheat husk is used as the filling material of pillow core which is granular and angular.
(3) Latex	It is made of natural rubber tree juice through a whole physical process, with a large number of honeycomb pores.
(4) Memory Sponge	Polyether polyurethane foam sponge with slow rebound mechanical properties, porous structure and fine fiber.
(5) Inflatable Pillow	It is made of high-grade composite PVC fabric, which is inflated inside.
(6) Chinese Medicine	The pillow filled with traditional Chinese medicine and tea as pillow core material has uneven particles (cassia seed, nocturnal vine, chrysanthemum, green tea, etc.)
(7) Pearl Cotton	The ball shaped cotton is made from polyethylene through special balling technology. The hollow inside of the cotton ball is also called EPE pearl cotton

Table 2: The information of experimental pillows.

Experimental method

The pressure distribution

The pressure distribution was measured and recorded using by the Tekscan body pressure measurement system (BPMS)[18]. Peak pressure and average pressure were calculated based on recorded pressure distribution data[19]. Peak pressure is the maximum pressure on the pillow. Average pressure is the mean value of all pressures on a pillow[20]. In the physical properties of pillow materials, peak pressure and average pressure can reflect the sleeping comfort of subjects, so they are important indicators of sleeping comfort[21].

• Peak pressure is the maximum pressure.

Pm=max(P1, P2, ……, PN) (N=measurement points). (1)

• Average pressure is the mean value of all pressures.

$$Pv = \frac{1}{Np}\sum_{t=1}^{Np} Pt$$

(Np=pressure measurement points) (2)

• Peak pressure gradient is the rate of change of pressure in a certain direction.

Gm=max (gradG1=gradG2.…, gradGN) (N=measurement points) (3)

• Average pressure gradient is the arithmetic mean of the pressure gradient at each pressure point.

$$Gv = \frac{1}{Np}\sum_{t=0}^{Np}(gradGt)$$

(Np=pressure measurement points) (4)

The pressure sensing mat placed on the subjects' head, neck, shoulder and back between experimental pillows. When pressure value was stable, the test was recorded for 30 minutes; each experiment was repeated 3 times.The pressure distribution of subject in supine and lateral positions is shown in Figure 1 and Figure 2.

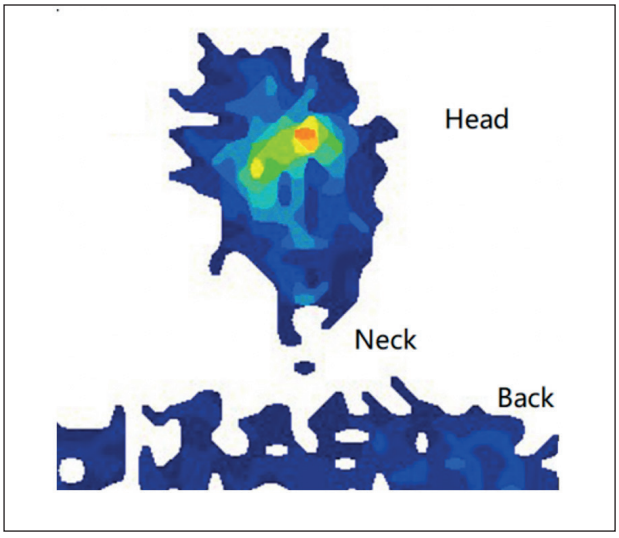

Figure 1: The pressure distribution of subject in supine position.

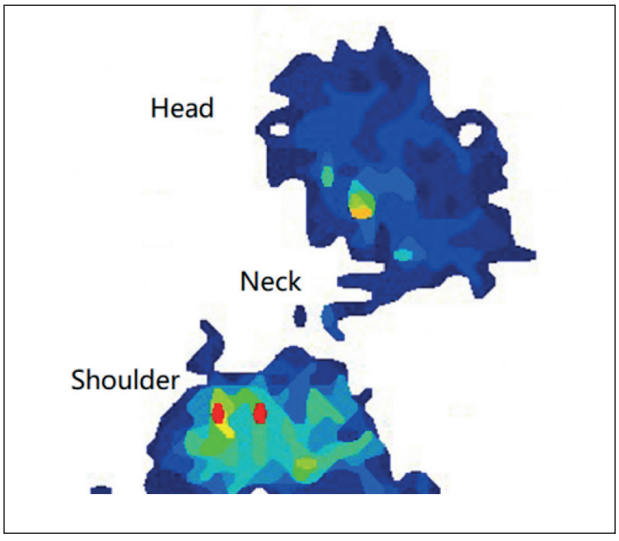

Figure 2: The pressure distribution of subject in lateral position.

The subjective evaluation

After pressure distribution, the subjects used every pillow for 3 days and finished the subjective evaluation which through subjective status and evaluation of each part of body. The subjective evaluation used the Semantic Differential (SD) method which has seven levels of evaluation criteria between +3 and -3 to represent the degree of excitement(22). The subjects evaluated the level according to their subjective feelings. Then the data were analyzed and statistically processed, and various characteristic parameters were obtained, so as to achieve the purpose of quantitative evaluation and analysis of subjective feelings. The standards of subjective evaluation as shown in Table 3.

Part of comfort	Score						
	+3	+2	+1	0	-1	-2	-3
The comfort of head, neck, shoulder, back and overall	Very comfort	Comfort	General	Slight pain	Little pain	Pain	Very pain

Table 3: The standards of subjective evaluation.

The analysis of the curve of the thoracic and cervical spine in lateral position

The human spine has 7 cervical vertebrae, 12 thoracic vertebrae, and 5 lumbar vertebrae. The upper part of the spine is associated with pillow comfort. Because it is difficult to determine the appearance of the spinous process, this experiment used equal distance positioning, every 5cm as a positioning point, a total of 5 key points were located for each subject (23-24). Through the positioning photos to research the trend of the cervical spine curve when subjects in lateral position.

Results

Body pressure distribution

The body pressure distribution experiment data results when subjects in supine and lateral position as shown in Table 4.

This paper put peck pressure, average pressure, contact area, and pressure gradient of different pillow material into a chart to compare the results in supine position as shown in Figure 3, and the results in lateral position as shown in Figure 4. From the Figure 3(a) shown that when the subjects in supine position, the overall peak pressure from the lowest to the highest were (3)latex, (4)memory sponge, (5) inflatable pillow, (1)chemical fiber, (1)pearl cotton, (2)buckwheat skin and (6)Chinese medicine. From the Figure 3(b) shown that the overall average pressure from the lowest to the highest were (4) memory sponge, (3)latex, (1)chemical fiber, (5) inflatable pillow, (7) pearl cotton, (2)buckwheat skin and (6)Chinese medicine.

From the Figure 3(c) shows that the overall contact area had an opposite trend with the average pressure and the peck pressure, indicated that the larger the contact area, the lower the pressure value.

The change of contact area on the neck-back is larger than the head, which means that the change of material has a great influence on the contact area of the neck and back.

The contact area of (5)inflatable pillow was the smallest, the (3)latex and (2)buckwheat skin pillows were the largest, which indicated that (3)latex and (2)buckwheat skin pillow could better support the neck pressure. From the Figure 4(a) (b) (d) shown that when the subjects in lateral position, the trend of the peak/average pressure, peak/average pressure gradient were relatively consistent, and the peak/average pressure of the head and neck shoulder have the opposite trend.

The overall peak pressure from the lowest to the highest are (3)latex, (2)buckwheat skin, (4) memory sponge, (1)chemical fiber, (7)pearl cotton, (5)inflatable pillow and (6)Chinese medicine. The contact area of (4)memory sponge, (2)buckwheat skin and (3)latex were larger and the pressure distribution was uniform.

From the Figure 4(c) shows that except the peck pressure points of (6)Chinese medicine and (2)buckwheat skin pillow were concentrated on the face, the rest of were concentrated on the subjects' shoulders. The subjects' neck contact area larger on (2)buckwheat skin, (3)latex and (7)pearl cotton which the neck was strongly supported and those pillow can relieve the neck muscle fatigue.

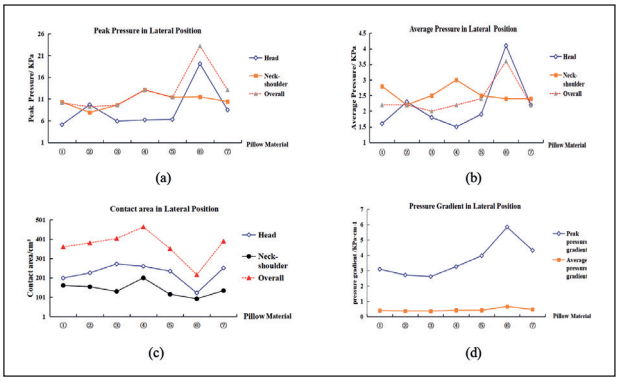

Figure 4: The relationship between the pillow material and the body distribution pressure in lateral position.

		Material of pillow									Material of pillow						
		Supine position									Lateral position						
		(1)	(2)	(3)	(4)	(5)	(6)	(7)			(1)	(2)	(3)	(4)	(5)	(6)	(7)
Head	I	6.8	8.9	4.4	5.5	6.5	23.7	7.6	**Head**	I	5.1	9.7	5.9	6.2	6.3	19.1	8.5
	II	2.0	2.4	1.6	1.6	2.2	4.3	1.9		II	1.6	2.3	1.8	1.5	1.9	4.1	2.2
	III	186	183	217	219	187	166	207		III	200	227	273	261	236	123	252
Neck Back	I	2.6	3.3	4.5	3.4	3.4	7.6	4.2	**Neck Shoulder**	I	10.3	7.9	9.6	13.1	11.4	11.5	10.4
	II	1.1	1.3	1.4	1.1	1.2	1.7	1.4		II	2.8	2.2	2.5	3.0	2.5	2.4	2.4
	III	197	200	209	161	89	144	196		III	162	155	131	201	116	93	135
Overall	I	6.8	8.9	4.9	6.5	6.7	23.8	7.6	**Overall**	I	10.1	9.2	9.6	13.1	11.4	23.2	13.1
	II	1.5	1.8	1.5	1.4	1.6	2.6	1.7		II	2.2	2.2	2.0	2.2	2.4	3.6	2.2
	III	391	375	434	388	310	276	315		III	362	382	405	465	352	217	391
	IV	1.93	2.53	1.73	1.68	1.73	3.35	2.14		IV	3.09	2.71	2.61	3.26	3.97	5.84	4.32
	V	0.22	0.29	0.20	0.25	0.22	0.35	0.21		V	0.39	0.36	0.35	0.41	0.41	0.65	0.46

Table 4: The relationship between pillow material and body pressure distribution.

Note: I: Peck pressure/KPa, II: Average pressure/KPa, III: Contact area/cm², IV: Peak pressure gradient/KPa·cm -1, V:Average pressure gradient/KPa·cm-1.

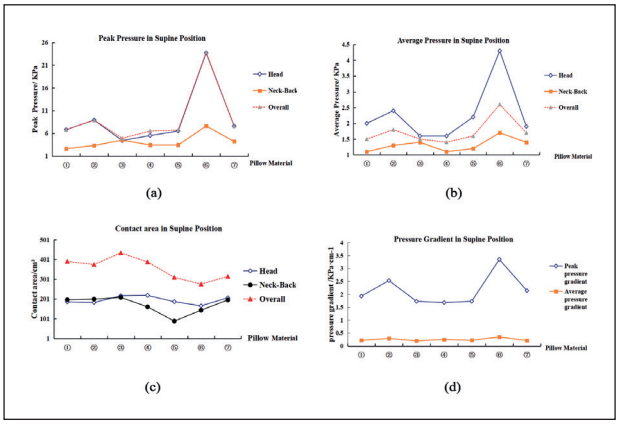

Figure 3: The relationship between the pillow material and the body distribution pressure in supine position.

Subjective evaluation

This paper recorded the subjects' subjective evaluation about the body parts comfort with different pillow materials in supine and lateral position, the parts of body evaluation as shown in Figure 5. From the Figure 5(a) (b) shown that When the subjects used (4)memory sponge and (3) latex pillows in supine position, there had higher evaluation in head, neck, shoulder, back and overall, which indicated that memory sponge pillow and latex pillow have higher comfort for supine position. When the subjects used (2)buckwheat skin pillow, their neck comfort subjective evaluation were higher. The subjects thought that the (6)Chinese medicine and (2)

buckwheat skin pillows had better air permeability but poor elasticity. At the same time, the subjects thought that (3)latex and (4)memory sponge pillows had better air permeability and elasticity.

From the Figure 5(c)(d) shows that when the subjects were in lateral position, the evaluation on (3) latex and (2)buckwheat skin pillows in the neck, arm, and the overall were higher. The subjects thought that the material of (4)memory sponge pillow and (1)chemical fiber pillow were soft, the pressure on the face was less and the face more comfort. The subjects thought that (2)buckwheat skin pillow had better air permeability, the (3)latex, (1)chemical fiber and (4)memory sponge pillows had better elasticity. In the overall evaluation, the subjects had lower evaluation on the (6)Chinese medicine and (5) inflatable pillows, and also thought these pillows had poor air permeability, poor elasticity, and the most uncomfortable overall feeling.

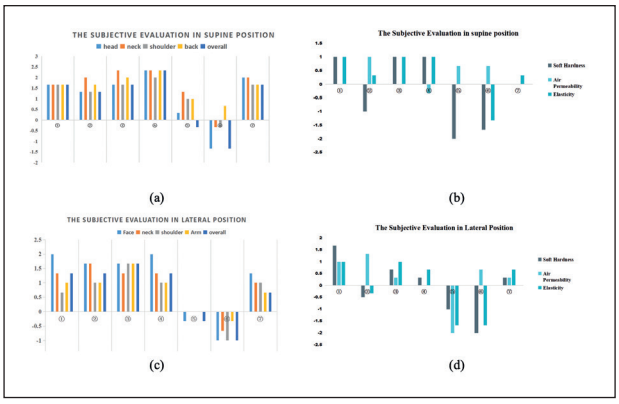

Figure 5: The subjective evaluation in supine and lateral position.

The correlation of subjective and objective

This paper analyzed the correlation of subjective and objective results which used "fuzzy theory", the results are shown in Table 5.

		Head Comfort	Neck Comfort	Shoulder Comfort	Back Comfort	Overall Comfort
In supine position	Peck pressure	-.852*(.015)	-.888**(.008)	-.891**(.007)	-.817*(.025)	-.779*(.039)
	Average pressure	-.868*(.011)	-.915**(.004)	-.925**(.003)	-.855*(.014)	-.810*(.027)
	Contact area	.698(.081)	.881**(.009)	.739(.058)	.833*(.020)	.775*(.041)
		Face Comfort	Neck Comfort	Shoulder Comfort	Arm Comfort	Overall Comfort
In lateral position	Peck pressure	-.780*(.039)	-.732(.061)	-.812*(.027)	-.741(.057)	-.798*(.031)
	Average pressure	-.871*(.011)	-.801*(.030)	-.920**(.003)	-.807*(.028)	-.858*(.013)
	Contact area	.703(.078)	.531(.220)	.717(.070)	.604(.151)	.632(.128)

Table 4: The correlativity of subjective and objective results.
*Note: 1, *α=0.05 **α=0.01.*

There was a significant negative correlation between the subjective evaluation of the comfort of body parts and the overall comfort with the peck pressure and average pressure in the body pressure distribution. The overall comfort and average pressure were extremely significant level, indicating that the average pressure can reflect the sleep comfort.

In order to know the difference between pillow materials, this paper selected the average pressure (n=3) which had the least fluctuation in body pressure index and the highest correlation for variance comparison, the results are shown in Table 6.

Effect	Position	Value	F	Hypothesis df	Error df	Sig.
Pillow	Supine	.997	103.904	6.000	2.000	.010**
Material	Lateral	1.000	16.342	2.424	2.424	.005**

Table 6: The results of variance analysis about average pressure of pillow.

From the Table 6 showed that the F value was 103.904 when the subjects in supine position and the F value was 16.342 when the subjects in lateral position. P = 0.010 < 0.05, which indicated that the F value was significant under the significance level of α= 0.05, indicating that different pillow materials had a significant impact on the pressure value of the subject's body parts.

Analysis of changes of spinal curve in lateral position

Because of the complexity of human cervical vertebra structure, this experiment used the method of locating feature points of the spine which was based on the human bone structure feature points, took the positioning photos and researched the change trend of the cervical spine curve when the subjects in lateral position. Positioning method: There are 7 cervical vertebrae, 12 thoracic vertebrae, and 5 lumbar vertebrae which the upper part of the spine is related to the pillow. This experiment used

equal distance positioning, every 5cm as a positioning point, positioning 5 key points, used this method to measure the curve changes of the upper part of the spine, the spine equal distance position method as shown in Figure 6.

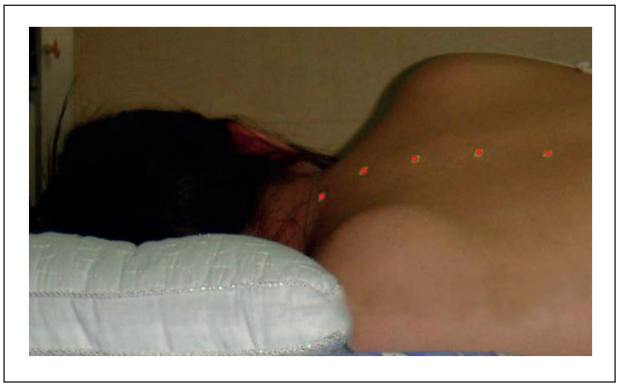

Figure 6: The spine equal distance position method.

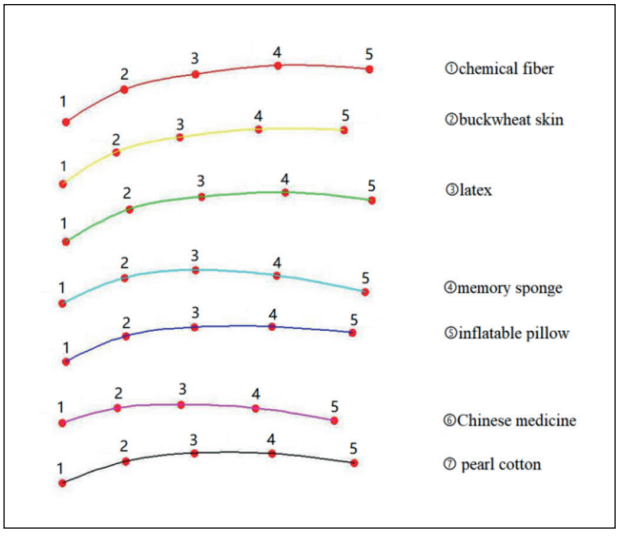

Figure 7: The spine shape in different pillow.

From the Figure 7 showed that when the subject lying in the lateral position, the shape of the spine more closer the horizontal natural state, the compression force inside the spine was the lowest. When subject using the (3)latex, (2)buckwheat skin and (5)inflaTABLE pillows , only location 1 deviated from the horizontal position, other positioning points tended to be horizontal, and the pressure in the spine was the lowest. When the pillow core materials were (4)memory sponge, (6)Chinese medicine and (7)pearl cotton, positioning points 2, 3 and 4 deviated from the horizontal position and bent upward to form a "convex" shape, and the spine had large deformation.

When the pillow core material was (1)chemical fiber, positioning points 2, 3, 4 and 5 all deviated from the horizontal position and bend upward, forming a large angle with the horizontal, forming an upper "/" line shape.

Conclusions

The above results show that: the different pillow material had a great influence on subjects' pressure distribution and subjective comfort evaluation when lying in supine and lateral positions. The correlation between body pressure distribution index and subjective comfort evaluation was consistently. From the pillow material group $P=0.005 < 0.01$, it shown that different pillow materials had a significant impact on the pressure value of the subjects, and the selected materials had significant differences.

Under the condition that subjects were lying in a supine position, the peck pressure was concentrated on the subjects' posterior head spot. When subjects used the memory sponge pillow and the latex pillow, the overall contact area was larger, the pressure was reasonably distributed on the head, neck, and back, and average pressure and peck pressure value were lowest. The evaluation of material properties was in moderate hardness and softness and good elasticity. The overall comfort of the memory sponge pillow and the latex pillow were high.

When the subjects used Chinese medicine pillow and inflatable pillow in supine position, the head and neck's contact area was small, and the pressure was more concentrated. The material's subjective evaluation was hard and poor elasticity, and the overall evaluation was lowest. Under the circumstance that the subjects used the buckwheat skin pillow in a supine position, the neck contact area was more extensive, and the neck got more support. The subjective evaluation of neck comfort was higher, which is the verification of buckwheat skin pillow can alleviate cervical disease. When the subjects were lying in lateral position, the peck pressure point in Chinese medicine pillow and buckwheat skin pillow were concentrated on the face, the other material pillows the peck pressure points were concentrated on the arm.

In the case that the subjects used latex pillow and buckwheat skin pillow in lateral position, the pressure was evenly distributed on the head, neck, shoulder, and arm, and the deformation of the spine was small, and the overall comfort evaluation was high. The neck contact area was large and strongly supported, which can relieve the fatigue of neck muscles. In addition, the latex pillow had higher elasticity evaluation and the buckwheat skin pillow had higher air permeability evaluation.

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