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Analysis of changes in gingival contour from three-dimensional co-ordinate data in subjects with drug-induced gingival overgrowth

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Abstract

Objectives: This aim of this study was to develop and assess a technique that could be used to assess accurately the gingival volume changes seen in drug-induced gingival overgrowth by the analysis of data obtained from an entire gingival surface by means of three-dimensional imaging.

Material and Methods: Stone dental models of patients before and after gingivectomy procedures were digitized with a laser scanner and then regenerated as computer models constructed from the acquired three-dimensional co-ordinate data. A comparison of superposed ''before'' and ''after'' surfaces was undertaken to assess and accurately quantify changes in gingival contour.

Results: The mean vertical tissue reduction varied from 1.58 to 2.56 mm in the four study subjects and individual differences are shown. The maximum thickness of removed buccal gingival overgrowth was found to range between 1.20 and 3.40 mm. The volume of tissue removed from each inter-dental papilla ranged from 4.2 to 46.1 mm^3 and the mean volume of the papilla removed from each subject ± SD values was 24.8 ± 13.1 mm^3.

Conclusion: This method will measure changes in gingival tissues to within 60 μm in one plane, making it ideal for the assessment of longitudinal changes in gingival contour as seen in the development of gingival overgrowth, its recurrence after surgery or the changes in volume brought about by surgery.

Key words: assessment measurement; ciclosporin; drug-induced; gingival overgrowth; laser; scanning

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Phenytoin, ciclosporin and calcium channel blockers may induce gingival overgrowth. This usually occurs within 3 months of commencement of medication and begins as an enlargement of the inter-dental papillae. As enlargement increases the condition can become disfiguring and it is frequently the change in aesthetics that causes the patients to seek treatment. However, enlargement of the lingual and palatal gingival tissues can also lead to difficulties with pronunciation and impaired clarity of speech. In addition, gingival overgrowth affects normal oral hygiene practice, and where the soft tissue encroaches onto the occlusal surface of the teeth, it may interfere with both masticatory function and be the source of pain. Gingival changes are seen in approximately 50% of patients medicated with phenytoin (Angelopoulos 1975), 6% with the calcium channel blockers (Ellis et al. 2001) and 25% with ciclosporin (Thomason et al. 1996) but this may rise to more than 60% in patients medicated with both ciclosporin and a calcium channel blocker (Thomason et al. 1995).

Assessment of Gingival Overgrowth

The changes in gingival contour seen in patients with gingival overgrowth have been classified using a wide range of methods. The simplest classifications are in the form of ordinal scales describing different levels of severity as mild, moderate or severe but with little or no attempt to describe the thresholds between the categories (Frankel 1940, Harris & Ewal 1942, Spira 1955, Klar 1973). A second form of ordinal scale classifies the severity of the overgrowth according to the amount of the tooth surface that it covers. These scales are often very similar, although the actual definition of each category may differ in different reports (Gardner et al. 1962, Aas 1963, Angelopoulous & Goaz 1972, McGaw et al. 1987, Bäckman et al. 1989, Pan et al. 1992, Pernu et al. 1992, 1993a, b).

A number of authors have used the measurement of probing depths as a means of assessing gingival overgrowth although this only measures overgrowth in the vertical plane (Lundstrom et al. 1982, Dahllof & Modéer 1986, Modeer et al. 1986, Modéer & Dahllöf 1987, Wondimu et al. 1993, Somacarrera et al. 1994). In an attempt to overcome this weakness, one group of workers also incorporated the measurement of gingival width in the assessment of phenytoin-induced gingival overgrowth (Dahllof & Modéer 1986, Modeer et al. 1986, Modéer & Dahllöf 1987).

Objective Evaluation

With the notable exceptions of those recording probing depths and gingival width (Dahllof & Modéer 1986, Modeer et al. 1986, Modéer & Dahllöf 1987), classification has been based on changes of contour in the vertical plane only. In an attempt to overcome this limitation, Hassell et al. (1984) proposed a more objective method of scoring the three-dimensional changes in overgrowth. Dental models were sectioned with a die saw in the inter-dental region. The long axis of the tooth and the depth of the sulcus were inscribed on the cut stone surface and the cut surface was then photographed. The resulting 35 mm slide was projected from a set distance onto a screen, together with a second image of a scale grid. Grid squares were counted, and the total number of complete grid squares for all the cut surfaces was divided by the number of surfaces (teeth) counted in order to derive the total patient score.

The problem of assessing the volume of overgrowth rather than just the increase in size in one plane was addressed the following year by a different group of workers (Seymour et al. 1985). Scoring was undertaken on plaster study models derived from alginate impressions. Gingival units based on a single inter-dental papilla were identified, and overgrowth was assessed in both the horizontal and vertical planes. The two scores were added, giving an overgrowth score for each gingival unit. Twenty gingival units were identified, each potentially scoring a maximum of five and thus a maximum overgrowth score for a patient of 100; this can be conveniently expressed as a percentage (Seymour et al. 1985). This system of scoring gingival overgrowth, like the system proposed by Hassell, allows assessment of overgrowth in both horizontal and vertical planes. Ultimately, it may be criticized in relying more on assessment of changes from an assumed normal, rather than absolute measurement of change.

This aim of this pilot study was to provide a more objective and accurate assessment of the volume of overgrowth and also of its extent and distribution by the analysis of data obtained from the entire gingival surface by means of three-dimensional imaging. Because of its general applicability to many aspects of morphological analysis, this technique has been used in numerous dental investigations using a variety of data acquisition systems (Lambrechts et al. 1984, DeLong et al. 1985, Roulet 1987, McDowell et al. 1988, Jovanovski et al. 1996, Chadwick et al. 1997, Mehl et al. 1997, Jovanovski & Lynch 2000). Typically, replicas of the study surface are digitized by a device that captures (x, y, z) co-ordinates by tactile or optical means. From the acquired data, a computer model of each study surface is constructed and measurements are made using appropriate software. Additionally, a sequence of replicas of the same oral structure can be superposed (brought into a common reference frame) to enable detection and measurement of changes such as post-surgical re-growth, which occur over a period of time. In this way, the use of three-dimensional imaging at two separate time points should allow an objective and accurate assessment of the changes in contour that occur over specific time periods.

Material and Methods

As outlined in the previous section, the measurement of changes in gingival contour is carried out on reconstructed computer models of a sequence of replicas of the study surface. The procedures consist of the following stages:

(a) Production of models before and after the period of change.
(b) Data acquisition.
(c) Construction of a mathematical description and a corresponding computer model of the replicated surfaces.
(d) Superposition of a sequence of surfaces in order to bring them into a common reference frame.

An overview of the methodology is presented here. Details of the underlying theory can be found in the original articles by Taylor et al. (1993) and Jovanovski & Lynch (2000).

Clinical procedures and replication methods used in the present study

It is frequently necessary to consider surgical re-contouring of the gingival tissue to facilitate oral hygiene, as well as to overcome problems with aesthetics, speech or masticatory function in patients with drug-induced gingival overgrowth. The surgical treatment of choice is gingivectomy, which was first advocated for drug-induced gingival overgrowth in 1941 (Thompson & Gillespie 1941). Conventionally, the excess tissue is released by means of a long bevel incision, which should ideally allow the complete removal of pocket tissue as part of the excised tissue mass, particularly in the inter-dental region. Plaster models derived from alginate impressions (Kromopan BDS-International, Barnsley, UK) taken in stock trays before and 1 week after surgery were used to record the gingival contour from four subjects who were undergoing gingival surgery to reduce the severity of their gingival overgrowth.

Data acquisition

The study models were digitized by a Laserscan 3D Pro system (Willytec GmbH, Gräfelfing, Germany.) located at the Queen's University Dental School in Belfast (Fig. 1). Designed specifically for dental applications, the Laserscan operates on the principle of optical triangulation. The model is illuminated with a stripe of light from a semiconductor laser to produce a planar curve that is imaged by a charge-coupled device (CCD) camera. This is a type of semiconductor image-sensing device that is commonly used in video cameras, consisting of a rectangular matrix of microscopic, individual sensing elements, each of which corresponds to an image pixel. The known relative positions of the laser source and the camera optics permit computation of the spatial co-ordinates of points on the curve. A series of successive planar data sets are obtained by the stepwise movement of the translation stage on which the model is mounted. The resulting speed of acquisition is 8000–14,000 points per second. The manufacturer's specifications give the accuracy of the system as better than 8 μm and its reproducibility as 2 μm. These values are in line with the evaluation performed by Mehl et al. (1997).

The data point spacing for this study was selected to be 100 μm in the *x*–*y* plane. Each set of acquired data contained an average of 100,000 points. A pair of pre- and post-operative regions of interest are shown in Fig. 2 as are the corresponding sets of acquired data points.

Fig. 1. Laserscan 3D Pro system with model in situ.

Surface reconstruction

Each acquired data set consists of discrete (x, y, z) data points. The nature of the data acquisition process is such that for any data point acquired at a particular location (x_0, y_0) on a pre-operative study model, it is not possible to guarantee the existence of a corresponding data point acquired at the same (x, y) co-ordinates on the post-operative model. As the measurement of changes in gingival contour requires computation of the difference in the z co-ordinates between pre- and post-operative data sets, it was necessary to produce a continuous surface representation whose mathematical form is $z = f(x, y)$. Such a representation was obtained by interpolating each data set with bicubic spline surfaces (Cox 1982). The spline surface representation permits rapid evaluation of the z co-ordinates, accurate measurement and realistic rendering of the reconstructed surfaces (Fig. 3).

Superposition

The detection and measurement of differences between a pair of sequential data sets requires that the data sets lie in the same frame of reference, i.e. that the numerical co-ordinates of corresponding anatomical features are the same on both data sets. In practice, the study models cannot be mounted on the laser scanner's measuring platform with sufficient accuracy to ensure identical placement and orientation. Instead, the adjustment of orientation is performed on the acquired numerical data by a co-ordinate transformation that fits the post-operative data set onto the pre-operative one. However, as the two data sets are not identical the fitting is performed only on the basis of data from the *stable regions* provided by the ''visible'' (i.e. exposed) portion of the buccal surfaces of the teeth – regions that are assumed to have remained unchanged or undergone only small changes (Fig. 4).

A co-ordinate transformation τ that corresponds to the motion of a rigid object is uniquely determined by six parameters – three rotation angles and a 3×1 translation vector. If S denotes the bicubic spline interpolant of the pre-operative data set and P denotes the set of points that form the stable regions of the post-operative data set, then an optimal transformation leading to a best fit will have the property of minimizing the sum of squares of distances between the surface S and the set of transformed points $\tau(p)$. The process of determining the optimal transformation is therefore a least squares problem with six unknowns and as such is readily solved by standard methods (Gill et al. 1981). Previous accuracy assessments have shown that method errors in computing co-ordinate transformation are negligible (Jovanovski 1999).

Measurement of linear dimensions and volume

With appropriate software, the superposed computer models can be analysed in a number of ways that permit differences in shape to be visualized and accurately measured.

Cross-sections can be made through pre- and post-operative surfaces at the same locations. Figure 4 illustrates two such cross-sections, one through the stable reference regions formed by the tooth surfaces, and the other through the gingivae. As expected, there is a very close match along the cross-section that passes through the stable region. Simultaneous cross-sections permit the thickness of removed tissue to be measured at any selected location (Fig. 5).

An overview of the magnitude of change over an entire region of interest is provided by colour-coded subtraction maps (Fig. 6). The subtraction method is also used to measure the volume of removed tissue and to provide additional statistics relating to the distribution of

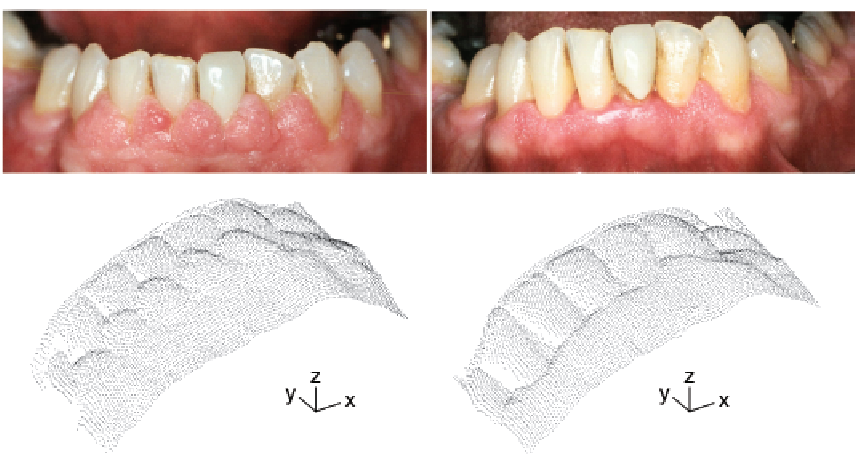

Fig. 2. A region of interest, before and after surgery shown clinically and as acquired data (shown with reduced density).

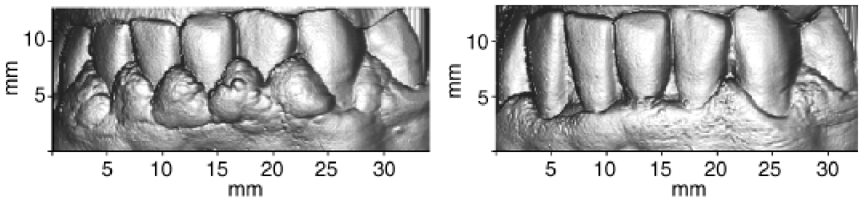

Fig. 3. Surfaces of Fig. 2 reconstructed from acquired data.

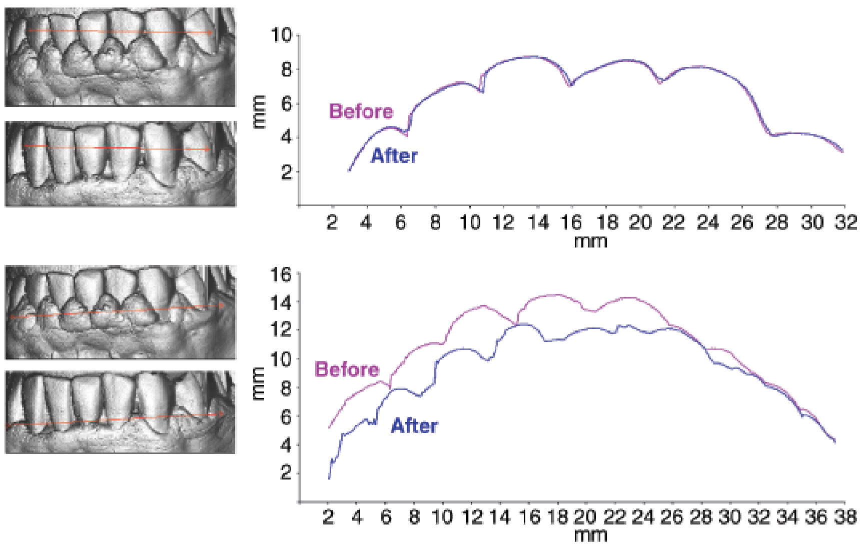

Fig. 4. Cross-sections through superposed surfaces.

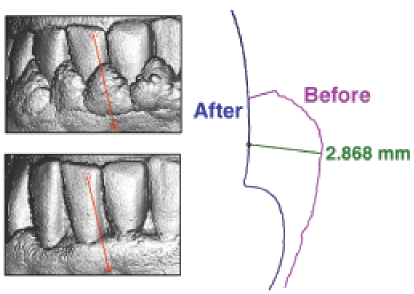

Fig. 5. Measurement of thickness of removed tissue.

the differences between the two surfaces (Fig. 7).

Results

The reductions in the maximum vertical coverage of the buccal surface of the teeth by the overgrown gingival papillae are shown in Table 1. The mean tissue reduction varied from 1.58 to 2.56 mm in the four study subjects, and individual differences are shown. The maximum thickness of removed gingival overgrowth was found to range between 1.20 and 3.40 mm. The overall mean ± SD of measurements made on four subjects were 2.15 ± 0.60 mm (data not shown).

The reduction in the volume of each individual papilla (as represented by Fig. 6) resulting from the surgical procedure is shown in Table 2. The mean volume removed for each subject ranged from as little as 7.10 to 34.72 mm^3. The volume of tissue removed from each inter-dental papilla ranged from 4.2 to 46.1 mm^3, and the mean volume of the papilla removed from each subject ± SD values was 24.8 ± 13.1 mm^3. Both the greatest reduction of any one papilla (between 13 and 12) and the greatest variation in the volumes of papilla tissue removed were seen in subject no 4 (SD of 12.25). The missing data for 22–23 in subject 2 resulted from incomplete recording of the papilla area in the impression at the post-surgical visit.

Discussion

The accuracy with which changes in gingival contour can be detected and quantified is directly dependent on the accuracy of the pairwise superposition of the pre- and post-operative models. If the models are not accurately superposed, then all measurements of lengths and volumes will be subject to an additional error proportional to the extent of the misalignment (Fig. 8).

Previous assessments of the method accuracy, performed on synthetically generated computer models of teeth, have shown that method errors in computing the optimal co-ordinate transformation are negligible and that errors in superposing occur because the stable (unchanged) reference regions, which form the basis for superposing, are not perfectly identical in practice (Jovanovski 1999).

Dissimilarities in the nominally identical stable regions can be attributed to errors in replicating, digitizing and reconstructing the computer models of the tooth surfaces. These errors have been found to be 10 μm on hard tissue and 45 μm on soft tissue (e.g. gingivae), whose replication exhibits lower reproducibility than that of hard tissue (Jovanovski & Lynch 2000).

Furthermore, errors can be introduced by incorrect assumptions about the extent of the stable regions when their outline is traced by the operator of the superposition software, although it is possible to compensate for this automatically by removing outlier points from consideration. Superposition accuracy is also dependent on the size and spatial distribution of the stable regions. A detailed analysis is given by Jovanovski & Lynch (2000).

Regardless of the causes of errors, it is possible to determine whether the superposition has been performed with sufficient accuracy by analysing the goodness of fit of the superposed stable regions. This can be carried out visually by means of a subtraction map similar to the one in Fig. 6 or numerically by computing the root mean square (RMS) of the differences in the z co-ordinate between the baseline pre-operative and superposed post-operative surface.

In this study, the stable regions consisted of the surfaces of the teeth adjacent to the gingival region of interest. Replication was performed with plaque removed. In some cases, much of the tooth surface was obscured by the overgrown gingivae but not to an extent that would have a significant adverse effect.

The RMS goodness of fit ranged from 10 to 30 μm except in cases where

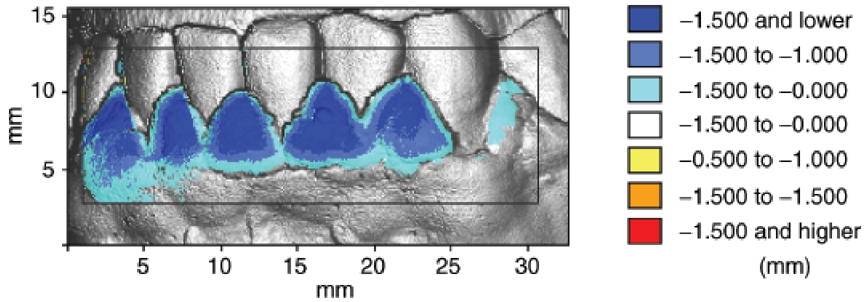

Fig. 6. Subtraction map showing overall magnitude of change. Blue colour indicates loss.

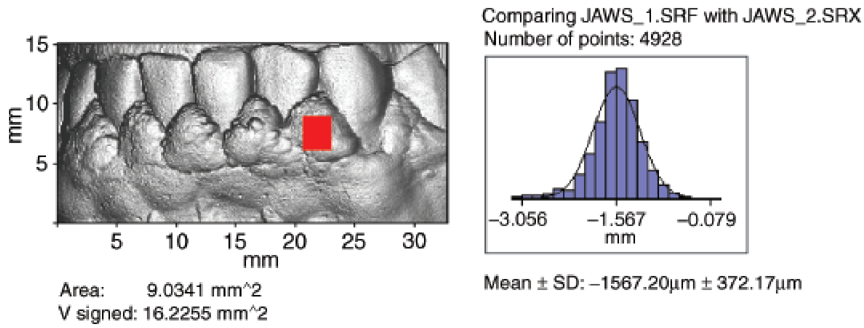

Fig. 7. Measurement of change over a selected rectangular region of 9 mm^2, showing a total volume loss of 16.2 mm^3 over that region. The mean depth loss over that region was 1.567 mm.

Table 1. Mean height of tissue removed (mm)

Subject no.	Inter-dental papilla					Mean	SD
	13–12	12–11	11–21	21–22	22–23		
1	3.0	2.0	1.8	3.4	2.4	2.52	0.60
2	1.6	1.3	1.9	1.5	Missing	1.58	0.22
3	2.5	2.6	3.3	2.5	1.9	2.56	0.45
4	1.9	2.2	1.2	2.0	1.8	1.82	0.34
Mean	2.25	2.03	2.05	2.35	2.03		
SD	0.54	0.47	0.77	0.70	0.26		

Table 2. Volume of tissue removed from each inter-dental papilla (mm^3)

Subject no.	Inter-dental papilla					Mean	SD
	13–12	12–11	11–21	21–22	22–23		
1	21.8	24.5	14.8	39.8	14.1	23.00	9.30
2	6.8	4.4	13.0	4.2	Missing	7.10	3.56
3	33.0	28.2	36.8	38.5	37.1	34.72	3.73
4	46.1	18.6	17.0	43.9	28.5	30.82	12.25
Mean	26.93	18.93	20.40	31.60	26.57		
SD	14.46	9.06	9.57	15.94	9.49		

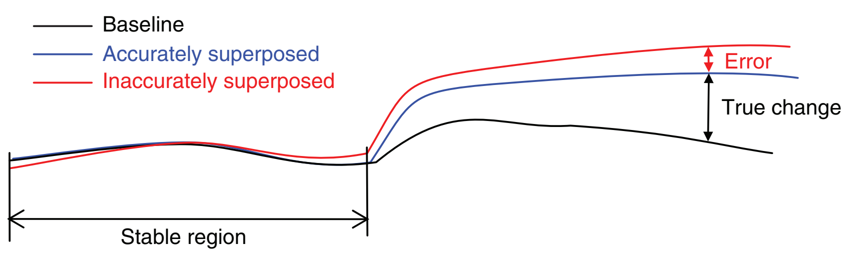

Fig. 8. Inaccurate superposition and its effect on measured changes.

movement of individual teeth had occurred (Fig. 9). Such cases were readily detectable by their poorer goodness of fit and instead of assuming a single stable region consisting of all the tooth surfaces, measurements were obtained by consecutively performing locally accurate superposition of individual teeth.

On the basis of the values given above, it can be concluded that measurements of changes in gingival thickness are accurate to 60 µm, or 3% of the mean measured change.

This methodology allows the assessment of small gingival changes and as such would be an ideal method for assessment of longitudinal changes in gingival overgrowth. Equally, it could be applied to other assessments of soft tissue changes such as following crown lengthening procedures and assessment of the re-establishment of biological width.

Conclusions

This methodology of analysing digitized replicas has been applied in a number of previous studies (Savill et al. 1998, Snider et al. 1999, Yeganeh et al. 1999a, b) that have showed it to be capable of providing objective and accurate assessment of morphological change. This method will measure changes in gingival tissues to within 60 µm in one plane, making it suitable for the assessment of small changes in gingival contour. As such, it would be an ideal method for assessment of longitudinal changes in gingival contour as seen in the development of gingival overgrowth, its recurrence after surgery or the changes in volume brought about by surgery.

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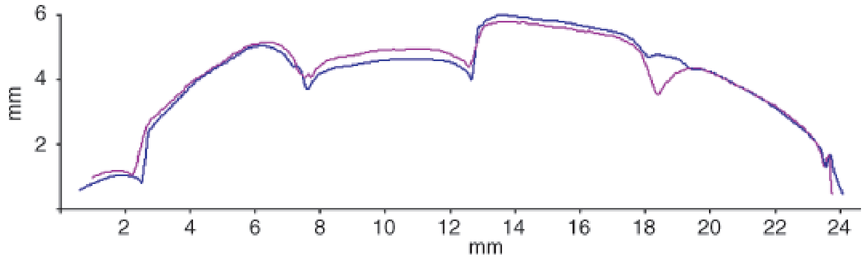

Fig. 9. Cross-section showing movement of teeth.

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