

Digital videographic measurement of tooth display and lip position in smiling and speech: Reliability and clinical application

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Introduction: Tooth display and lip position in smiling and speech are important esthetic aspects in orthodontics and dentofacial surgery. The spontaneous smile and speech are considered valuable diagnostic criteria in addition to the posed social smile. A method was developed to measure tooth display in both smile types and speech. **Methods:** The faces of 20 subjects were individually filmed. Spontaneous smiles were elicited by a comical movie. The dynamics of the spontaneous smile were captured twice with a digital video camera, transferred to a computer, and analyzed on videoframe level. Two raters were involved. Posed social smiles and speech records were also included. Reliability was established by means of the generalizability theory. It incorporated rater, replication, and selection facets. **Results:** Generalizability coefficients ranged from .99 for anterior teeth to .80 for posterior teeth. The main sources of error were associated with rater and selection facets. The replication facet was a minor source of error. **Conclusions:** This videographic method is reliable for measurement of tooth display and lip position in spontaneous and posed smiling and speaking. Application of the method is warranted especially when obtaining an emotional smile is difficult, such as cleft lip and palate or disfigured patients. (*Am J Orthod Dentofacial Orthop* 2007;131:301.e1-301.e8)

The smile is an important form of facial expression.¹ Facial expressions and physical attractiveness in general form essential parts of social interactions.^{2,3} Nowadays, the smile is even more important because of its increasing role in the esthetic ideal. A bright smile is associated with intelligence, sympathy, extroversion, and attractiveness.^{4,5} Moreover, in studies with photographs, higher intellectual and social abilities were attributed to people with esthetic smiles, who were also judged to be more attractive than the same people with modified lower-level esthetic smiles.⁶⁻⁸

An esthetically pleasing smile depends not only on

components such as tooth size, shape, color, and position, but also on the amount of visible gingivae and the framing of the lips. All these components should form a harmonic and symmetric entity. The lips are the controlling factor in which portions of the teeth, gingivae, and dark spaces will be seen in a person's smile.⁹ Yet, the higher the lip is elevated when smiling, the more visible the teeth and gingivae are, and the greater their role in the esthetic value of the smile.

In the dental literature, the smiling upper lip position is often called the smile line.¹⁰⁻¹⁴ Sometimes synonymous terms are used, such as smiling lip line,^{15,16} upper lip line,¹⁷ upper lip height,¹⁸ lip line,^{9,19-21} and high, average, and low smiles.^{22,23} It is a source of confusion that smile line^{9,24-26} and smiling line²⁷ are also used to indicate the relationship between the curve of the lower lip and the curve formed by the incisal edges of the maxillary incisors.^{17,28-32} In this article, "smile line" is defined as the projection line of the upper lip's lower edge on the maxilla when smiling. It is used as a diagnostic parameter in orthodontics,^{15,16,18,33} periodontics,^{20,21,34} prosthodontics,^{35,36} esthetic dentistry,⁹ implantology,³⁷ and oral surgery.^{11,13} Esthetic starting points are that the smile line height should be about the level of the gingival margins of the maxillary central incisors^{15,18,20,38} or show some gingiva.^{12,30} Furthermore,

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the continuous gingival contour should be parallel with the smile line.^{9,12,21} The most ideal incisal line of the maxillary dentition is established in relation to the curve of the lower lip.^{17,28-32}

In the dental literature, 3 approaches are suggested to determine the height of the smile line: the qualitative,³⁹ the semi-quantitative,^{22,23,25,40} and the quantitative approaches.^{10,12,13,17,28,29,31,41} In the qualitative approach, the orthodontist observes the patient. As soon as the patient smiles, a qualitative statement about the height of the smile line is made. In the semi-quantitative approach, a patient is asked to smile, and the smile is recorded by a photograph. With this photograph, the height of the smile line is visually classified. In the quantitative approach, the smile line height is determined with a measuring instrument. The methods in this approach range from simple to sophisticated. Ackerman et al^{17,28,29} and Sarver and Ackerman³¹ used computer software programs for measuring smile line height and tooth display. At first, digitized smiling photographs from orthodontic records were measured. Later, they used digital video cameras for smile registration.

A drawback of most semi-quantitative and quantitative methods is that only posed smiles were measured. It is claimed that smiling on request has the advantage that it is reproducible,^{10,17} but the question is whether the posed social smile is the same as a spontaneous smile of joy. The smile is not a singular category of facial behavior. In psychophysiology, a distinction is made between emotion-elicited spontaneous smiles and voluntary posed smiles. It appears that emotional and nonemotional facial activities originate from different areas of the brain (subcortical and cortical motor strips, respectively) and appear in the face through different motor systems (extrapyramidal and pyramidal, respectively). The emotion-elicited spontaneous smile is also called "Duchenne smile."⁴² It differs from the voluntary posed smile by more muscle activity in regions other than the zygomaticus major muscle, such as the orbicularis oculi pars lateralis muscle and the depressor angulis oris muscle.^{43,44} The orbicularis oculi pars lateralis muscle contracts the outer portion of the eye; this cannot be done voluntarily by most people. Because of the unconscious character of the spontaneous smile, it can be seen as a person's authentic smile expression.

Emotional backgrounds influence a voluntary posed smile.⁴⁵ A well-known phenomenon in clinical practice is that patients guard their smiles because of dissatisfaction with them. When asked for a posed smile, they show only what they consciously or subconsciously want to present.^{9,11} Another example of interfering emotional factors on the posed smile is feelings of

shame by victims of undisclosed childhood sexual abuse. Their social smiles appeared to be considerably less expressive.⁴⁶

On the basis of some structural differences mentioned above between spontaneous and posed smiles, spontaneous smiling is a logical focus point in smile diagnostics. This is in line with recommendations of oral surgeons¹¹ and esthetic dentists.⁹ Also, Ackerman et al²⁹ proposed that an orthodontist should view the dynamics of anterior tooth display as a continuum delineated by the time points of rest, speech, posed social smile, and Duchenne smile. Most methods for smile measurement, however, are not designed to measure spontaneous smiles. Moreover, ear rods are often used to standardize head position. This is not a favorable position to elicit a spontaneous smile from a patient. Therefore, the development of a less interfering registration method for the smile was studied. Central ideas guiding the development were that (1) a spontaneous (Duchenne) smile can be recorded precisely at the exact moment, (2) standardization should interfere minimally with the subject's natural behavior (eg, no ear rods), (3) the visibility of the teeth when speaking can be investigated, and (4) the technique should be simple, inexpensive, and feasible for the clinician. The aims of this study were to develop a dynamic registration method for assessment of spontaneous smile and speech and to subject this method to an extensive reliability test with regard to differences between raters (intrarater and interrater reliability), between records of the same subject, between types of teeth (anterior teeth, premolars, and molars), and between spontaneous smiling, posed smiling, and speech.

MATERIAL AND METHODS

Twenty men were selected at random from an air force base. All were native white Dutch and ranged from 35 to 55 years of age. Selection criteria were full maxillary and mandibular arches up to and including first molars, no excessive dentofacial disharmonies, and no caries or periodontal diseases. In this study, there was no need to differentiate between age or sex. Informed consent was obtained from the subjects according to the guidelines of the Academic Centre of Dentistry Amsterdam.

Four digital video recordings were made of each subject: spontaneous smile of joy, posed social smile, speech, and full dentition with the aid of cheek retractors (Fig 1). The full dentition was measured to obtain the actual lengths of tooth crowns. All recordings of a subject were taken during 1 day.

The video recordings were made in a setup consisting of a chair with a digital video camera (XM 1 [3

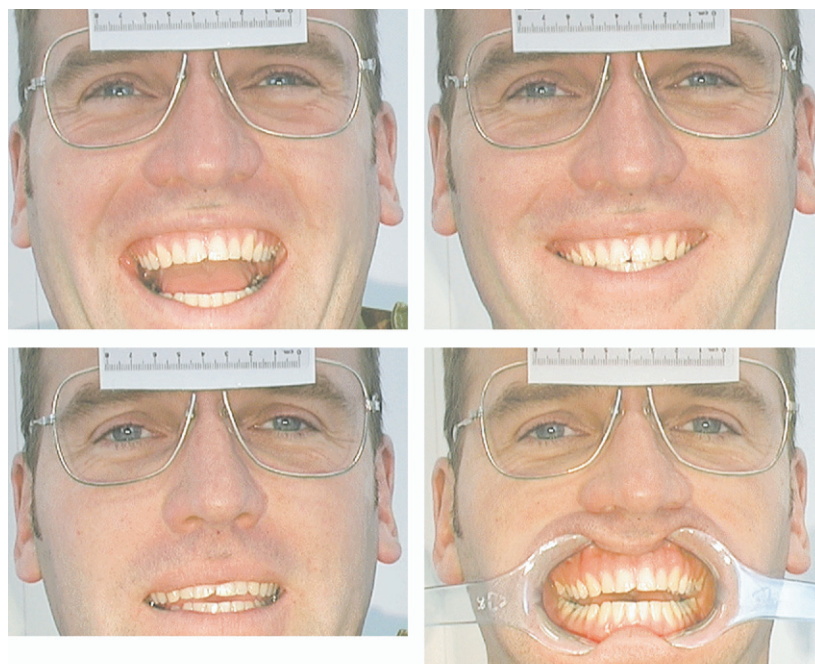


Fig 1. Digital videographic records: spontaneous smile of joy, posed social smile, speech, and full dentition.

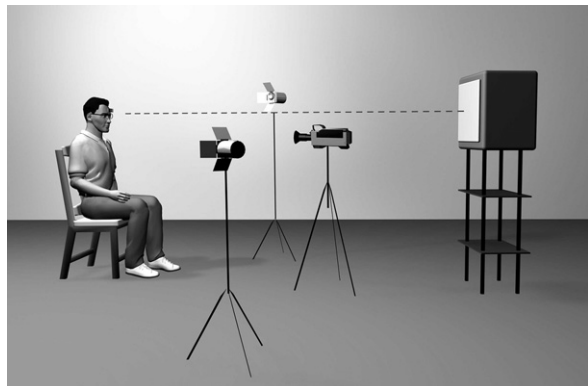


Fig 2. Digital videographic method: schematic reproduction of test configuration.

CCD], Canon, Tokyo, Japan), a television set, and 2 spotlights mounted in front of the chair (Fig 2). The television screen was placed at eye level. When the visual axis was horizontal, the subjects kept their heads mainly in a natural head position.^{47,48} The video camera was adjusted to the subject's mouth level at a 55-cm distance and continuously registered the face. To prompt spontaneous smiling, the subjects watched television fragments of practical jokes, which had been assessed by a panel as the funniest from a film of 50 practical jokes. The subjects were unaware of the exact

aim of the study. While watching the television, the subjects wore glasses with a clipped-on reference standard to enable calibration in a digital measurement program. In this way, a maximum spontaneous smile was recorded with minimal intrusion of the subject. After the video registration, the digital recordings were transferred to a computer. Then, the dynamics of smiling and speech could be observed frame by frame. The video frames of smiling and speech with maximum visibility of teeth and gingivae in both jaws were selected. If these criteria could not be realized in a single frame, several video frames were selected.

The selected video frames, referred to as the records, were measured with the help of the Digora program for dental radiography (Orion Corporation Soredex, Helsinki, Finland). For each record, the measurement program was recalibrated with the filmed reference standard. On the smiling and speech records, displays of teeth and gingivae were measured. Length of teeth was measured on the full dentition record. In the maxilla and mandible, a central and a lateral incisor, a canine, a first and a second premolar, and a first molar were measured. The most incisal point of each tooth and the lip edge were marked with a horizontal line, parallel to the pupil line (Fig 3). The vertical distance between these lines was measured. If a tooth was not visible, tooth display was denoted as zero.

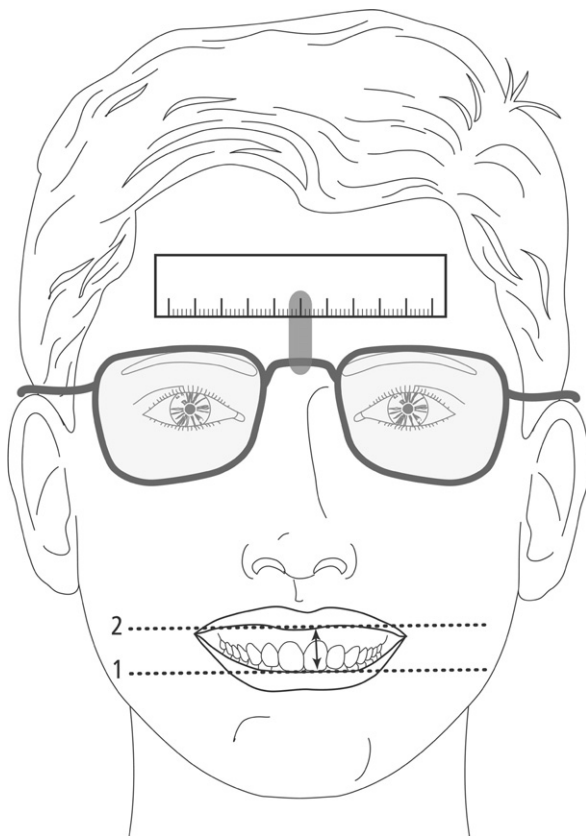


Fig 3. Digital videographic method: measurement of maxillary central incisor. *Line 1*, Most incisal point; *line 2*, lip edge.

Table I. Design of study

Selection (video capture)	Rater 1	Rater 2	Rater 2
1	A	B	
2		C	D

Analysis of sources of error: part 1, A vs B—evaluation of rater facet (interexaminer reliability); part 2, B vs C—evaluation of selection facet (video captures 1 and 2); part 3, C vs D—evaluation of replication facet (intraexaminer reliability); part 4, A vs C, A vs D—joint evaluation of facets.

To test the suitability of the method for general use, the 4 situations (full dentition, spontaneous smile, posed social smile, and speech) were captured twice (selections 1 and 2), and 2 raters were included in the setup of the study design (Table I). This resulted in a total of 3840 measurements (20 subjects \times 4 situations \times 2 selections \times 2 ratings \times 12 teeth). Based on this design, various sources of error could be analyzed. Four parts of the study design were defined in which 4 aspects were investigated: the error related to different raters (part 1), different records of the same subjects

(part 2), replications with the same rater (part 3), and combinations of different raters and records (part 4). Part 4 addresses the measurement method in clinical settings; the other parts were included to investigate the importance of the various potential sources of error.

Statistical analysis

The accuracy of the measurements was estimated by the generalizability theory.^{49,50} The accuracy is expressed in the generalizability coefficient (GC) and the standard error of measurement (SEM). The GC is a measure related to the intraclass correlation for analyses when several observed factors (facets) influence a measurement. In dentistry, the generalizability theory was successfully applied previously.^{51,52}

In the context of the generalizability theory, a distinction was made between differentiation facets (aspects of the units of analysis that we wanted to investigate) and instrumentation facets (measurement procedure).⁵⁰ In this case, subject and teeth are differentiation facets; rater, selection, and replication are instrumentation facets. In the generalizability theory, the influence of these facets are investigated by computing the amount of variance they take into account.

These analyses were performed for the 4 parts of the study defined in Table I. In part 4, there were 2 sets of measurements that could be used for the analysis (A vs C and A vs D). For this part, the mean value of the 2 sets is given. Moreover, for the analyses, types of teeth were clustered (anterior teeth, premolars, and molars) to study the effect of tooth position (anterior vs posterior) on reliability.

RESULTS

Table II shows the means and standard deviations for the measurements in the 4 situations. During spontaneous smiling, the maxillary teeth and the gingivae were displayed more than in any of the other situations.

In Table III, the GC and the SEM were calculated for part 4. There was high conformity between the measurement values: the GCs varied between 0.99 and 0.80, with an average of 0.94. Sometimes teeth were not displayed during smiling or speech. For some types of teeth, this occurred in more than 50% of the cases. Then no values were reported because this could lead to flattered reliability results. Table III shows that conformity between the observations decreased when the observations were localized more to the posterior. This had consequences for the accuracy of the measurements as can be concluded from the increasing SEM.

The dynamics of the registered situation also played a role in the accuracy of the measurements. The posed social smile was a more static recording; spontaneous

Table II. Means and standard deviations (mm) of tooth and gingival display in 4 situations

Situation	<i>I1</i>	<i>I2</i>	<i>C</i>	<i>P1</i>	<i>P2</i>	<i>M1</i>
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Maxilla						
Full dentition*	10.8 (1.3)	9.6 (1.3)	10.7 (1.3)	8.4 (1.0)	7.6 (1.0)	7.2 (0.8)
Spontaneous smiling	11.2 (2.7)	11.2 (2.8)	11.7 (2.9)	11.4 (2.9)	10.5 (3.1)	9.0 (3.6)
Posed smile	9.7 (3.7)	9.5 (3.8)	9.6 (4.0)	8.8 (3.8)	7.7 (3.8)	5.0 (4.3)
Speech	8.1 (2.5)	7.5 (3.1)	6.4 (2.8)	5.6 (3.0)	4.3 (3.2)	2.4 (3.0)
Mandible						
Full dentition*	8.5 (1.9)	9.2 (1.7)	10.2 (1.5)	8.4 (1.3)	7.2 (1.0)	7.2 (1.0)
Spontaneous smiling	3.9 (2.8)	3.6 (2.8)	2.9 (2.5)	1.3 (1.8)	0.5 (1.1)	0.2 (0.8)
Posed smile	2.9 (2.6)	2.6 (2.4)	2.1 (2.2)	1.1 (1.6)	0.4 (1.1)	0.3 (0.8)
Speech	6.6 (3.4)	6.5 (3.2)	5.3 (2.7)	3.4 (2.6)	1.8 (1.9)	1.1 (1.7)

*Full dentition: actual length of tooth crowns.

I1, Central incisor; *I2*, lateral incisor; *C*, canine; *P1*, first premolar; *P2*, second premolar; *M1*, first molar.

Table III. GC and SEM (mm) for part 4

Situation	Maxilla			Mandible			Maxillary central incisor GC (SEM)
	Anterior	Premolars	First molar	Anterior	Premolars	First molar	
	GC (SEM)	GC (SEM)	GC (SEM)	GC (SEM)	GC (SEM)	GC (SEM)	
Full dentition	0.96 (0.3)	0.85 (0.4)	0.80 (0.4)	0.97 (0.3)	0.92 (0.4)	0.82 (0.4)	0.97 (0.2)
Spontaneous smiling	0.98 (0.4)	0.96 (0.6)	0.85 (1.4)	0.98 (0.4)	---/---	---/---	0.98 (0.3)
Posed smile	0.99 (0.3)	0.99 (0.5)	0.92 (1.2)	0.99 (0.3)	---/---	---/---	0.99 (0.3)
Speech	0.97 (0.5)	0.95 (0.8)	---/---	0.98 (0.5)	0.94 (0.7)	---/---	0.95 (0.5)

---/---, no display of teeth in >50% of subjects.

Table IV. GC and SEM (mm) for spontaneous smile

	Maxilla			Mandible Anterior GC (SEM)
	Anterior	Premolars	First molar	
	GC (SEM)	GC (SEM)	GC (SEM)	
Part 1 (rater effect)	0.98 (0.4)	0.98 (0.5)	0.91 (1.1)	0.99 (0.3)
Part 2 (selection effect)	0.98 (0.4)	0.98 (0.4)	0.86 (1.3)	0.98 (0.4)
Part 3 (replication effect)	0.99 (0.3)	1.0 (0.2)	0.99 (0.3)	1.0 (0.1)

smiling was more dynamic, and, during speech, the lips moved a great deal. The difficulty of selecting the optimal image increases so that there is a greater chance of discrepancies between the first and second selections. These dynamics are shown in Table III by the decreasing GCs and the increasing SEMs. In addition to the types of teeth, the last column in Table III shows the GCs and the SEMs for the maxillary central incisor so that the reliability of this method could be compared with other research methods when measurements were only taken at the maxillary central incisor. The values in Table III address the situation in which all sources of error were incorporated. To assess the influence of these sources separately, the reliability estimates for the first 3 parts are shown in Table IV. It shows that the reliability coefficients of the premolars and first molar

are not so much influenced by inaccuracies of the actual measuring (part 3) but, rather, by the selection of the records (part 2) and differences of interpretation between the raters (part 1) of the outermost edges of the teeth and the lips.

DISCUSSION

Until now, few researchers investigated tooth display and lip position, and reported reliability analyses of their methods. In the reliability analysis of Ackerman et al,¹⁷ an operator photographed 5 consecutive posed smiles in each of 10 subjects. These pictures were measured digitally by 2 raters. Intraclass correlations for gingival and incisor exposure varied between 0.90 and 0.86. Comparability with the digital video-graphic method is somewhat compromised because the

study of Ackerman et al¹⁷ involved posed social smiles. The high GCs in our study, varying between 0.99 and 0.80, show that the digital videographic method is a reliable way for smile line measurement; as in medical statistics, reliability coefficients higher than 0.80 are considered almost perfect.⁵³ Peck and Peck¹² established smile line measurement reliability with 30 double determinations at the maxillary central incisor directly on subjects with a ruler. Strauss et al⁴¹ photographed 20 subjects 5 times and measured smile lines at the maxillary central incisors and the first premolars. The SEMs were 0.2 mm (Peck and Peck¹²) and 0.3 and 0.8 mm (Strauss et al⁴¹). In both studies, smile lines were measured from the gingival margin to the border of the lip and rounded to the nearest millimeter. With measurements rounded to the nearest 0.1 mm, the digital videographic method achieves a SEM of 0.3 mm for the maxillary central incisor; this is 2.8% (value from Table III expressed relative to mean tooth length).

When measuring the more posterior teeth, the SEM increases. However, the SEMs for full dentition in Table III show that the length of a tooth can be measured accurately and that this accuracy decreases only slightly toward the posterior.

There are a number of reasons for the higher posterior SEMs in the smiling and speech situations. During smiling, only a small part of the premolars and an even smaller part of the molars are visible. This makes selection of the optimal record for these teeth complex, and, due to the shadow of the corner of the mouth, visibility is sometimes poor. Especially when only 1 or 2 mm of a tooth are visible, there is a greater possibility that it will be overlooked by a rater. In spite of the low SEMs, the GCs for full dentition decrease more toward the posterior than for other situations. This is a consequence of low variances of differentiation facets in the full dentition situation compared with the other situations. Because GC is a relative measure, in situations with low variances of differentiation facets, the instrumentation facets take a relative greater amount of variance into account.

At first sight, the restriction of the sample to military men seems to be a limitation of this study. However, because our aim was to investigate the reliability, clinical application, and scientific application of the measurement method, confounding of the results is unlikely. Regarding the feasibility of the digital videographic method, the less intrusive recording of the spontaneous smile is a main advantage of this method. The subjects felt at ease because of the absence of interfering medical devices for head standardization as used in some other studies. In combination with the comical video, it appeared not difficult to arouse

emotion-elicited spontaneous (Duchenne) smiles. Freedom of head movement was made possible by wearing glasses with a clipped-on reference standard. In spite of this, the subjects did not make large movements with their heads, according to our clinical observations. An explanation for this could be the natural eye-head synergy toward the objects observed.⁴⁸

Another important advantage of the method is that it can be used for other purposes at the same time. This study showed that it is possible to measure smile line height and tooth display not only in smiling but also in speech. The method allows other measurements to be made in the face at the same time—eg, for facial orthopedics or facial surgery.

Moreover, the scientific and clinical relevance of the digital videographic method is high. To establish perfect smiles, a diagnosis based only on clinical observation is inadequate.^{15,32} Precise measurements are needed when positioning the teeth and their gingival margins in the most attractive way relative to the smile line; especially in patients with reduced tooth display, unharmonious gingival contour, exposed posterior gingiva, occlusal cant, asymmetry of the upper lip when smiling, and gummy smile. The combined approach of orthodontic treatment and periodontal surgery in crown-length problems requires smile line and tooth display measurements for optimal planning of tooth length and gingival contour. In addition, further scientific research in lip and tooth characteristics and facial esthetics is needed in groups such as cleft lip and palate (CLP) patients, and facial paralysis and trauma patients. In particular, in CLP patients, studies analyzing smile line and smile esthetics are relatively rare. In addition to anatomical restrictions, nonverbal behavior in CLP patients is often psychologically influenced by negative self-esteem based on facial disfigurement. Adachi et al⁵⁴ reported infrequent and less expressive smile behavior in CLP patients. In these expression-inhibited groups, the digital videographic method has unique possibilities for research because of the capacity of recording and measuring emotion-elicited spontaneous smiles. An adequate smile analysis in other expression-inhibited groups—ie, psychologically compromised patients with depression or anorexia nervosa—is also an application for this method.

Those who worked with the digital videographic method found it easy to use. Assistants could carry out this method very well. It can easily be used in a clinical setting because the equipment—digital video camera, television set, and spotlights—is commonly available. In this study, calibration, measurement, and filing of the records were done with the help of the Digora program for dental radiography. Many dental radiographic and

other software programs are available, containing digital measurement devices in which pixel distances can easily be calibrated. The choice of an equivalent software program is therefore conceivable.

CONCLUSIONS

A reliable assessment of the smile line and tooth and gingival display during smiling and speech can be obtained with this digital videographic method. Moreover, this method is suitable for clinical practices. In view of the increasing esthetic demands of patients with regard to orthodontics, esthetic dentistry, and dental surgery treatment, irreversible procedures in dentofacial esthetics should be undertaken only when adequate information is obtained regarding the smile and functional tooth display.

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