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The feasibility of measuring three-dimensional facial morphology in children

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Structured Abstract

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Objective – An investigation to determine the feasibility of measuring soft tissue morphology in children using a three-dimensional laser-scanning device.

Design – Prospective clinical trial.

Setting and Sample Population – University of Wales, College of Medicine and one secondary school in the South Wales region. Sixty live subjects (30 adults, 30 children) were recruited in the study.

Experimental Variables – Laser scanned images of the subjects were obtained under a reproducible and controlled environment with two Minolta Vivid 900 (Osaka, Japan) optical laser-scanning devices assembled as a stereo-pair. A set of left and right scanned images was taken for each subject and each scan took an average of 2.5 s. These scanned images were processed and merged to form a composite three-dimensional soft tissue reproduction of the subjects using commercially available reverse modelling software.

Outcome Measure – The shell deviations between left and right scan of each patient were recorded and analysed for differences. These differences determined whether the subjects could remain still during the time of the scans.

Results – The results showed that the mean differences between shell deviations for the adult scans and children scans were 0.25 ± 0.09 and 0.30 ± 0.09 mm, respectively. Paired *t*-tests showed that the mean error between subject groups was 0.05 ± 0.15 mm indicating that there was no difference between the two subject groups ($p = 0.18$).

Conclusion – The technique as described is clinically reproducible for children and adults and can be used for

studies assessing facial changes due to growth or clinical intervention.

Key words: three-dimensions; laser scanning; children; prospective trial; feasibility; facial morphology

Introduction

Three-dimensional laser scanning is a useful tool in the study of facial morphology. The scanning process is non-invasive and normally completed within a few seconds. These systems have been used to evaluate the effects of growth and surgical and non-surgical treatment procedures in the facial region (1–4).

Advancement in technology has meant that these laser-scanning devices are now smaller and can be assembled in any location for studies on facial morphology. This, however, requires the systems to be carefully evaluated and validated before use in field settings. Previous studies have reported on the validity and high accuracy of the Minolta 700 and 900 scanners and found them to be accurate to the level of 1.9 ± 0.8 mm (4) and 1.1 ± 0.3 mm (5). Other studies by the authors show that the Minolta 900 is accurate to a level of 0.56 ± 0.25 mm and the error in computerized registration of left and right scans is 0.13 ± 0.18 mm (6).

Most validation studies use adults to verify their systems (1, 7, 8). No study has compared the differences in the quality of laser scans obtained from adults and children. This step is important as children behave differently to adults in front of a laser-scanning device. For example, they may be less compliant to instructions given. Therefore, trying to keep them still enough to obtain a good laser scan can be challenging.

This study was carried out prospectively to determine the changes that occur when obtaining a set of laser scans from children and adults and was used to determine if children could be suitable subjects for the study of facial morphology using a laser-scanning technique.

Subjects and methods

Subjects

Thirty adults and thirty children were selected to participate in this study. The adults consisting of 15 males

and 15 females, with a mean age of 28.4 years, and all of whom had given prior consent, were recruited at the University Dental Hospital of Wales, College of Medicine.

The children consisting also of 15 males and 15 females, with a mean age of 11.6 years, were recruited as part of a growth study for which ethical approval had previously been sort. Approval for the study was obtained from the Directors of Education, Headteachers, school committees and the relevant ethics committee. In addition, positive written consent was obtained for the child to be included in the growth study.

Three-dimensional imaging system

The laser scanning system consisting of two high-resolution Minolta Vivid VI900 3D (Osaka, Japan) cameras, with a reported manufacturing accuracy of 0.3 mm, operating as a stereo-pair, was used. Each of these cameras emits an eye safe Class I laser (FDA) $\lambda = 690$ nm at 30 mW with an object to scanner distance of 600–2500 mm and a fast mode scan time of 0.3 s. The system uses a one-half-frame transfer charged couple device (CCD) and can acquire 307 000 data points. The scanner's output data is 640×480 pixels for three-dimensional and red, green and blue (RGB) colour data. Data was recorded on a desktop workstation with a 2 GHz Pentium 4 processor. For surface registration, a Minolta medium range lens with focal length of 14.5 mm was used. The scanners were placed at a distance of 1350 mm from the head frame (Fig. 1). The scanners were controlled with Multi-scanTM software (cebas Computer GmbH, Eppelheim, Germany) and data coordinates were saved in a vivid file format (vvd). Information was transferred to a reverse modelling software package RapidformTM 2004 (INUS Technology Inc., Seoul, South Korea) – RF4 for analysis. This software provides nine different three-dimensional work activities and together allows high quality polygon meshes, accurate freeform Non-Uniform Rationale B-Spline (NURBS) surfaces and geometrically perfect solid models to be created. RF4

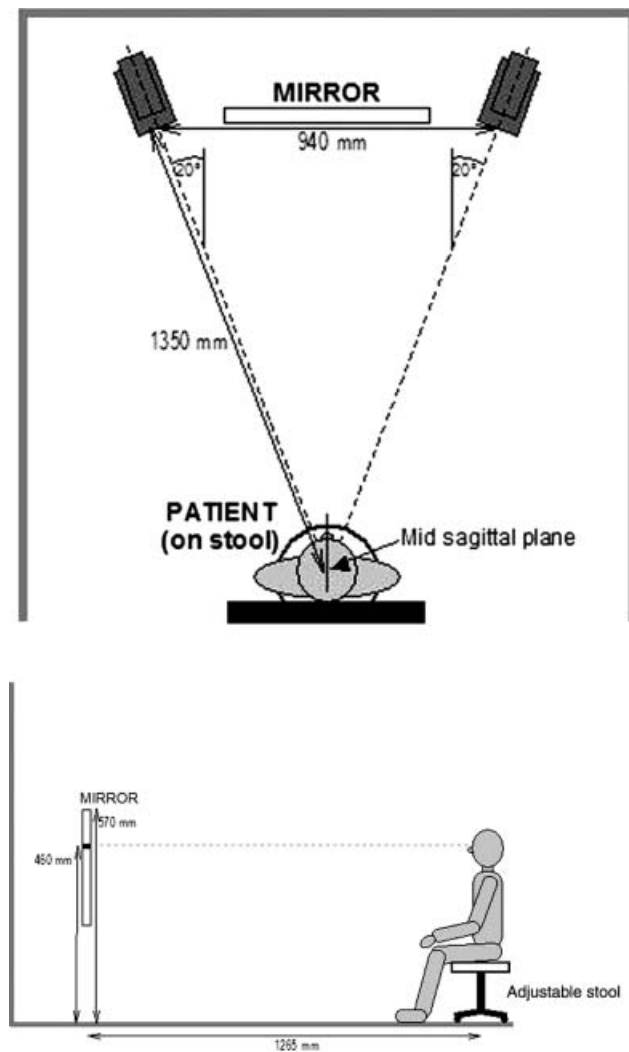


Fig. 1. Camera set-up and patient positioning.

generates data as absolute mean shell deviations, standard deviations (SD) of the errors during shell overlaps, maximum and minimum range maps, histogram plots and finally colour maps. All linear measurements were made in millimetres.

Data capture technique

A custom made portable studio facilitated standardized light conditions. The studio was sufficiently compact to fit into a corner of a classroom or medical room without difficulty and house all the necessary equipment. Natural Head Posture (NHP) was adopted for this study as this has been shown to be clinically reproducible (9).

The subjects sat on a self-adjustable stool and were asked to look into a mirror with standard horizontal and vertical lines simulating a cross-marked on it.

They were asked to level their eyes to the horizontal line and the midline of the face was aligned to the vertical line. Adjustments to seating heights were made to assist the subjects in achieving NHP. The subjects were also instructed to swallow hard and to keep their jaws in a relaxed position just before the scans were taken. The total scan time was approximately 7.5 s. If it was perceived that the subjects moved between scans, the procedure was repeated. One raw data set, comprising one left and right laser scan, was taken of each subject.

Data processing of left and right facial scans

Extraneous data was removed by an in house developed software sub-routine (10), which took 30 s to complete. This automatic and systematic process further reduced the scanned images into shells and identified those small shells that represented minor scanning distortions. These images were smoothed out, while preserving all shape and volume, and the left and right scans were aligned to one another based on the areas of overlap of the faces. The pre-merged scans were carefully checked individually and unwanted areas that could not be automatically removed were done so manually by dividing the unwanted areas from the main shell before proceeding to the next stage. Finally, one whole face was generated for each subject (Fig. 2).

Tolerance levels

To obtain a fuller clinical picture, coloured face maps were generated to determine the patterns within the face where the error was considered to be high. Tolerance levels were set for mean shell deviations at levels corresponding to 0.3, 0.5 and 0.75 mm.

Statistical analyses

Within RF4, a shell-to-shell deviation map is computed and automatically produced. The results include the maximum and minimum range of shell deviations, the average distance between the two shells and the standard deviation (SD). This function was used to statistically analyse the means shell deviations and SD for left and right pre-merged scans. Any subject who had large differences between the two shells was

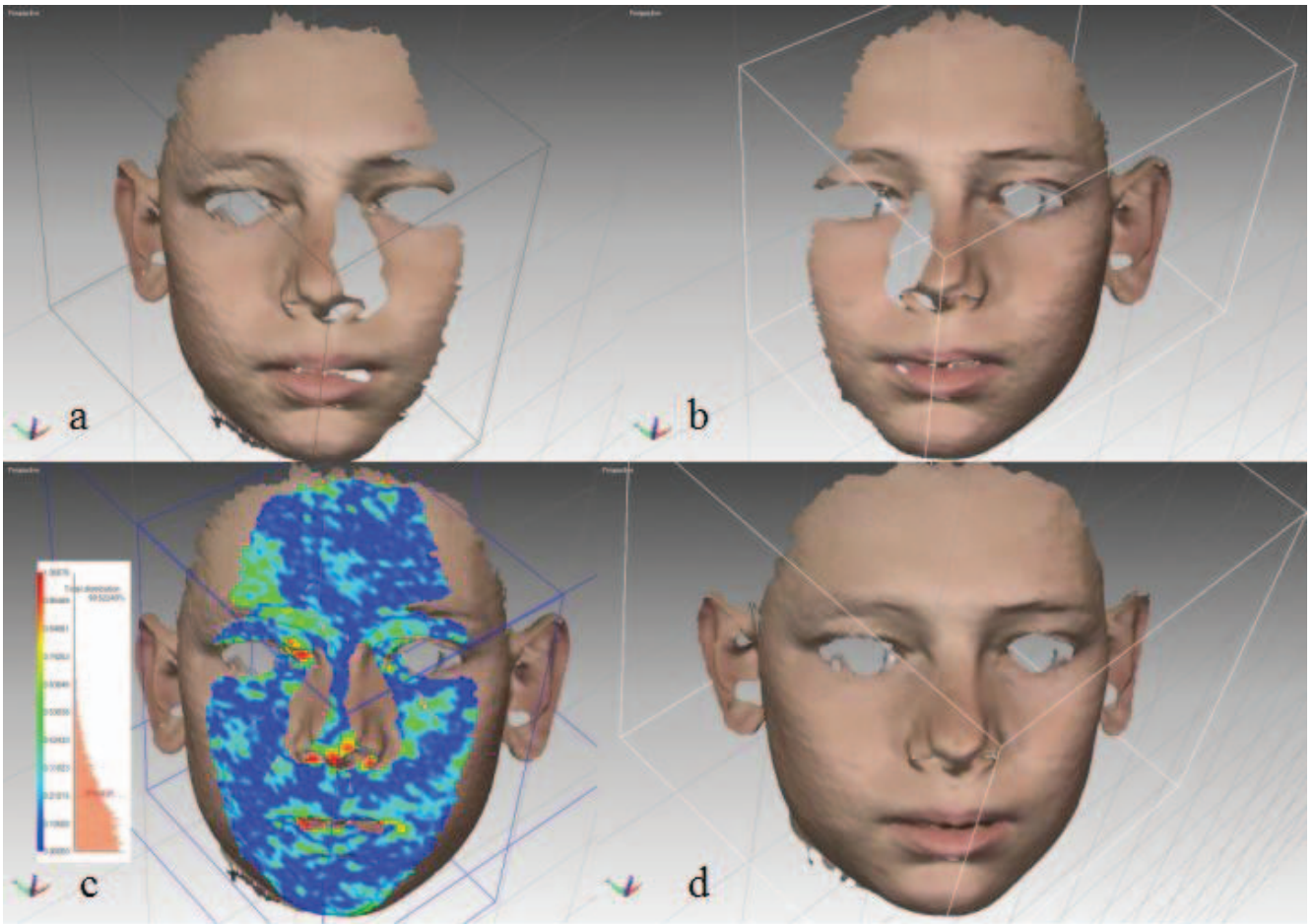


Fig. 2. (a) Left scan of child, (b) Right scan of child, (c) Mean shell deviation map. The colors indicate the levels of deviations (blue: 0.01–0.3 mm, green: 0.3–0.75 mm, red: 0.75–1.0 mm), (d) Final merged whole face.

deemed to have moved or made a facial expression that caused distortions to one shell. This would ultimately affect the quality of the final whole face produced.

The mean shell deviations were tested for normality and differences between the groups measured were analysed using the Students *t* test (SPSS, Chicago, IL, USA). *p*-Values less than 0.05 were considered significant.

Results

The results are summarized in Tables 1 and 2.

Mean shell deviations of left and right scans according to sex within subject groups

The mean ± SD shell deviations for the adult females and males were 0.24 ± 0.08 and 0.27 ± 0.10 mm. The

Table 1. Average mean ± SD of the left and right laser scans of the adult and children groups

Subjects	Number	Mean (mm)	SD (mm)	Minimum (mm)	Maximum (mm)
Adults					
Males	15	0.27	0.10	0.16	0.49
Females	15	0.24	0.08	0.16	0.45
Total	30	0.25	0.09	0.16	0.49
Children					
Males	15	0.31	0.11	0.20	0.53
Females	15	0.30	0.08	0.18	0.45
Total	30	0.30	0.09	0.18	0.53

differences in means for these two groups were 0.03 mm. Paired *t*-test revealed no significance between gender in the adult group (*p* > 0.05).

Table 2. Mean differences of the shell deviations of the males and females within each group and the total sample as a whole

Subjects	Number in each group	Mean differences (mm)	SD (mm)	p-Value	Significance
Males					
Adult and children	15	0.04	0.19	0.42	NS
Females					
Adult and children	15	0.06	0.10	0.44	NS
Total number					
Adult and children	30	0.05	0.15	0.18	NS

The mean ± SD shell deviations for the male and female children were 0.31 ± 0.10 and 0.30 ± 0.08 mm, respectively. The differences in means for these two groups were 0.01 mm. Paired *t*-test revealed no significant differences in these two groups (*p* > 0.05).

Mean shell deviations of left and right scans for females and males

The mean ± SD shell deviations for females and males in each group were analysed. The results of the female adult and children showed no significant differences between the groups. Likewise, mean shell deviations ± SD for male adults and children showed no significant differences.

Mean shell deviations of left and right scans for the adults and children

The mean ± SD shell deviations for the total sample of adult and children groups were 0.25 ± 0.09 and 0.30 ± 0.09 mm, respectively. The difference between these two groups was less than 0.05 mm. Paired *t*-test revealed that there was no significance between these two groups of subjects (*p* > 0.05).

Tolerance levels

A summary of the different level of tolerance is presented as percentages in Table 3. To achieve a final usable scan for the study of facial morphology, 90% of the face map must be aligned closely with one another, before merging the images.

The results showed that the left and right scans were aligned within a tolerance level of 0.75 mm for both

Table 3. Summary table of average percentages at the different levels for adults and children

Subjects	Number	Average percentages at tolerance level (mm)		
		0.3	0.5	0.75
Adults	30	73.4	89.5	95.8
Children	30	65.0	83.2	92.7

groups [at the 90% level] with the adult group having a better score of 0.5 mm.

Discussion

Children are generally considered as less ideal candidates in the study of facial morphology using laser-based scanning devices (11). However, this study has showed that laser scans obtained from children are as good as those of adults. The differences in mean ± SD shell deviations were very low between both groups, indicating that in general the children were as compliant as the adults. The face maps also revealed that the alignment of two scans was within acceptable limits.

Interestingly, this study also showed that in general, males had the higher mean ± SD shell deviation scores than females. The male subjects tended to be easily distracted when asked to remain perfectly still for the scanning process.

Further analysis revealed a small difference in the facial maps of adults and children. The tolerance levels for the adults were more uniform than the children. This may be attributed to the fact that adults have

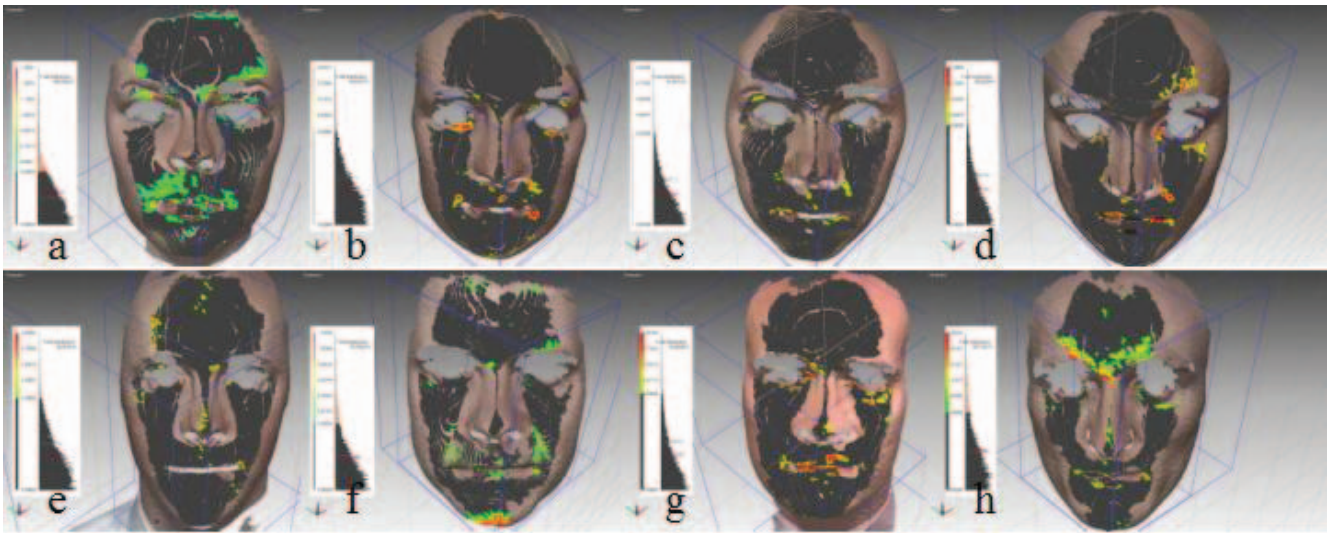


Fig. 3. Adult facial maps set at a tolerance level of 0.5 mm. Black <0.5 , green <0.75 mm and red 1.1 mm. (a–d) Tolerance maps of female subjects. (e–d) Tolerance maps of male subjects.

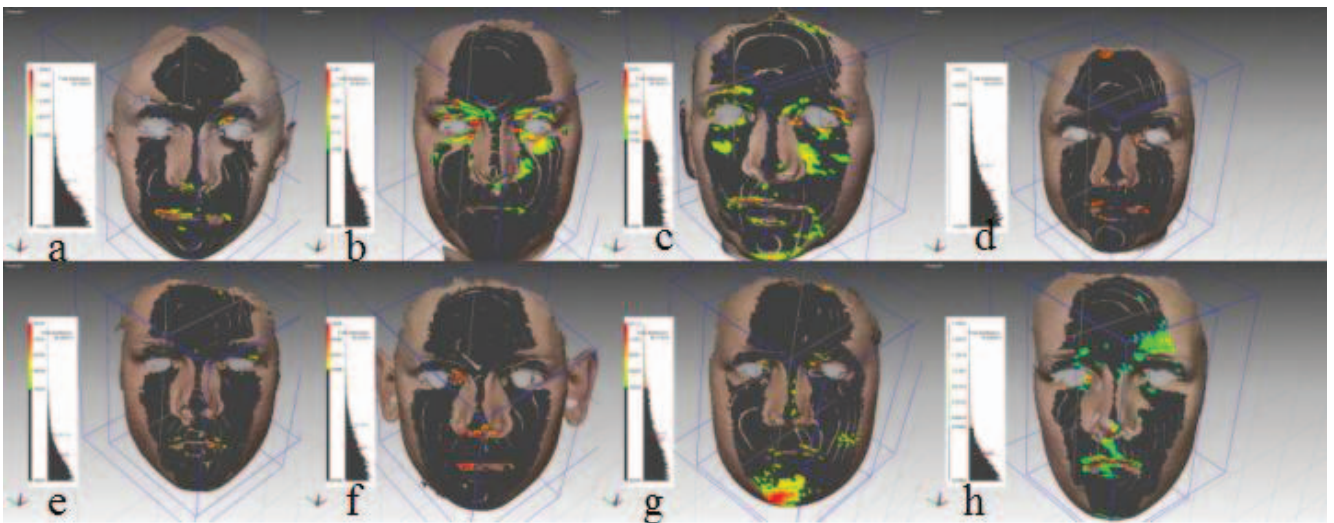


Fig. 4. Facial maps of children set at a tolerance level of 0.75 mm. Black <0.75 mm, green <0.90 mm and red <1.20 mm. (a–d) Facial maps of female subjects. (e–h) Facial maps of male subjects. In general, the levels of error are very small, patchy and non-uniform. This level of error is highly acceptable and non-significant.

better facial muscular control as compared with the children (Fig. 3). The children scanned also seemed to be prone to minor muscular responses in the eyelid region and areas near the lips and chin. These errors were however, small, patchy and did not exceed 1.2 mm (Fig. 4).

Finally, the scanning time to capture facial morphology has been criticized for being slow. This study has shown a high level of compliance both for a group of adults and children. The image capture of three-

dimensional soft tissue morphology is complex (12) and should not be based solely on the speed of a scanning system alone, but on the ability to capture reliable soft tissue morphology over a range of time frames. Many facial expressions can occur within a minute, and it is important that the best and most consistent representation of facial morphology is captured each time a subject is scanned. Therefore, the reliability of a laser-scanned image is dependent not only on the accuracy and speed of the capture system,

but an ideal and relaxed subject posture and a compliant subject. The system as described here enables the facial morphology to be captured from left to right ear providing a comprehensive picture of the face.

Conclusion

The following conclusions may be drawn from this study:

- (1) The laser scanning system employed in this study has great potential in the capture and study of facial morphology.
- (2) In obtaining a three-dimensional image, small differences between scans can occur, but the mean \pm SD differences are small (<0.3 mm).
- (3) Children are reliable candidates for laser-based studies of facial morphology.

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