Three-dimensional Representation of Relief Changes on Body Trunk Surface during Abduction of Upper Extremities. An application of the moiré method.

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ABSTRACT The relief changes on the body trunk surface during movement of the upper extremities were studied on a female subject with the aid of moiré contourography. To represent these changes three-dimensionally and quantitatively, the superimposing method of moiré photographs was introduced. A new contour map was obtained which provided information on antero-posterior relief changes on the body surface. Orthomorphic projection charts were also drawn in order to grasp the relief changes at a glance.

Traditional measurements of the human body were linear or one-dimensional such that the distance between two measuring points was measured in a static condition. But the human body comprises irregular, three-dimensional structures which cannot be measured comprehensively with the traditional methods. Recently, three-dimensional measurement of the body form, which is called "biostereometrics" (HERRON 1973), has been introduced with the development of the stereo-camera and other instruments. Photostereo-

metry with the use of the stereo-camera is the most common technique for taking three-dimensional measurements, but it is by no means an easy method since it requires extraordinarily expensive apparatus and a long period of time for the plotting of contour lines.

The moiré method recently developed by TAKASAKI(1970,1971,1972,1973) is a new, simple technique for taking three-dimensional measurements. A few studies with the use of this technique have been reported (HASHIMOTO 1973, MORITA *et al.* 1973, TERADA 1973, TERADA &

Fig. 1. The moiré photographs of frontal view of the trunk. Five figures show the five positions of the upper extremities. The contour interval is 4 mm.

KAMAGAWA 1974). In this technique, the three-dimensional coordinate values x , y and z are obtained on the photograph and the volume and surface area can be measured accurately and inexpensively. This technique is suitable for the measurement of dynamic and continuous changes of the body surface during movement.

The relief changes on the body trunk surface

during movement of the upper extremities are an interesting problem in the field of somatology and human engineering, but a three-dimensional quantitative analysis has never been undertaken. The purpose of this communication is to introduce our trial representation of relief changes on the trunk surface during abduction of the upper extremities.

Fig. 2. The moiré photographs of rear view of the trunk. Five figures show the five positions of the upper extremities. The contour interval is 4 mm.

MATERIALS AND METHODS

The subject was a Japanese woman in good health aged twenty. The moiré photographs were taken in frontal and rear views of the trunk with and without movement of upper extremities. The standard pose was in anatomical position with upper extremities at

sides, palms of hands forward with fingers and thumbs in extension (0° position). Then, the upper extremities were abducted in four steps so that the arms were raised approximately 45° (45° position), horizontally (90° position), about 135° (135° position), and fully upward (180°

Fig. 3. New contour lines (black) showing a linear area with equal relief changes drawn by the superimposing method.

position), respectively. The contour interval was 4 mm. To avoid antero-posterior unsteady wavering of the body during arm abduction, the subject was supported by a metal pole set upright behind her body trunk.

Superimposing method : A photograph of the 45° position was superimposed on that of the 0° position. The points of intersection of two contour stripes with equal stripe number

from the grating were marked. A line connecting these points represents a new contour line which shows a linear area with no relief changes antero-posteriorly after the arm abduction. Then, the points of intersection of a contour stripe and another stripe with the next stripe number were connected, and this line represents an area with relief changes by 4 mm after the abduction of the upper extremities. In this way, the lines showing the relief changes by 4 mm, 8 mm etc. and -4 mm, -8 mm, -12 mm and so on were drawn. The new contour map thus obtained provides information on antero-posterior changes of the body surface after the 45° abduction of the upper extremities. The same procedure was made in photographs of 90°, 135°, and 180° positions superimposed on that of 0° position.

Orthomorphic projection charts : A lattice with 1 cm squares was placed on a moiré photograph enlarged to natural size. The three-dimensional coordinates (x , y , z) were obtained on the intersections of the lattice. Based on these coordinate values, the orthomorphic projection charts viewed from different angles were drawn manually.

RESULTS AND DISCUSSIONS

Superimposing method : (1) Frontal view of the body trunk (Fig. 4). When both arms were raised 45° little change took place in the relief of the body surface; the region of clavicle moved forward slightly. In 90° abduction, upward movement of the breast is clearly

shown. The rising of the lateral abdominal region and the upheaval of the pectoral region due to translocation of the pectoralis major muscle was also seen. The rising of the body surface was more accelerated in the 135° and 180° positions, but no relief changes were seen

Fig. 4. The relief changes of the frontal body surface in the 45°, 90°, 135° and 180° positions of upper extremities compared with the 0° position, represented by the contour lines showing equal relief changes. The contour maps are painted in serial colors simulating the common denotation of geographic maps.

Fig. 5. The relief changes of the back body surface in the 45°, 90°, 135° and 180° positions of upper extremities compared with the 0° position, represented by the contour lines showing equal relief change.

Fig. 6. Orthomorphic projection (left) charts of the thoracic region, showing 0° position of the upper extremities (right) and 180° position.

in the abdominal region through all position.

(2) Rear view of the body trunk (Fig. 5). The surface of the shoulder or suprascapular region was elevated in the process of the upward motion of the arms because of the contraction of the trapezius muscle. The lateral abdominal region was slightly depressed by the relaxation and elongation of the latissimus dorsi muscle. The region along the vertebral column bulged in the process of arm abduction. This suggests changes in the curvature of the vertebral column.

Orthomorphic projection charts: The orthomorphic projection charts of the thoracic region were drawn in 0° and 180° positions (Fig. 6). On these charts the actual form of the body surface can be grasped at a glance. The upward shift of the breast and the pro-

trusion of the costal arches were demonstrated clearly.

The continuous changes of the body surface can be recorded easily with the aid of the moiré apparatus. The quantification of the change is also accomplished by superimposition of two moiré photographs. The method of expression of three-dimensional body form described in this paper would be useful in the field of clothing design, clinical medicine and anthropometry. As for automatic plotting out of the orthomorphic projection charts, the program for the computer has been developed mainly in the field of the architecture and civil engineering. Its application to the biological or medical field (DUNCAN1974) will be rewarded with many good results.

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上肢の挙上運動に伴う生体体幹表面の起伏の変化：モアレ法による変量表現

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上肢の動きに応じて体幹表面の起伏がどのように変化するかは生体学的にも人間工学（特に被服構成学）の面からも興味のある問題であるが、従来この種の3次元的な数量分析は行なわれていない。著者らは20才健康女性を対象とし、上肢を下垂位(0°)、45° 挙上、90° 挙上、135° 挙上、180° 挙上の各位置に外転運動させて体幹の前面観と後面観のモアレ縞写真を撮影した。これら各運動位置の写真をそれぞれ上肢下垂位の写真と重ね合わせて、各等高線の交点を一定の方法で結ぶことにより、体表の起伏の変化を示す等変形線図を描出することを試みた。

この等変形線図は上肢の運動による体幹各部位の標高の変化を定量的に表現している。すなわち胸部では上肢45° 挙上まではほとんど変化が見られないが、90° 以上に上肢を挙上すると乳房が上方へずれるので、乳房がもとあった部位は最大30～40mmくぼむ。また逆に乳房がずれてきた上方の

部位は20～30mm隆起する。もちろんこれらの起伏量の変化には大胸筋の移動による影響が加わっているはずである。なお肋骨弓に相当する部位も180° 挙上では10～20mm隆起することがわかった。背部では上肢の挙上に伴い、肩甲骨の移動のためと思われる起伏の変化のほかに、肩に近い上方の部位がいちじるしく隆起し（僧帽筋の収縮）、腰部にかけて次第に起伏量を減ずる等変形線図が得られた。これらの等変形線図に一定の標高差ごとに地図で用いられるような色を塗ると、運動に伴う体表の起伏の変化が一目で理解される。

また、各モアレ写真に一定間隔の方眼の網目をかけ、各方眼の交点の直交座標値 x 、 y 、 z 、を求めると背部・胸腹部を任意の角度から見た等角投影図を描くことができる。この図示法は運動による体表の起伏の変化を直感的に把握するのに適している。