MOIRÉ-BIOSTEREOMETRICS IN THE CASE OF PREGNANCY

G.E.Karras
Laboratory of Photogrammetry,
National Technical University, Athens, Greece
COMMISSION V

Abstract

Local changes in the geometry of the human body during pregnancy may be grasped anthropometrically using the moiré fringe method. The diverse requirements of this particular biostereometric task, which calls for procedures adapted to the characteristics of various body parts, are discussed in this paper.

Introduction

Gains in total weight, amounting to 50 lb or more and partly retained after child-birth, "reshape" spectacularly the external body surface during pregnancy. The abdominal area is not the exclusive site of these changes. Hytten (1954) has thus reported breast enlargements up to 165%; the "average" thighs gain 10% to 20% while more than 1 kg of fat is stored there; in the buttocks striking variations are also observed. There are a variety of important clinical reasons why these changes should be grasped quantitatively (Tympanidis and Karras, 1982).

Curiously enough, these tremendous variations in size and shape have not been viewed hitherto from a photogrammetric angle. Put schematically, the usual question confronting the photogrammetrist is: how to achieve a desired accuracy in measuring a given object? The peculiarity of biostereometrics lies precisely in the fact that the objects are seldom "given".

Incorrect posing, to start with, may produce contour patterns which are not directly comparable. In the case of moiré topography, furthermore, these patterns are not generated after photography; they are actually recorded on the image during the exposure. This, and the scarcity of natural "control" points, render the conventional procedure of absolute orientation impracticable. But even correct posing may be damaged by body posture, particularly during pregnancy (the subject balances the weight of the abdomen by adapting its posture). Posture is related to shape; patterns may be thus obtained which are neither directly nor indirectly comparable: they simply correspond to "different" bodies. On the other hand, the exact limits of body segments are not always naturally defined. Reliably reproducible boundaries must be established if comparable results are to be obtained. In the absence of appropriate natural detail points the definition of body segments, affected by posing and posture, may prove rather complicated.

The above questions definitely fall within the scope of the photogrammetrist since they may well undermine the actual reliability of an, otherwise precise, photogrammetric measurement. It is in this context that the present paper, extending the initial remarks of Karras and Tympanidis (1983), discusses this novel application of moiré-monophotogrammetry.

Moiré Photography

The geometric principle of shadow-moiré topography is schematically illustrated in Fig. 1. Our set-up consists of a vertical linear grating (p_o=2 mm); a 6x9 cm^2 Mamiya camera with a 100 mm lens; and a light source on either side of, and at distances d from, the camera. Lens and light sources are equidistant (L) from the grating. This geometry generates dark and light fringes on the surface of the object which define non-equally spaced vertical planes, parallel to the grating. Successive fringes are

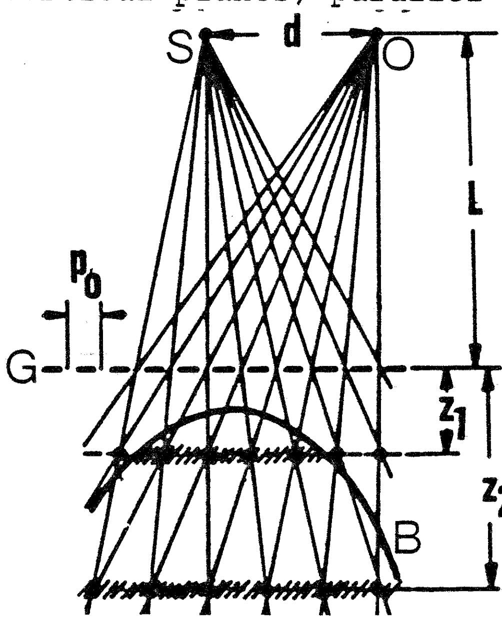

Figure 1. *The geometric principle of shadow-moiré topography (after H. Takasaki). If the shadow a grating G casts on an object B, when illuminated by a point light source S, is photographed through a lens O, moiré fringes are recorded on the film. If S and O are equidistant from the grating, the fringe of order N (1,2,..) represents a plane parallel to the grating at distance z(N) from it, z(N) being a non-linear function of N. Hence, the fringes are not equally spaced in depth.*

$$z(N) = \frac{Np_0L}{d - Np_0}$$

assigned successive orders N and hence define depths z(N) and Z(N)=L+z(N) from the grating and the lens, respectively. These fringes on the surface represent contour-lines. From the x,y image coordinates of a point lying on the Nth fringe its object space coordinates X,Y,Z can be calculated.

In the present case the mean depth interval of successive fringes is 5.5 mm. The mean photographic scale is 1:12. Measurements are made on enlarged prints. For further matters regarding photography reference is made to Petsa et al. (1982). With this set-up frontal, side-view and rear-view moiré photographs are taken in the third, sixth, ninth month of pregnancy and 45 days post partum, and used for measurements of the abdomen, the buttocks, the breasts and the thighs.

Data Reduction

A digitizer-computer system is employed for measurements and calculations. As each fringe is being digitized, its rectangular coordinates x_i, y_i are transformed in a six-parameter mode; scaled to life as X_i, Y_i; and, consequently, corrected from the effect of central projection. The program further calculates fringe length and included surface area. End products are the total surface area and the volume of the body segment in question. The sign of the slope defined by successive fringes of a certain moiré pattern may be either negative or positive. In the present case, however, all concentric fringes represent "hills"; thanks to this property of the body segments studied the computer program is considerably simplified.

The accuracy of volumetric and planimetric calculations from moiré photographs has been assessed by Petsa et al. (1982) using well-defined artificial objects. Standard deviations of 0.2% to 0.4% have been found to describe the repeatability of measurements. Regarding accuracy in the strict sense, the standard errors reported did not exceed 1% (individual measurements all differed by less than 1.5% from the "true" values). In the present application the precision obviously remains the same; the objects, however, are neither artificial and rigid nor unambiguously defined.

The Abdominal Area

Shape and Relief

In the course of pregnancy the abdomen tends to acquire an almost hemispheric shape. Its variations in relief are such that, towards the ninth month, the lower and lateral parts of the abdominal area become practically flat (Fig. 2), and, in position for frontal photography, they may be almost perpendicular to the grating and the film plane. This is aggravated by central projection if the abdomen is centrally photographed. Accordingly, fringes are often resolved only with great effort; even worse, they may be virtually overlapped as strikingly illustrated in Fig. 2. This problem evidently depends upon the individual body characteristics.

Raising of the hands upwards, a movement followed by the abdomen, helps reveal the lower abdominal area (cf. Fig. 3). This movement is eventually accompanied by changes in shape, relief and posture: only moiré patterns corresponding to identical position of the hands are comparable. Lowering of the camera is a further step towards better fringe visibility (cf. Fig. 3).

Fringe resolution at the sides may be improved by translating the subject itself (our system moves only in the vertical sense) alternately revealing the one side and further obscuring the other. Only half of the abdomen can be measured from such images

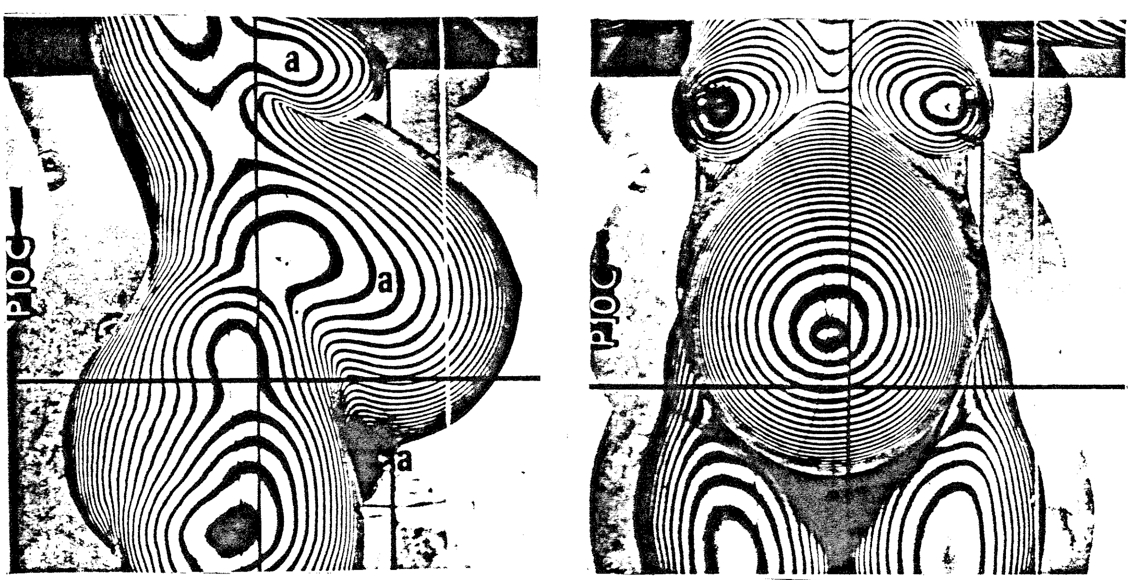

Figure 2. *The body areas denoted by* a *are often almost flat (left); frontally photographed, they are nearly perpendicular to the film plane (right).*

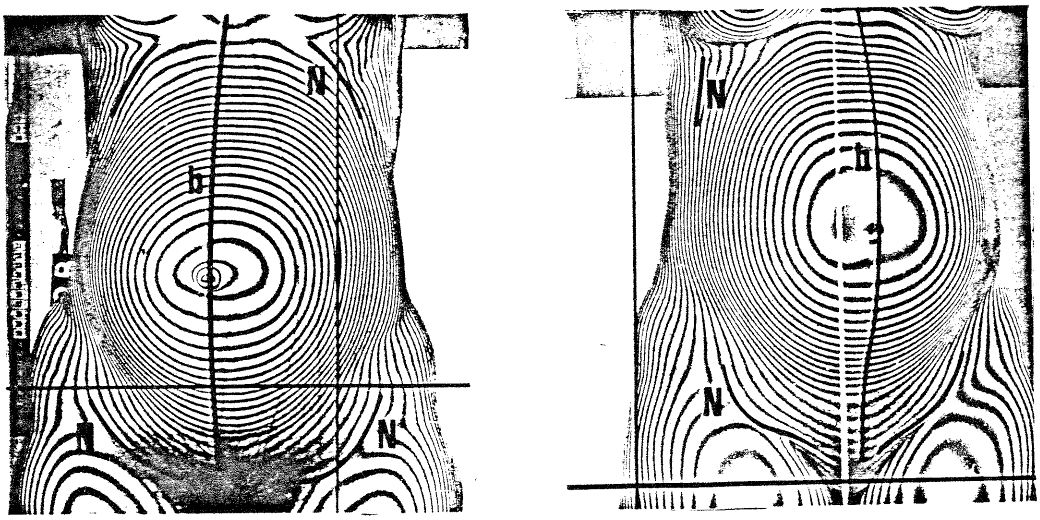

Figure 3. *Frontal photography of two subjects in the sixth (left) and the ninth month of pregnancy (right) with lowered camera. The subjects, with hands raised upwards, have been translated. The abdomen is divided in two parts through central cross-sectioning (b). The average fringe (N) of the two fringes through the inguinocrural furrows provides the vertical datum.*

using the vertical cross-section through the navel. This curve-shaped cross-section is constructed graphically on the prints by calculating its x image coordinates as $x_i=Xc/Z_i$, whereby X is the object space coordinate of the navel (Fig. 3). Due to asymmetries, both halves of the abdominal area should be measured separately and added. Translation must be free of tilts.

Definition of Body Segment

As regards the definition of its boundaries in space, the concept "abdomen" is somehow vague. One must therefore define, more or less arbitrarily but reproducibly, body segments which allow the estimation of net gains and losses, though not strictly comparable from subject to subject. To this end two planes, one horizontal defining the upper limit and one vertical providing the datum plane, are necessary.

The horizontal plane can be determined analytically. One may select a fixed natural detail point, calculate its Y_j coordinate in the "geodetic" system of the jth photograph, and employ, for all photographs, the same height difference ΔY in order to define the plane $Y_{\bar{j}}=Y_j+\Delta Y$. The intersection of this plane with the body, to which it has the same relative position on all photographs, can be again constructed graphically on the prints from its coordinates y_{ij} (Fig. 4).

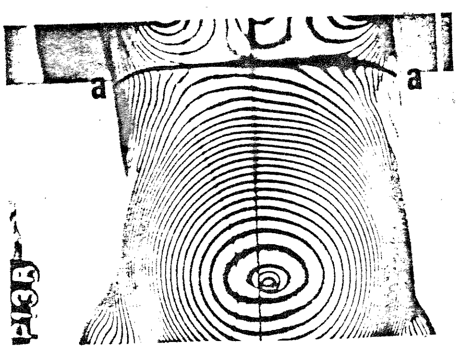

Figure 4. *Intersection of body and the horizontal plane which provides the upper limit of the abdominal segment. The plane should be tangential to lower breast area.*

The navel cannot be used as a fixed natural detail point owing to its downward movement with respect to the skeleton in the course of pregnancy. The top of the sternum is a point both recognizable on the images and pertaining to the skeletal structure; however, it is affected by posture. If the latter is controlled, the above procedure may be followed. Alternatively, one may identify (and actually premark) a point of the sternum and use, throughout, the plane through it. Regardless of its definition, the horizontal plane must be selected in a position neither too low to exclude variations in the abdominal area nor too high to interfere with the breasts; it should run tangentially, so to speak, to the lower breast area (cf. Fig. 4).

The vertical datum plane may be provided by the fringe through the inguinocrural furrows, areas almost flat and parallel to the grating (cf. Fig.3). The repeatability of this definition has been checked by photographing 20 subjects, each positioned five times. The depth differences between the right and the left furrows gave standard deviations ranging from 2 to 6 mm (0.6 and 1.7° in agular terms). The estimated overall standard deviation, which describes the repeatability of posing, was 1.1° or 3.8 mm (i.e. 2/3 of a fringe).

Besides posing, however, this definition is also dependent upon body asymmetries, and natural pelvic tilt in particular. Drerup (1982), using 90 subjects, has reported a pelvic tilt described by $0.3^{\circ}\pm2.7^{\circ}$. In the present case the result was $0.6^{\circ}\pm2.4^{\circ}$. As expected in view of the scatter, the normal pelvic tilt of the majority of subjects repeatedly photographed was statistically different from zero. Hence, different fringes may pass through the two inguinocrural furrows. The problem caused by random as well as systematic pelvic tilt is met by selecting the average fringe as the datum plane of measurements (Fig. 3; cf. Fig. 6). The behaviour of pelvic tilt was practically identical in all phases of pregnancy.

The repeatability of measurements

The above procedure has been checked by repeatedly calculating the volume of the abdomen. In the third month and 45 days after delivery the repeatability of calculations, i.e. the precision of the whole procedure described up to now, was found to be no worse than 2-3%. This value decreases as the volume increases: in the ninth month it is not expected to exceed 1.0 to 1.5%.

The actual accuracy of the measurements, however, is a somewhat different question. The true values are obviously neither known nor easy to obtain, e.g. by water-displacement techniques. Thus, accurate measurements simply mean comparable measurements, separated by time spans of three months. Body posture, as distinct from posing, is crucial in this respect.

Body Posture

Posture in fact refers to the spine. The repeatability of positioning was again checked, this time using the depth differences between the right inguinocrural furrow and the top of the sternum. The overall standard deviation was estimated as 11 mm or 1.5°. This value, however, overestimates the uncertainty in reproducing posture since it refers simultaneously to photographs taken with the hands of the subject stretched both sidewards

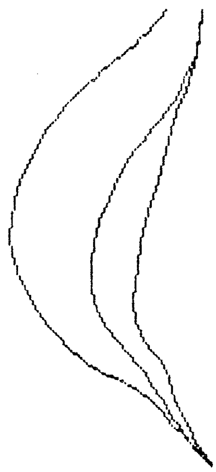

Figure 5. *Central vertical cross-sections through the navel in the third, sixth and ninth month of pregnancy. In the last case the subject has over-corrected its posture by leaning forward: the calculated volume will not be comparable.*

and upwards, a movement affecting the clavicle.

As already noted, the subject alters its posture during pregnancy; in fact it leans backwards. Consequently, the above differences vary inacceptably in the course of pregnancy if current "normal" postures are retained. The initial assumption of Karras and Tympanidis (1983) that posture may be reproduced by careful positioning is rather overoptimistic: it does not actually prevent posture from being either under-corrected or over-corrected (an exaggerated exapmle is given in Fig. 5).

Changes in posture, apart from deforming the moiré pattern, also mean that different volumes are measured in different phases of pregnancy. In order to control them, the difference in depth between one of the inguinocrural furrows and the middle of the sternum (or its top) is kept constant. This is done by measuring the distances of these points from the grating in the third month and adjusting them accordingly at each photographic session. Provided that posing ensures changes in pelvic tilt of an order not higher than the one given above (otherwise the remaining inguinocrural furrow should also be controlled), the procedure described in fact fixes three non-collinear points practically pertaining to the skeletal structure. Thus, "absolute" orientation of the body, regarded now as rigid, is reproduced before exposure.

The Buttocks

Changes in the buttocks, an issue apparently neglected up to now, may be remarkably big. The experimental results reported by Tympanidis and Karras (1982) showed gains up to 40%; 60% to 80% of these were still there one and a half month later.

The buttocks, not being rigorously defined as segment, present difficulties similar to those of the abdomen. The fringe through the coccyx, the only natural detail point of the area, cannot provide the necessary datum since a considerable portion of the buttocks would be then excluded. The use of a fringe passing

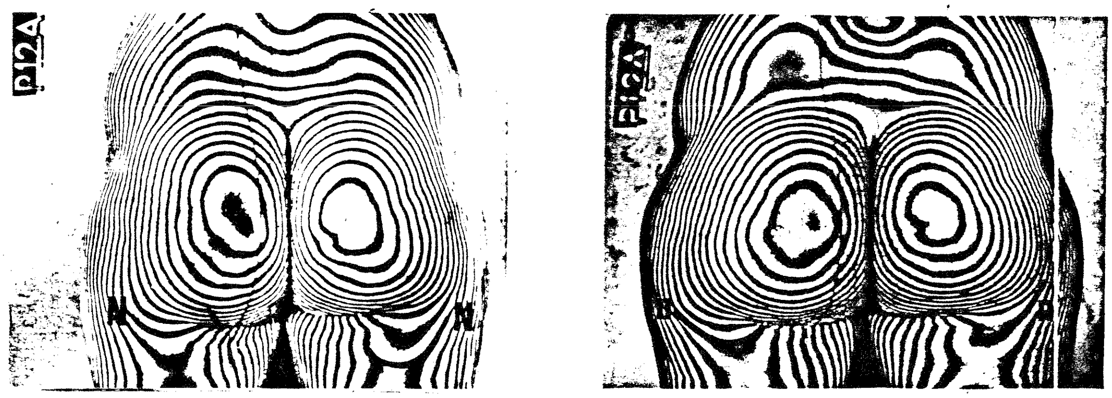

Figure 6. *Photographs of the buttocks of the same subject in the third month of pregnancy (left) and 45 days after delivery (right) showing considerable changes. The average fringe through the gluteal folds provides the datum plane (N and n, respectively).*

at a constant depth from the coccyx, on the other hand, presupposes unchanged body posture. Since, however, the back-view photographs are also used to detect changes in posture, it has been refrained from adding a new photograph to an already long series, and the subject is allowed to retain its posture. Instead, the fringe through the gluteal furrows is employed as the vertical datum in a way similar to that of the inguinocrural furrows (Fig. 6). The upper limit is provided by a horizontal plane through a point of the waist (or at a standard height from the coccyx). This cross-section, being in the vincinity of the image x-axis, appears as a straight line. The repeatability of measurements has not been assessed.

The Thighs

The thighs are the most problematic body part, as far as measurement is concerned, since they cannot be wholly recorded on a single image. Karras et al. (1982) have presented a simple method for leg volume determination: the leg is considered as a succession of truncated cones, the diameters of which are determined from scaled leg-diameter measurements on frontal and side-view moiré photographs. The differences of volumes thus calculated from those obtained from direct anthropometric measurements of leg circumferences of 36 subjects gave a zero mean and a standard deviation of 1.7% (the direct anthropometric approach has been validated against water-displacement techniques by other authors). The accuracy is slightly better for the thighs. Gains in the size of the thighs may be estimated by this method.

The Breasts

Pregnancy enlargement of the breast (cf. Fig. 7) has been studied quantitatively by Hytten (1954) with a water-displacement technique: a special construction was used, the frame of which was intended to fit the "average" breast; an error of 5% was reported.

Regarding the problems in breast measurement reference is made to Tympanidis and Karras (1984). Suffice it to mention here that, as in the case of the abdomen, the main sites of diffi-

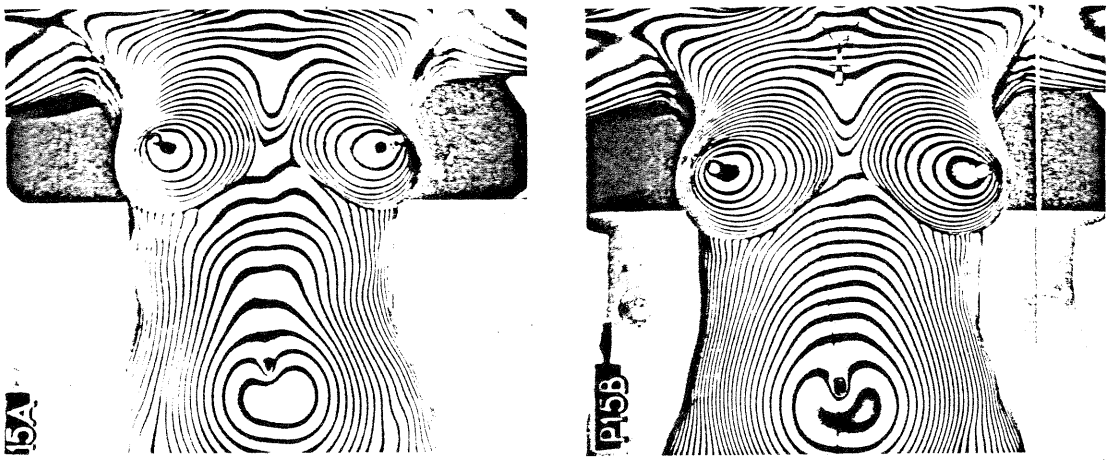

Figure 7. *Central photography of breasts in the third (left) and the sixth month of pregnancy (right) revealing considerable enlargement as well as asymmetry.*

culty are the lower and outer areas (Fig. 7; cf. Fig. 2). If the subjects are photographed in a standing position, raising of the hands and lowering of the camera reveal the lower area in most cases. Translation of the subject towards the edges of the photographic field helps reveal the outer parts. It is advisable, nonetheless, that the subject be photographed in a slightly tilted position. In exceptional cases (not all that rare if the patient is already a mother) the breast may be "drawn" upwards with adhesive tape.

According to Hytten (1954), the definition of the posterior surface, i.e. the chest wall underlying the breast, presents difficulties. It should be ensured that this surface, if not true to life, is at least constant for all poses of the same subject. Hence, the outline of the breast area should be identified in advance, premarked, and used as the plane of reference. The latter is neither parallel to the grating, if the subject is tilted, nor necessarily vertical; instead, it is recorded on the image. The two breasts are very often non-symmetrical (cf. Fig. 7). Each breast should be measured separately.

Concluding Remarks

The present paper, far from suggesting a finished procedure (the more so as this application is both in its initial stage and probably unique in its diversity of requirements), has considered possible solutions to the problems facing the medical specialist as well as the photogrammetrist. The lively discussion going on (see e.g. Moreland et al., 1981) shows that several questions concerning the measurement of three-dimensional non-rigid bodies with curved surfaces are still open. However, a few closing remarks may be briefly made here.

The x,y image coordinates (N being in fact the third "image" coordinate) can be used, if appropriately transformed, for plotting the moiré pattern in an orthogonal projection x′,y′. All cross-sections discussed will then appear as straight lines. The procedure may be considerably simplified, therefore, if the program is modified to intersect fringes expressed in terms of orthogonal projection with lines of the type x' (or y')= constant.

The versatility of 3-d digital coordinates can be further exploited towards an analytical representation by reconstructing body surfaces in a point to point fashion (Drerup, 1981; Windischbauer, 1981). This approach has obvious advantages: above all, it may produce results which are independant of particular positionings. In addition, planes defining body segments could then be expressed analytically, if reliably reproduced, and intersected with the model, thus allowing 3-d measurement in a purely analytical mode.

Despite the above alternative, however, several problems discussed here remain: the fact, for instance, that the peculiar geometry of the object does not always allow its measurement from single images. The definition (and its reliability) of segments is to a certain extent independant of the particular mode of data reduction. An analytical model reconstruction, finally, applies to rigid bodies; body posture must be therefore controlled in vivo.

Acknowledgement. The valuable collaboration of K.N.Tympanidis, M.D., and Eleni P.Petsa is readily acknowledged.

References

Drerup B.(1981). A procedure for the numerical analysis of moiré topograms. *Photogrammetria,* 36:41-49.

Drerup B.(1982). Die Bestimmung des Kyphosenwinkels aus der berührungslosen Rückenvermessung. *Z. Orthop.,* 120:64-70.

Hytten F.E.(1954). Clinical and chemical studies in human lactation (VI). *British Medical Journal,* April 17, pp. 912-915.

Hytten F.E., Taggart N.(1967). Limb volumes in pregnancy. *J. Obstet. Gynaec. Brit. Cwlth.,* 74:663-668.

Karras G.E., Petsa E.P., Tympanidis K.N.(1982). Lower limb measurements using moiré photography. *Int. Arch. Phot.,* 24(5):261-271.

Karras G.E., Tympanidis K.N.(1983). Studying abdomen size and shape variations during pregnancy: an application of moiré topography. In: R.E.Herron (ed.), *Biostereometrics '82,* Proc. SPIE 361, pp. 89-91.

Moreland M.S., Pope M.H., Armstrong G.W.D.-eds.(1981). *Moiré Topography and Spinal Deformity,* Pergamon Press, N.York.

Petsa E.P., Karras G.E., Badekas J.(1982). Assessing the accuracy of moiré topography measurements. *Int. Arch. Phot.,* 24(5):367-376.

Tympanidis K.N., Karras G.E.(1982). Partial body surface area and volume measurements during pregnancy using moiré fringe topography. *10th World Congr. Obstet. Gynaec.,* S. Fransisco, USA, October 17-22.

Tympanidis K.N., Karras G.E.(1984). A non-contact approach of variations in breast geometry during pregnancy. *Int. Congr. Series,* vol. 631, Elsevier, Amsterdam. (In print.)

Windischbauer G.(1981). Moiré-contourography - Recommendation for standardization criteria based on computer aided modelling. In: *Moire Fringe Topography and Spinal Deformity, op. cit.,* pp. 244-8.