A study to evaluate the reliability of using two-dimensional photographs, three-dimensional images, and stereoscopic projected three-dimensional images

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Abstract

Clinicians are accustomed to viewing conventional two-dimensional (2D) photographs and assume that viewing three-dimensional (3D) images is similar. Facial images captured in 3D are not viewed in true 3D; this may alter clinical judgement. The aim of this study was to evaluate the reliability of using conventional photographs, 3D images, and stereoscopic projected 3D images to rate the severity of the deformity in pre-surgical class III patients. Forty adult patients were recruited. Eight raters assessed facial height, symmetry, and profile using the three different viewing media and a 100-mm visual analogue scale (VAS), and appraised the most informative viewing medium. Inter-rater consistency was above good for all three media. Intra-rater reliability was not significantly different for rating facial height using 2D ($P = 0.704$), symmetry using 3D ($P = 0.056$), and profile using projected 3D ($P = 0.749$). Using projected 3D for rating profile and symmetry resulted in significantly lower median VAS scores than either 3D or 2D images (all $P < 0.05$). For 75% of the raters, stereoscopic 3D projection was the preferred method for rating. The reliability of assessing specific characteristics was dependent on the viewing medium. Clinicians should be aware that the visual information provided when viewing 3D images is not the same as when viewing 2D photographs, especially for facial depth, and this may change the clinical impression.

Key words: stereoscopic, photographs, projected, three-dimensional, facial deformity, orthognathic, class III

Introduction

Following the clinical assessment of patients with dentofacial deformities, additional records including pre-treatment extraoral photographs, radiographs, and study models are recommended[1]. These are used to document the initial presentation, for diagnosis and treatment planning, as well as providing evidence of treatment. The records also have a role in patient communication, education, audit, and research[2]. Pre-treatment records should therefore be valid, accurate, complete, and contemporaneous[3]. Given the longitudinal nature of orthognathic surgery, the pre-treatment records should enable the different members of the orthognathic team to re-identify the key features of the clinical assessment, in the absence of the patient. One of the assumptions for the present clinical practice is that the extraoral photographs are valid in this context.

Using stereophotogrammetry or laser scanning it is possible to capture the photorealistic three-dimensional (3D) facial soft tissue appearance[4,5]. Clinicians are accustomed to viewing conventional two-dimensional (2D) photographs and assume that working with and viewing 3D images will be similar. However, even though the individual's facial images are captured in 3D, they are currently not viewed in 'true 3D'. This may result in underutilization of the additional information acquired during 3D capture and may be clinically important.

Currently the 3D facial images are viewed after they have been reconstructed (rendered) onto a 2D plane, i.e. the screen of an LCD computer monitor. Image depth perception is created using monocular cues, such as the size differential generated by perspective projection and the texture gradient by lighting and shading. These perspective techniques are not able to provide a true perception of depth as experienced by the human visual system, i.e. binocular vision. This can only be recreated using ‘stereoscopic viewers’, such as active or passive 3D projection systems[6]. Passive 3D projection systems project two different images with a spatial disparity onto a screen; each eye views each image at the same time using polarized glasses. The differences between these two images (known as stereo-pairs of images) are recovered by the human visual system as depth[7]. In a medical context, stereoscopic displays offer significant clinical improvements, especially in the areas of diagnostic applications including ophthalmic imaging, mammography, vascular imaging, and orthopaedic imaging[7].

There appears to have been no study investigating the reliability of using 2D photographs and 3D images (both relying on monocular cues) or stereoscopic projected 3D images (binocular cues) to assess specific features of a facial deformity. Therefore the aim of this study was to evaluate the reliability of using these three different viewing media to rate specific facial characteristics in a group of pre-surgical class III patients: facial height, symmetry, and profile. The null hypothesis was that there are no differences in ratings of the facial height, symmetry, and profile (as assessed using a visual analogue scale (VAS) score) using the three different viewing media ($P < 0.05$). In addition, the raters were asked supplementary questions to appraise which viewing medium provided the most information during the assessment.

Materials and methods

Subjects

Ethical approval for the study was obtained from the Institutional Review Board (IRB) of Hong Kong University and Hospital Authority Hong Kong West Cluster. Forty pre-surgical orthognathic patients attending the Department of Orthodontics or the Department of Oral Maxillofacial Surgery of Prince Philip Dental Hospital, Hong Kong, were recruited. All patients had previously been diagnosed with a skeletal class III deformity by the orthognathic team and required surgical correction. Patients with craniofacial syndromes or anomalies, including cleft lip and palate, were excluded. Written informed consent was obtained from all patients included in the study. The average age of the patients was 22.9 years ± 3.2 months; 22 were female and 18 were male.

Image acquisition

Each patient was imaged using a conventional digital camera (2D images) and a 3D stereophotogrammetry system (3D images). To standardize the images, hair was kept away from the face, the lips were kept in repose, and the head was maintained in the natural head position (NHP)[8].

2D images

Seven standardized 2D photographs of each patient (frontal view, right and left profiles, right and left three-quarter profiles, bird's eye view, and worm's eye view) were captured using a Canon EOS 700D camera (Canon, Tokyo, Japan) with Canon Macro Ring Lite MR-14EX II and Canon Macro Lens EF-S 60mm 1:2.8 USM (Canon). All photographs were taken using the same camera settings, illumination, background, and distance. A vertical plumb line was used as the true vertical reference. Using Adobe Photoshop CS (Adobe Systems Inc., San Jose, CA, USA), each facial image was cropped to remove the headband, ears, neck, and shoulders, producing a standardized image. The photographs for each patient were organized onto one PowerPoint slide (Microsoft, Redmond, WA, USA) and saved (Fig. 1). This was repeated for each patient using the same template PowerPoint slide.

[Figure 1 here]

3D images

Immediately following 2D photographs, 3D facial images were taken using the Di3D system (Dimensional Imaging Ltd, Glasgow, UK) based on the standardized capture protocol and saved as Wavefront files (OBJ). Using MeshLab software (STI-CNR, Rome, Italy; http://meshlab.sourceforge.net/), each facial image was cropped to remove the headband, ears, neck, and shoulders, producing a standardized image. The 3D facial image was then reoriented to NHP according to a previously published technique[9] and saved in OBJ format (Fig. 2).

[Figure 2 here]

Viewing method

2D images and 3D images

The 2D photographs were viewed as PowerPoint slides and the 3D facial images in NHP were viewed using Di3DView (Dimensional Imaging Ltd). Both were projected onto a smart board (SMART Technologies, Calgary, Canada) by a projection system (EB-480; Epson, Suwa, Nagano, Japan) during the rating sessions.

Stereoscopic projected 3D images

The 3D facial images in NHP were imported into 3D-Hub software (WSP[av], Colchester, Essex, UK; Instant Effects, Santa Barbara, CA, USA), and projected onto a large projector screen (Da-Lite Versatol Tripod Screen 99″ (70 × 70) Silver Lite 2.5; Da-Lite, Warsaw, IN, USA) using a passive 3D projection system (EB-W16SK; Epson) (Fig. 3). The stereoscopic projected 3D facial images were viewed using a pair of polarized 3D glasses.

[Figure 3 here]

Raters

Eight raters (with a Membership in Orthodontics diploma (MOrth) or equivalent from the Department of Orthodontics at Prince Philip Dental Hospital, Hong Kong, were asked to rate the facial images. All raters were involved in the management of dentofacial deformities and were acquainted with orthognathic surgery.

Rating scale

The raters assessed the severity of the facial deformity for 40 patients using a 100-mm VAS. The descriptor at the left end of the VAS (0 mm) was 'too short', 'acceptable symmetry', and 'acceptable' for facial height, facial symmetry, and profile, respectively, whilst on the right (100 mm) the descriptor was 'too long', 'very asymmetric', and 'very severe', respectively (Fig. 4). Each rating sheet was completed by each rater for only one patient using each viewing medium.

[Figure 4 here]

Rating process

Verbal introduction

All image viewings were undertaken by all raters under the same conditions. Prior to commencing the main study, all raters were calibrated by explaining the rating scale. In addition, the raters were shown the 2D photographs of the 40 patients in a random order prior to each rating session to familiarize them with the range in severity of facial height, asymmetry, and class III profile, so they could use the fullest possible extent of the VAS scale[10].

Initial rating session (T1)

The raters assessed the 2D photographs, 3D images, and stereoscopic projected 3D images alternately, i.e. 10 2D photographs, 10 3D images, and finally 10 stereoscopic projected 3D images, under standardized viewing conditions. This was repeated until the images of all 40 patients had been rated using the three viewing media. The orders of 2D photographs, 3D images, and stereoscopic projected 3D images were chosen at random.

During the 3D assessments, the same operator (SZ) manually rotated the image in the same manner. During the rating session, raters were not allowed to go back to the previous rating sheet.

The raters were asked two additional questions: (1) Which viewing medium provided the most information during the assessment? (2) What percentage of the class III discrepancy is due to maxillary retrusion?

Re-rating session (T2)

The same eight raters reassessed the 2D photographs, 3D images, and stereoscopic projected 3D images of 20 randomly selected patients 1 week later. In total, 60 images (20 2D photographs, 20 3D images, and 20 stereoscopic projected 3D images) were assessed in series of 10, as in the initial rating session.

Statistical analysis

A Shapiro–Wilk test indicated that the data were not normally distributed. Intra-rater reliability was assessed using intra-class correlation (ICC). A Wilcoxon signed-rank test was used to detect any significant differences in the median VAS between the two rating sessions (T1 and T2).

Cronbach's alpha was used to test the internal consistency of the VAS for inter-rater reliability. Comparison of the three viewing media to assess the severity of facial height, symmetry, and profile was evaluated by performing a Kruskal–Wallis test on the mean rater score (mean of scores at T1 and T2). The same test was used to determine whether there was a statistical difference in the percentage of the class III discrepancy due to maxillary retrusion between the three viewing media.

Results

The inter-rater reliability was good to excellent (Cronbach's alpha ≥0.8) for the three different viewing media when assessing the three components of the face, i.e. height, symmetry, and profile (Table 1). Cronbach's alpha ranged from 0.82 for assessing facial height using 3D images to 0.97 for assessing symmetry using projected 3D images.

[Table 1 here]

All ICC values for assessing intra-rater reliability were between 0.50 and 0.76, representing moderate to good levels of reliability[11]. There was a significant difference in median VAS when rating facial symmetry (P = 0.001) and profile (P = 0.001), but not facial height (P = 0.704) using 2D photographs. For 3D imaging there was no significant difference for rating symmetry (P = 0.056), but there was for rating facial height (P = 0.004) and profile (P = 0.018). Finally, based on projected 3D images there were significant differences in ratings for facial height (P = 0.001) and symmetry (P = 0.001), but not profile (P = 0.749) (Table 2).

[Table 2 here]

Kruskal–Wallis tests showed that there were significant differences in the median VAS scores between the three different viewing media for all three facial characteristics. Subsequently, pair-wise comparisons were performed using a Bonferroni correction for multiple comparisons. Adjusted P-values are presented. For facial height, the post hoc analysis revealed a significantly lower median VAS score for 2D photographs than 3D images (P = 0.001) and 3D projected images (P = 0.005), but there was no difference between 3D images and 3D projected images (P = 0.903). For facial symmetry, the post hoc analysis revealed a significantly lower median VAS score for 3D projected images compared to both 3D images (P = 0.002) and 2D photographs (P = 0.001), but no difference between 3D images and 2D photographs (P = 0.166). Finally, for facial profile, the post hoc analysis showed a significantly lower median VAS for 3D projected images in comparison to both 3D images (P = 0.024) and 2D photographs (P = 0.001), but no difference between 3D images and 2D photographs (P = 0.310) (Table 3).

[Table 3 here]

All raters reported that 3D viewing in either form provided more information for reaching a clinical diagnosis than 2D viewing. Six out of eight (75%) raters reported that projected 3D viewing provided the most information; the remaining two raters indicated that the two methods of 3D viewing were similar.

There was no significant difference between 2D and 3D viewing ($P = 0.4217$) in assessing the percentage of the class III discrepancy due to maxillary retrusion (30%). There was, however, a significant difference between 2D and projected 3D, and between 3D and projected 3D viewing ($P < 0.001$). There was a greater contribution of maxillary retrusion using projected 3D viewing (42%).

Discussion

This study reports on the reliability of using 2D photographs, 3D images, and stereoscopic projected 3D images to assess the severity of the condition in patients with a class III dentofacial deformity. This study is different to previous studies in two main areas. Firstly, rather than assessing the global facial attractiveness or beauty of the individual as an outcome measure, specific facial characteristics were assessed, i.e. height, symmetry, and profile. This provides a more objective evaluation rather than a subjective assessment. Secondly, 'true 3D' visualization using projected stereoscopic 3D images was introduced as a novel viewing method in a clinical setting.

The assessment of facial characteristics in the three planes of space, i.e. vertical (height), transverse (symmetry), and anterior–posterior (profile), was felt to be important, as each could be emphasized differently by the three viewing media. It has been reported that it is easier for raters to evaluate a specific facial feature rather than the overall features[12]. The use of a VAS allowed objective quantification of a subjective evaluation. This is a well-reported method used in assessing facial appearance and outcome[12].

A limitation of this study is that it compared the severity rating relative to the three viewing media but did not relate the findings back to the gold standard of a clinical assessment. It would have been unethical to delay surgical treatment for this group of patients whilst the viewing sessions were being organized and taking place. However studies involving outcome assessments in cleft patients have found that clinical ratings and 2D image ratings are similar. This may not be the case for orthognathic patients, as assessing the nasolabial region following cleft lip repair is often based on a 'close-up' of the region rather than a more global facial view. Localization on a specific region, ignoring the pan-facial appearance, has recently been questioned[13].

The results of this study suggest that the intra-rater reliability is dependent on which facial characteristics are being rated and by which viewing method. For instance rating facial height is more reliable using 2D photographs, rating symmetry is more reliable using 3D imaging, and rating the profile is more reliable using stereoscopic projected 3D images. The relatively small median differences in VAS for assessing facial height between the three viewing methods are probably not clinically significant. Assessing facial height is normally based on using facial proportions from the frontal view and as such can probably be assessed equally well in 2D or 3D, as it is probably not depth-sensitive.

The intra-rater reliability using 3D images to assess facial symmetry was highest (ICC = 0.76). The median difference between rating sessions was larger for 2D and projected 3D images. This result is interesting, as it suggests that these two viewing methods may not allow consistent assessment of the severity of facial symmetry; this is also indicated by the large interquartile ranges. A possible explanation for this is the fact that clinicians are probably assessing the seven 2D images of each patient and mentally re-constructing a 3D image in their minds based on the visual monocular cues captured in the photograph. The results would suggest that during the transition from the 3D clinical patient to 2D images (photographs) and back to the 3D mental reconstruction, information is being lost, misinterpreted, or distorted. Direct viewing of the 3D image negates this process. This is a noteworthy finding given that conventional 2D photographs are the current method of documenting facial symmetry.

The wide interquartile range in the VAS (−21.5 to 5.6) seen with projected 3D viewing for the facial symmetry assessment could be explained by the unfamiliarity with the viewing method and the effect of depth perception on the viewing angle or spatial separation (binocular disparity) of the images. The effect of the viewing angle was minimized by using a projection system rather than a 3D monitor and ensuring that the raters were seated directly in front of the projection screen. The spatial separation of the projected image was hard to control and may affect depth perception. When a pair of 3D images is simultaneously projected onto a screen in the absence of stereo glasses, a horizontal difference between them would be seen, i.e. two images overlapped but with a horizontal shift; this difference is referred to as ‘screen parallax’. When these are translated to our retinas and processed by our brains, this parallax produces stereopsis. The greater the horizontal disparity of the two images, the more the screen parallax and the greater the depth perception. There is a possibility that this could change the perception of the image and make it more difficult to rate symmetry. The viewing software used in this study pre-defines this horizontal disparity and therefore the depth perception, and must assume that the disparity is universally correct for all individuals.

There was no significant difference in median VAS between the rating sessions using projected 3D images to rate facial profile. This may be explained by differences in the neural processing of the two image types. A recent study using electroencephalography (EEG) compared the brainwave activity of individuals when they viewed 3D movies using a passive 3D projection system and 2D images[14]. The study found statistically significant higher brainwave activity in the beta, delta, and gamma bands for 2D images and in the alpha and theta bands during 3D projection. It has previously been reported that activity in the theta and alpha bands is indicative of global information transfer and relates to memory function, attention, and decision-making[15,16]. It may be that the human brain interprets 2D and perspective 3D images similarly, but differently to projected 3D, as they are dependent on stereopsis.

This study also found that there were differences among the three different viewing media in rating the facial characteristics. There were statistically significant differences using 3D projected images for rating the severity of the class III profile deformity ($P < 0.05$) and symmetry ($P < 0.05$). These differences may also be clinically significant, as the median difference is approximately 15 mm on the VAS. Unfortunately as no direct clinical assessment was used as a gold standard, for the reasons mentioned previously, it is unknown whether 3D projection under- or over-estimates the anterior–posterior severity or symmetry. This may show that ‘facial depth’ (in projected 3D) is more dependent on binocular vision and that the monocular cues of conventional photographs and perspective 3D images may not provide enough visual information to recreate depth, i.e. facial protrusion or retrusion.

Interestingly all raters reported that 3D viewing provided more clinical information than 2D photographs. In addition, the majority felt that projected 3D was better than 3D viewing. This is not surprising as the human face is three-dimensional and therefore information should be displayed in 3D[17–19]. The fact that projected 3D was thought to be superior to perspective 3D viewing and increased the contribution of maxillary contribution to the class III deformity highlights the effect that the viewing medium may have on the diagnosis and clinical outcome.

In conclusion, this study found that stereoscopic 3D projection was the preferred method for rating facial characteristics. The intra-rater reliability for the assessment of each specific characteristic was dependent on the type of viewing method. Stereoscopic 3D projection was the preferred method for rating facial characteristics. Clinicians should be aware that the visual information provided when viewing 3D images is not the same as when viewing 2D photographs, especially facial depth, and this may change the clinical impression.

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Competing interests

None.

Ethical approval

Ethical approval was granted by the Institutional Review Board (IRB) of Hong Kong University and Hospital Authority Hong Kong West Cluster (Protocol Reference No. UW 14-355).

Patient consent

Written patient consent was obtained to publish the clinical photographs.

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Figure captions

Fig. 1.Seven two-dimensional images arranged in a PowerPoint slide for 2D image viewing.

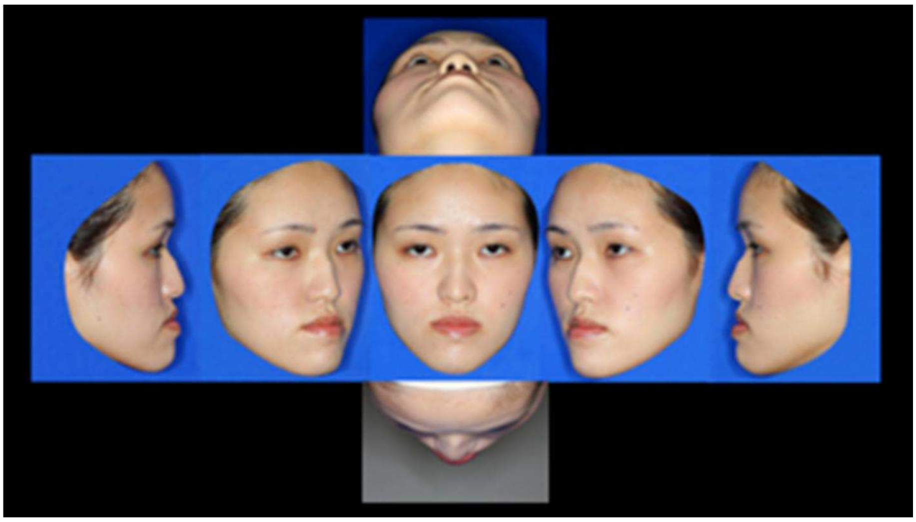

Fig. 2. Three-dimensional image used for rating of 3D image.

Fig. 3. (A) Stereoscopic projector setup used to display the 3D image. (B) Horizontal disparity used to create stereoscopic vision, as seen with no glasses on.

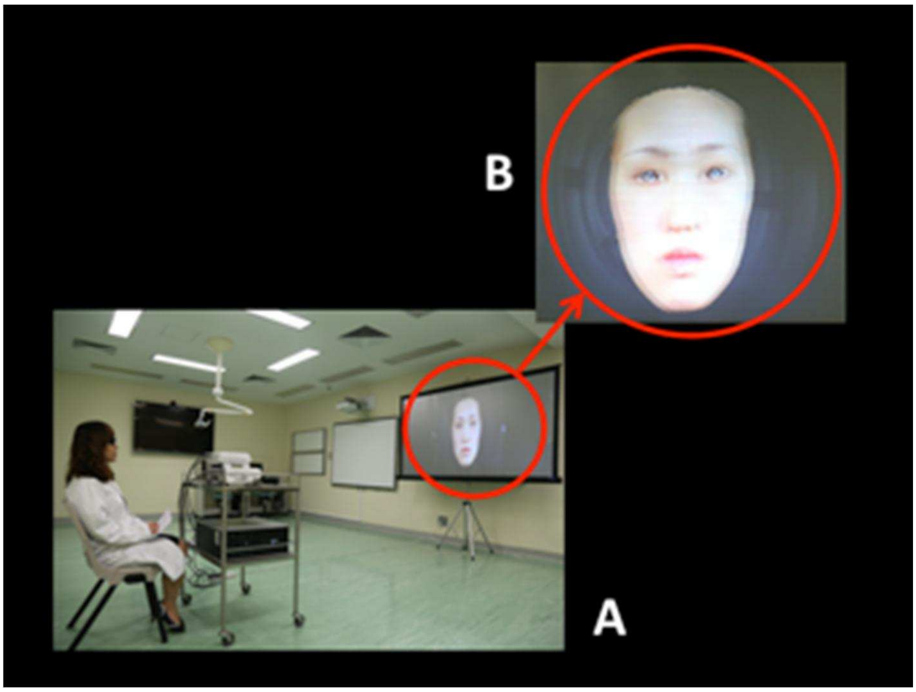

Fig. 4. The visual analogue scale (VAS) for assessing facial height, facial symmetry, and profile.

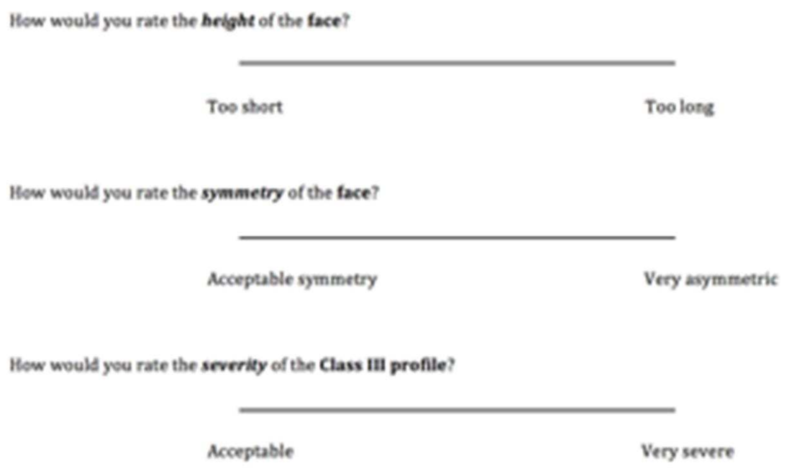

Table 1. Inter-rater reliability for the three characteristics of class III severity (height, symmetry, and profile) in 2D, 3D, and stereoscopic projected 3D; Cronbach's alpha.

Viewing medium	Height	Symmetry	Profile
2D	0.87	0.86	0.88
3D	0.82	0.93	0.90
Projected 3D	0.88	0.97	0.89

2D, two-dimensional; 3D, three-dimensional.

Table 2. Intra-rater reliability for rating the height, symmetry, and profile using 2D, 3D, and stereoscopic projected 3D. The median differences in VAS scores between T1 and T2 are shown, together with the intra-class correlation coefficients and outcomes of the Wilcoxon signed-rank test.

		ICC	Median difference	Interquartile range	P-value
2D					
	Height	0.61	0.0	-7.1 to 6.1	0.704
	Symmetry	0.57	-6.3	-18.0 to 4.5	0.001 [a]
	Profile	0.73	-3.0	-12.6 to 3.1	0.001 [a]
3D					
	Height	0.63	-2.5	-8.6 to 3.5	0.004 [a]
	Symmetry	0.76	-2.8	-11.5 to 7.0	0.056
	Profile	0.70	-3.0	-13.0 to 5.5	0.018 [a]
Projected 3D					
	Height	0.55	-3.5	-9.5 to -1.0	0.001 [a]
	Symmetry	0.48	-4.0	-21.5 to 5.6	0.001 [a]
	Profile	0.71	0.0	-10.1 to 9.6	0.749

2D, two-dimensional; 3D, three-dimensional; VAS, visual analogue scale; ICC, intra-class correlation.

[a]Statistically significant; $P < 0.05$.

Table 3. Median VAS and interquartile range for rating the height, symmetry, and profile using 2D, 3D, and stereoscopic projected 3D. The differences between the median VAS scores were assessed using the Kruskal–Wallis test (P < 0.05).

	Median	Interquartile range	P-values	
Height				
2D	51.6	44.0 - 57.9	0.001 [a]	
3D	56.5	49.3 - 63.4		0.005 [a]
Projected 3D	53.8	49.1- 62.3	0.903	
Symmetry				
2D	53.0	33.6 - 67.1	0.166	
3D	42.9	24.1 - 67.4		0.001 [a]
Projected 3D	35.8	17.0 - 51.6	0.001 [a]	
Profile				
2D	55.3	35.8 - 67.9	0.310	
3D	49.0	25.4 - 65.0		0.001 [a]
Projected 3D	41.4	16.5 - 58.2	0.024 [a]	

VAS, visual analogue scale; 2D, two-dimensional; 3D, three-dimensional.

[a]Statistically significant; P < 0.05.