Anthropometric Measurements from Photographic Images

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Abstract. Traditionally, anthropometric measurements are taken on a person in a standard posture. With the proliferation of e-commerce, it has become necessary to gather anthropometric data more efficiently. This study proposes a means to obtain anthropometric measurements from photographic images. A case study with respect to online apparel retailing has been presented. The method can be extended for any part of the body for custom-made items such as shoes or helmets. The system was tested for ten measurements with 20 male subjects who were also manually measured. Two experimenters "measured" the 20 subjects using the computerized system and the results were then compared with the manual measures. The ANOVA showed significant differences ($p < 0.05$) between the two methods for three of the ten measures. The differences can be attributed to an inability to see some of the critical locations when digitizing and the mathematical formulations used to obtain circumferences. Reliability was assessed using conventional as well as the generalizable approaches and these showed that intra-tester reliability was higher than the inter-tester reliability. Further investigations may be required to verify the external validity of the findings.

Keywords. Anthropometry, Body measurement, Made-to-measure, Imaging.

1. Introduction

Anthropometry still plays an important role in the design of products and equipment. The traditional means of obtaining measurements involve an experimenter measuring a person at critical locations in a standardized posture. With the rapid development of information technology worldwide, the internet has been used for selling various products to customers, locally and internationally. Hence, it becomes necessary to be able to obtain critical measurements of a person through electronic means with non-invasive methods in order to be able to customize or even mass-customize products. Some such products include footwear, helmets and clothing. This paper is an attempt to illustrate how measurements may be obtained using photographic images. Jupiter Research (2003) predicted online holiday retail sales in 2003 to be $17 billion, a 21% increase over online consumer spending in the previous year. However, the online footwear and apparel sales are far behind others such as books and CDs, due to the uncertainties of correct sizing, difficulties with product evaluation (for example color, texture, finish) and security issues in relation to payment (Beck, 2000).

In general, a majority of manufacturers and designers in the footwear as well as the garment industry do not use the same set of body measurements. Even though there are size labels, the uniformity of the size is still questionable due to various design features in a product. Most custom-made products evolved from measurements on a person that were then translated into hand made patterns and hand cut fabrics, for which the customer paid a high price.

Meunier and Yin (2000) proposed an anthropometric measurement system that can generate body measurements from two-dimensional images. Their system comprised two synchronized cameras that captured two views and image processing software. The system was evaluated by comparing the measurements with six tape measures (neck circumference, chest circumference, hip circumference, waist circumference, stature, sleeve length) on a number of persons, and they concluded that the manual techniques could be replaced with their system. However, Meunier and Yin (2000) reported, “linear measurements were more precise than circumferences, and neck circumference was more repeatable than other circumferences”. Even though such a system can be built and placed at customer centers in different cities, it may not be very cost-effective. The objective of this paper is to show the effectiveness of a simpler and cheaper system.

2. Methodology

2.1. Participants

Twenty (20) Hong Kong Chinese males between the ages of 20 and 38 years with a mean age of 24.15 years participated in the experiment. Their heights ranged from 161cm to 180cm and the weights ranged from 46 to 86kg. All participants were briefed about the nature of the experiment and were asked to fill a voluntary consent form at the beginning.

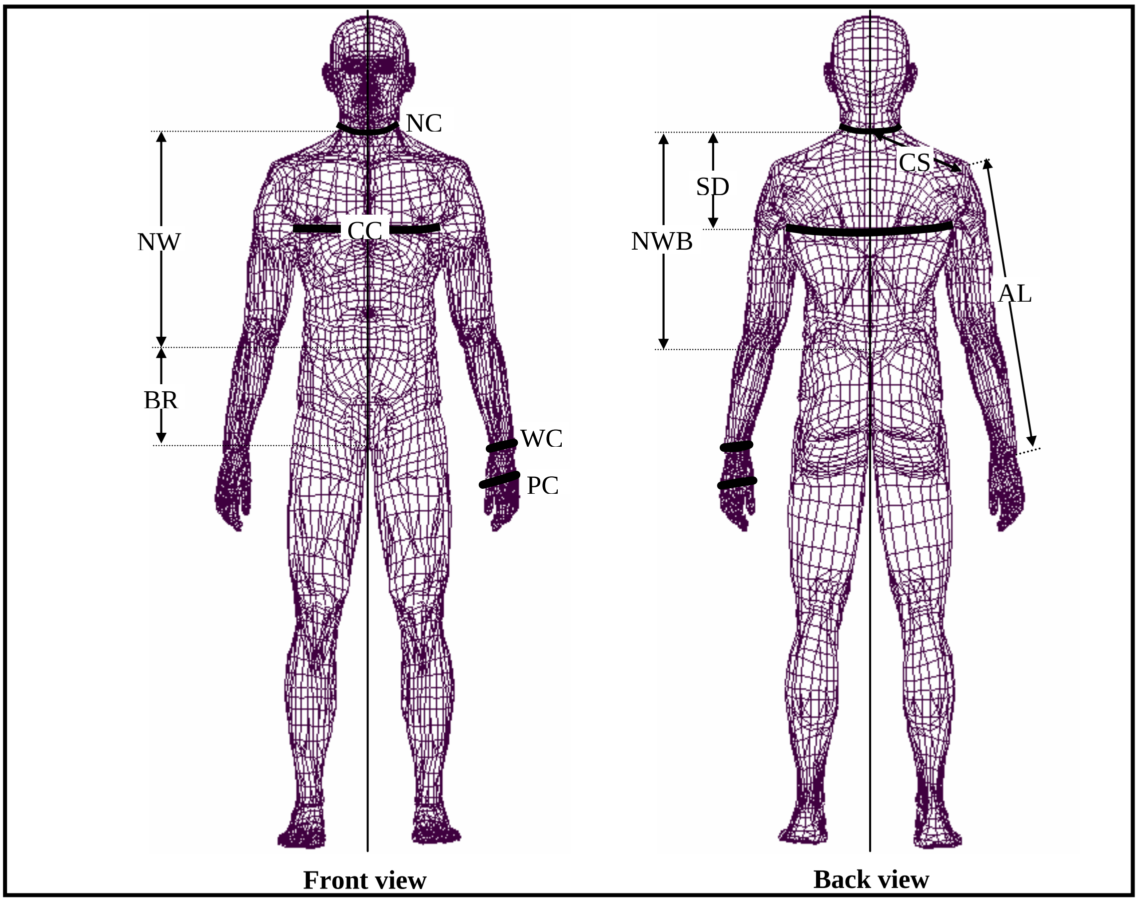

Figure 1. Anthropometric dimensions and associated abbreviations

2.2. Anthropometric dimensions and abbreviations

Six linear and four circumferential measurements were obtained (Figure 1 and Table 1). Arm Length, Neck Circumference, Chest Circumference and Palm Circumference have been recorded in Yoon and Radwin (1994), Meunier and Yin (2000) and Protopsaltou, Luible, Arevalo and Magnenat-Thalmann (2002). Furthermore, Aldrich (1990) and Taylor and Shoben (1990) have used Scye Depth (SD), Body Rise (BR) and Nape to Waist Center Back (NWB) measurements in shirt making. In addition to all these, Neck front to Waist (NW), Cross Shoulder over neck (CS) and Palm circumference (PC) were measured.

Table 1. Measured body dimensions

Measurement	**Dimension**	Abbreviation
Linear	Neck front to Waist	**NW**
	Nape -Waist Center Back	**NWB**
	Scye Depth	**SD**
	Cross Shoulder over Neck	**CS**
	Arm Length	**AL**
	Body Rise	**BR**
Circumference	Chest Circumference	**CC**
	Neck Circumference	**NC**
	Wrist Circumference	**WC**
	Palm Circumference	**PC**

2.3. Procedure

2.3.1. Manual measurements

All participants were manually measured using a conventional cloth tape that had 1mm precision.

2.3.2. 2D Image based measurements

The image-based system was designed to transform 2D digitizations into linear and circumference anthropometric measurements. A Visual Basic (VB) program was coded specifically for this process. The workflow is shown in Figure 2.

A Canon IXUS color digital camera (1600 x 1200 pixels) was used to capture the front view, back view and side view of a person. Each digital image was captured with a 15 cm x 15 cm black calibration square that had 3 mm thick white lines (Figure 2). This square was used to scale the image in order to obtain the actual dimensions using the following equation:

$$\frac{15\text{ cm}}{\text{Length of one side of square in image}} = \frac{\text{Actual dimension}}{\text{Length in image}} \quad (1)$$

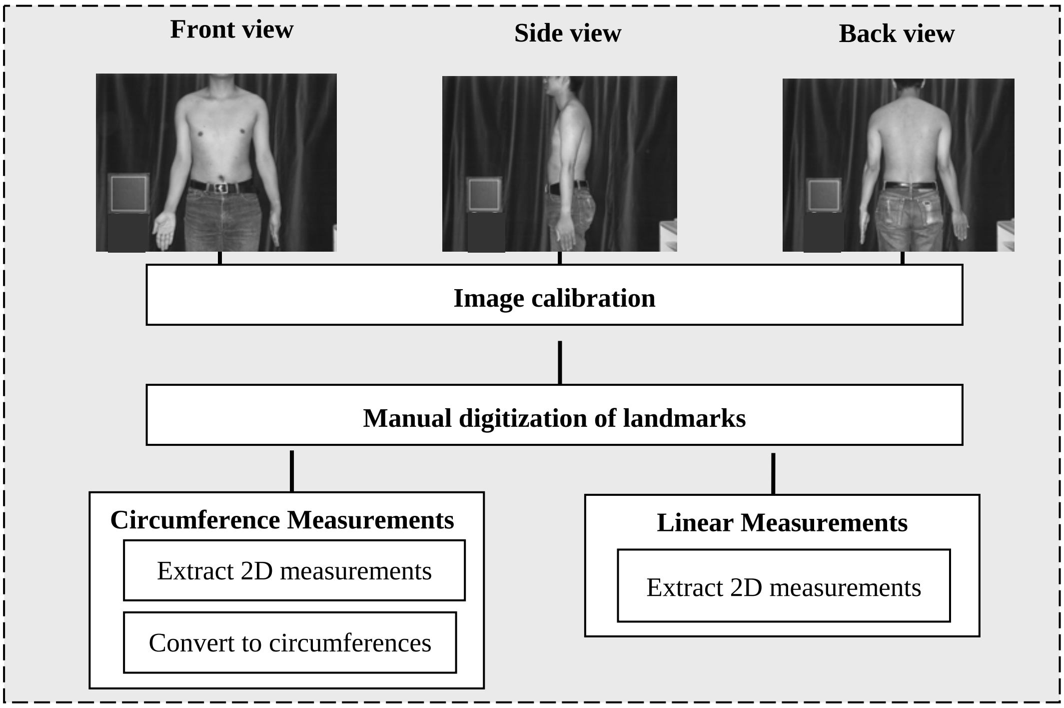

Figure 2. Work flow of the image-based system

After the calibration, each image was digitized to get the point-to-point Euclidian distances. The circumferential measures were generated by approximating the shape of the respective body part. For example, neck circumference was estimated using an ellipse (Figure 3). The major and minor axes lengths of the neck were obtained from the front and side views.

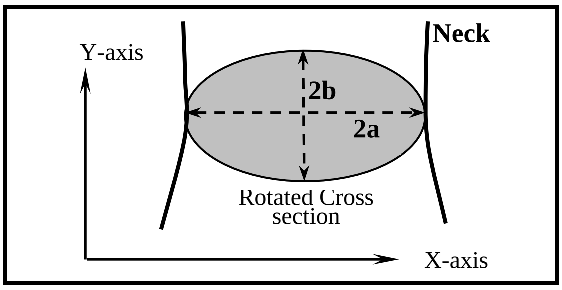

Figure 3. Approximate neck shape on transverse plane.

If the ellipse is represented as:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \quad \text{with } a>b \qquad (2)$$

where *a* is the major radius (2a is the width of neck in front view), and *b* is the minor radius (2b is the width of the neck in the side view), then the perimeter (P) of the ellipse (or the neck circumference, NC) can be calculated as:

$$\text{NC} = \text{P} \cong \pi[(3a+3b) - \sqrt{(a+3b)(3a+b)}] \qquad (3)$$

WC and PC were also approximated with the elliptical shapes. The chest circumference (CC) was determined by approximating the shape as a combination of a rectangle and an ellipse (figure 4). The chest circumference was calculated as (2a + 2b + P/2).

In order to investigate the reliability of the system, measurements were taken by two independent experimenters. Each of the experimenters obtained each measurement three times (three repetitions).

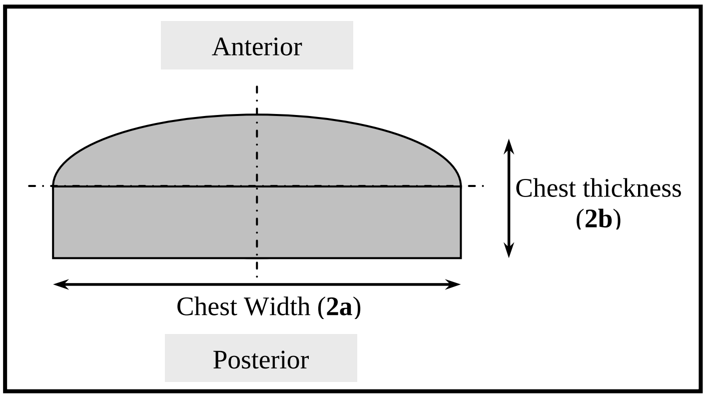

Figure 4. Shape for calculating chest circumference

3. Results

All analyses were performed using the SAS software. The mean, minimum, maximum and standard deviation for the manual, as well as the image-based system, are shown in Table 2.

Each image was 1600 x 1200 pixels. The calibration square of 15 x 15cm was on average of size 192.85 x 193.98 pixels (SD = 19.14 x 19.21 pixels due to focus differences) and hence each pixel corresponds to approximately 0.78 mm. Thus, variations in the digitized points will give an error depending on the discrepancy between the digitized point and the actual point. For example, circumferential measurements can vary within a range of 2.06 mm to 3.15 mm as a result of one pixel deviation from actual.

Table 2. Descriptive Statistics of the different measurements for the 20 subjects.
Exp. 1 and Exp. 2 are the two-experimenter measurements using the image-based system.

Measurement	**Method**	**Mean**	**Std. Dev**	**Min**	**Max**
Neck front to Waist (NW):	Manual 2D Image based *(Exp. 1, Exp. 2)*	45.97 47.12 *(46.31, 47.93)*	4.19 4.17 *(3.84, 4.35)*	38.10 38.74 *(39.12, 38.74)*	54.50 56.93 *(54.43, 56.93)*
Nape to Waist Center Back (NWB):	Manual 2D Image based *(Exp. 1, Exp. 2)*	48.19 48.19 *(46.91, 49.48)*	3.53 3.98 *(3.52, 4.01)*	40.00 39.88 *(39.88, 39.90)*	57.50 57.36 *(57.24, 57.36)*
Scye Depth (SD):	Manual 2D Image based *(Exp. 1, Exp. 2)*	21.07 21.92 *(20.01, 23.85)*	1.89 2.70 *(1.79, 2.00)*	18.50 15.84 *(15.84, 19.98)*	24.60 28.60 *(23.89, 28.60)*
Cross Shoulder over Neck (CS):	Manual 2D Image based *(Exp. 1, Exp. 2)*	21.93 22.61 *(21.91, 23.30)*	1.49 1.66 *(1.27, 1.72)*	19.00 18.23 *(18.23, 20.43)*	24.80 27.34 *(24.51, 27.34)*
Arm Length (AL):	Manual 2D Image based *(Exp. 1, Exp. 2)*	55.92 54.72 *(54.90, 54.55)*	2.98 3.31 *(3.30, 3.33)*	50.80 46.27 *(48.70, 46.27)*	61.30 62.64 *(62.64, 61.95)*
Body Rise (BR):	Manual 2D Image based *(Exp. 1, Exp. 2)*	24.22 27.19 *(26.02, 28.39)*	1.44 2.57 *(1.90, 2.59)*	22.00 21.49 *(21.49, 22.20)*	27.50 34.78 *(33.14, 34.78)*
Chest Circumference (CC):	Manual 2D Image based *(Exp. 1, Exp. 2)*	86.48 89.86 *(88.30, 91.41)*	4.99 5.76 *(5.34, 5.79)*	78.00 77.02 *(77.02, 82.84)*	97.20 102.56 *(100.49, 102.56)*
Neck Circumference (NC):	Manual 2D Image based *(Exp. 1, Exp. 2)*	35.78 34.58 *(34.33, 34.82)*	1.71 2.01 *(2.21, 1.77)*	32.40 29.41 *(29.41, 29.98)*	38.70 39.04 *(39.04, 37.72)*
Wrist Circumference (WC):	Manual 2D Image based *(Exp. 1, Exp. 2)*	15.61 15.79 *(15.21, 16.37)*	1.00 1.29 *(1.12, 1.19)*	13.30 12.70 *(12.70, 13.34)*	16.80 19.38 *(17.70, 19.38)*
Palm Circumference (PC):	Manual 2D Image based *(Exp. 1, Exp. 2)*	23.38 23.79 *(24.40, 23.18)*	1.48 2.05 *(2.05, 1.89)*	19.70 18.34 *(19.33, 18.34)*	25.80 28.54 *(28.54, 26.55)*

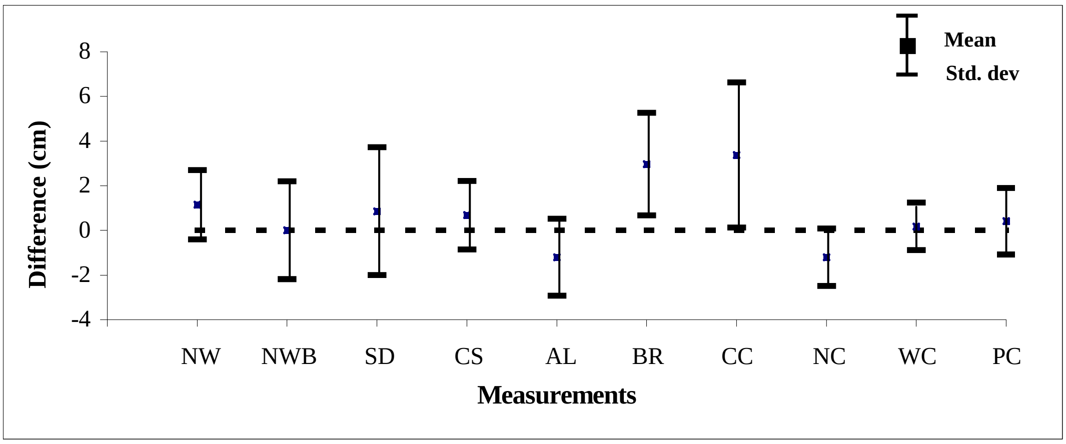

Figure 5. Mean and standard deviation of difference between manual and image-based methods of each measurement for all subjects

The ANOVA showed significant differences ($p < 0.05$) between the manual measurement and the image-based measurement for BR ($F_{(1,138)} = 25.73$; p = <0.0001), CC ($F_{(1,138)} = 6.10$; p = <0.0147), and NC ($F_{(1,138)} = 6.40$; p = <0.0125). The difference (or "error") between the image based measurement and the actual measurement was calculated for each of the ten measurements of every subject. The mean error and standard deviations are shown in figure 5.

Reliability is quantified in anthropometric studies using the Technical Error of Measurement (TEM), (Lohman, Roche, and Martorell, 1988) and calculated as,

$$TEM = \sqrt{\frac{\sum_{i=1}^{N}\left[\sum_{j=1}^{K} x_j^2 - \left(\sum_{j=1}^{K} x_j\right)^2\right]_i}{N(K-1)}} \qquad (4)$$

where x_j^2 - squared value of the j^{th} replicate ($j=1,2,\ldots,K$) and N is the number of participants.

The Coefficient of Reliability (R) is then calculated as:

$$R = 1 - \left(\frac{TEM^2}{s^2}\right) \qquad (5)$$

where, s^2 is the sample variance

The more generalizable approach to reliability uses Intraclass Correlation Coefficients (ICC) (Shrout and Fleiss, 1979). ICC(2,1) is used when all participants are measured by the same experimenters who are assumed to be a random subset of all possible experimenters (SAS, 2004). Hence Cronbach α, ICC(2,1), and the reliability calculated using TEM are presented in Table 3.

4. Discussion

The statistical analyses showed significant differences between the two methods for Body Rise (BR), Chest Circumference (CC), and Neck Circumference (NC). The differences in the body rise (BR) measurement may be due to digitizing an incorrect point. BR corresponds to the distance from waist to a point on the groin. With colored clothing, the color contrast may not be ideal and thereby errors can accrue. On the other hand, the differences in the chest (CC) and neck (NC) circumferences may be due to the fitted shapes or the manual digitization, as the maximum distances in the lateral as well as anterior-posterior directions have to be located. Since the acceptable value for Cronbach alpha is around 0.8 (Nunnally, 1978), it can be seen that SD, BR, and PC show relatively low inter-tester reliability. The low alpha value for SD can be attributed to the difficulty of locating a reliable point on the chest. The intraclass correlations (Shrout and Fleiss, 1979) are a more general form of reliability coefficients. In this experiment, two experimenters digitized the images of the same twenty subjects. Since the two experimenters were a sample from a larger population, and since each experimenter digitized each participant, ICC(2,1) is appropriate for this study. As there were two experimenters, it is not surprising that the intra-tester reliability is larger than the inter-tester reliability for all measurements. ICC(2,1) shows that experimenter 1 was relatively less reliable (< 0.8) for the measurements, SD, CS, BR, NC, WC, and PC while experimenter 2 shows relatively less reliability (< 0.8) for SD and AL. It should be noted that both experimenters may not have reached their plateau on the learning curve and hence training and experience may play a role with respect to the accuracy and reliability of the measures.

Physical measurements can have different sources of error. These include errors due to landmark identification, differences in the orientation and positioning of the instrument, and variations in applied pressure between instrument and the body (Davenport, Steggerda and Drager, 1935). In comparison, the potential sources of error for the 2D image-based measurement system are related to the difficulty of identifying the body landmarks, shape quantifications and calibration. Adequate training on the system and better knowledge of the different body shapes can improve some of the location difficulties. Incorporating different formulations to correspond with the different somatotypes (Winter, 1990) of any population may also increase the accuracy of the circumferential measures. It is important that the calibration square be correctly positioned in order to eliminate any parallax errors (Roebuck, 1995).

Even though the system does have some weaknesses, it is hoped that further improvements can be made to this relatively simple system to improve the reliability and accuracy of the measurements. With the use of such a system, customers will be able to provide the required information to a custom manufacturer such as a tailor, very quickly and efficiently without his or her physical presence. Measurements from photographs can be an extremely interesting alternative, as this would allow businesses to globalize, especially with respect to the sale of customized products. More research may be needed to determine the exact customer preferences and the elicitation of customer needs prior to implementing a full-scale business-to-consumer system.

5. Conclusions

Online apparel merchandising has been somewhat impeded by the high percentage of unsatisfied online customers due to sizing related issues. The results of this study show that linear and circumferential measurements can be obtained using an image-based system within a certain accuracy and reliability. The measurement ‘quality’ seems to depend for the most part on the proper identification of anatomical landmarks and the characterization of body shape. Further investigation may be required to verify the external validity of the findings.

Table 3. Inter and intra-tester reliability for image-based measurements

Measure	Inter-tester reliability			Intra-tester reliability					
				Experimenter 1			Experimenter 2		
	R (TEM)	ICC(2,1)	Cronbach α	R (TEM)	ICC(2,1)	Cronbach α	R (TEM)	ICC(2,1)	Cronbach α
NW	0.86	0.87	0.96	0.94	0.94	0.98	0.97	0.97	0.99
NWB	0.64	0.68	0.91	0.80	0.82	0.96	0.97	0.97	0.99
SD	-0.53	-0.02	-0.12	0.54	0.58	0.91	0.54	0.55	0.79
CS	0.40	0.49	0.82	0.68	0.69	0.86	0.88	0.89	0.96
AL	0.78	0.78	0.88	0.86	0.87	0.98	0.74	0.75	0.90
BR	0.16	0.31	0.64	0.49	0.50	0.77	0.79	0.80	0.92
CC	0.74	0.76	0.94	0.87	0.87	0.96	0.99	0.99	1.00
NC	0.74	0.74	0.87	0.68	0.70	0.95	0.95	0.95	0.99
WC	0.39	0.49	0.85	0.61	0.62	0.83	0.86	0.86	0.95
PC	0.37	0.42	0.66	0.57	0.58	0.81	0.86	0.86	0.95
NW	0.86	0.87	0.96	0.94	0.94	0.98	0.97	0.97	0.99

6. Acknowledgement

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