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An Evaluation of the Changes in Maxillary Pulpal Blood Flow Associated with Orthognathic Surgery

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Abstract: *The objective of this study was to evaluate the use of the Laser Döppler Flowmeter (LDF) in the measurement of pulpal blood flow following orthognathic surgery and to conduct an initial study of the effects of a Le Fort I osteotomy on the pulpal blood flow of the maxillary central incisors. The design consisted of a preliminary prospective controlled consecutive clinical trial undertaken at the Orthodontic Clinic, University Dental Hospital NHS Trust, Wales, 1994.*

The study group consisted of 15 consecutive patients who were to receive a standard advancement Le Fort I osteotomy. Seven patients who were to undergo a mandibular advancement only acted as a control. A further 20 separate patients participated in a study for the assessment of measurement error. The blood flow in relative perfusion units v. *time, was measured using a Laser Döppler Flowmeter.*

Measurement error for flowmeter recordings with hand-held application and custom-made splint support showed no consistent difference or significant random variation between the two methods for holding the probe against the teeth (pooled S.D. of reproducibility <u>*1/1*</u> *= 1·91/1·39 for custom splint location as opposed to 0·96/1·07 for hand-held/fixed bracket location).*

For the surgical patients under investigation no significant differences for maxillary pulpal blood flow were found in the control group (mandibular osteotomy) over time. However, in the maxillary osteotomy patients there was a tendency for an initial rise in the maxillary perfusion post-surgery as measured at the central incisor pulps, followed by an overall reduction at 6 months. As an example, the mean value for the upper right central showed a significant increase in blood flow during the immediate post-operative period ($P < 0·05$*), but at 6 months after surgery demonstrated a statistically significant overall reduction in comparison with the presurgical reading (*$P < 0·001$*).*

The laser Döppler flowmeter is not an easy instrument to use in the clinical assessment of pulpal blood flow. However, it would appear from these longitudinal series of readings, taken over a 6-month period on 15 patients, that the maxillary perfusion recorded at the central incisor pulps may be permanently affected in many Le Fort I osteotomy patients. For patients that already have a prejudiced blood supply this could lead to devitalization and discoloration of incisors. It is not known if this affect on the perfusion of the pulp continues beyond 6 months post-surgery.

Index words: Döppler Flowmeter, Le Fort I, Maxillary Osteotomy, Pulpal Blood Flow, Pulpal Perfusion.

Refereed Paper

Introduction

Orthognathic surgery for the correction of dentofacial discrepancy is now performed routinely in numerous centres around the world. Maxillary surgery to correct facial deformity was first described earlier in the century (Blair, 1907), but was popularized through the work of more recent authors (Willmar, 1974; Bell, 1975; Epker, 1984a,b). However, although surgeons and orthodontists, working as a team, routinely achieve results of consistent quality (Proffit, 1993; Epker *et al*., 1996), nonetheless, it is true that, as in all surgery, there is also an associated morbidity (De Mol Van Otterloo *et al*., 1991). Possible adverse consequences include infection, development of periodontal defects (Carroll *et al*., 1992), poor bony union, degenerative pulpal changes (Vedtofte, 1989), or, in extreme circumstances, the partial or total loss of a repositioned maxillary bony segment. The full spectrum of possible sequelae is reported by Lanigan and his co-authors (1990).

Frequently, the severity of such sequelae may be related to the degree of any vascular impairment (Epker, 1984a, b).

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Histological examination of the dental pulps of an experimental model in animals in which osteotomies have been conducted, suggests that the changes seen after an osteotomy are similar to those seen after a traumatic injury. Browne and co-workers (1990), following a similar investigation, concluded that a Le Fort I osteotomy could result in significant pulpal change. In contrast, other workers have suggested the pulpal changes as being likely to be less dramatic (Summers and Booth, 1975; Di *et al.*, 1988).

Although there has been significant research into the change in innervation to the teeth following surgery (Leibold *et al.*, 1971; Tajima, 1975; Kahnberg & Engstrom, 1987) and it has been identified that 6–29 per cent of teeth remain insensible for up to 54 months after surgery (De Jongh *et al.*, 1986), this does not provide any information as to the actual change in tooth vitality. With this in mind it would seem that further and more specific research is needed in this area, and that the more sensitive versions of the Laser Döppler Flowmeters (LDF) now being developed to work in the dental arena (Gazelius *et al.*, 1986, 1993; Olgart *et al*., 1988) may be able to provide more detailed information as to the changes in pulpal blood flow following a maxillary osteotomy. There have been some early reports of initial LDF applications to the examination of gingival (Geylikman *et al.*, 1993) and pulpal (Ramsay *et al.*, 1991) blood flow changes in the months following maxillary surgery. More recently, work has been published where the Laser Döppler Flowmeter has been applied to examine gingival blood flow changes during maxillary surgery following ligation of the greater palatine artery (Dodson and Bays, 1997).

The two main objectives of the current study were:

(1) to evaluate the use of the Laser Döppler Flowmeter (LDF) in the measurement of pulpal blood flow on patients in the clinical environment;
(2) to conduct an initial study of the effect of a Le Fort I Osteotomy on the maxillary perfusion as related to pulpal blood flow of the maxillary central incisors over the 6 months following a Le Fort I osteotomy.

Method and Materials

Two studies to address these objectives are reported, the method for each being separately described.

Study 1: to compare the stability (reproducibility) of LDF readings of pulpal blood flow in human subjects when using two different methods of contacting the probe to the tooth surface.

Study 2: to analyse the effect of a Le Fort I osteotomy on the maxillary perfusion, recorded as central incisor pulpal blood flow, in a series of patients.

Apparatus

The instrument used for all measurements was the Laser Blood Flow Monitor MBF 3D (Moor Instruments, Axminister, Devon. U.K.). The full specification of this instrument has been described previously (Buckley, 1994). When using the LDF, the blood flow measurement is the product of moving red blood cells and their mean velocity. It is usually termed ‘flux’ and is measured in arbitrary perfusion units.

Procedure

Prior to data collection patients rested supine for 5 minutes in the dental chair. They were then encouraged to remain as stationary as possible during the measurements. In every instance the probe was brought consistently, by one of the techniques to be described, into steady contact with the tooth after the enamel had been dried using cotton wool. The probe was placed midway mesiodistally approximately 4–5 mm from the gingival margin. During the first 2 minutes of recording the flux signal was observed and its pulsatile nature confirmed. Once steady, a sample of this reading was taken over a 3-minute period. From this sample the mean flux was then calculated, any obvious artefacts being excluded, and a calculation applied to allow for the background ‘noise’ in the system. When the LDF is functioning, even if the returning laser beam has been reflected off a stationary object, there will be background noise in the system. Such noise, generated by the L.D.F. at any moment, is related to the direct current (DC) reading at that time. A table of values was recorded which correlated the background flux reading to the corresponding DC reading (Matthews, 1992; Boggett, 1992, personal communication). For any given flux reading, by noting the DC reading, it was possible to allow for the portion of the flux signal which was attributable to the background noise in the system.

Study 1

In this study two groups, each of 10 subjects, were collected.

In group A, consecutive patients, about to start orthodontic treatment, had LDF measurements taken using a hand-held probe. This group, although they had brackets attached to the teeth, had no archwire placed, since there is some evidence that initial loading can have an effect on pulpal blood flow (McDonald and Pitt Ford, 1994). The exact technique is described elsewhere (Buckley, 1994), but essentially the probe was localized using the fixed appliance bracket bonded to the tooth. In particular, the probe was held, using digital pressure, in between the superior wings of the Siamese bracket and maintained in a steady position perpendicular to the enamel surface. A similar technique has been described previously (Anderson *et al.*, 1995). Encouragingly, these workers found such an approach to provide both stable and repeatable blood flow measurements, during surgical manipulations.

In group B, 10 further subjects had readings taken prior to placement of any brackets, using a custom-made splint to localize and stabilize the probe. The nature of the splint is described more fully elsewhere (Buckley, 1994), but broadly followed techniques described previously, where a rubber base material was employed (Olgart *et al.*, 1988; Matthews, 1992, personal communication). This is a polyvinyl siloxane impression material (Kerr Extrude: Kerr UK Ltd, Peterborough). The material was supported by a standard orthodontic impression tray, and stainless steel tubes were placed to facilitate the accurate application and location of the probe.

For every subject a steady sample of the LDF reading for each maxillary central incisor blood flow was taken on three different occasions, 1 week apart.

Study 2

In this part of the study 15 consecutive patients due to undergo a standard Le Fort I osteotomy were recruited. In addition, another seven patients due to receive a mandibular operative procedure alone were also recruited. The age of the subjects ranged from 16 to 34 years.

The mean blood flow (flux) was recorded on four occasions:

T1 within 1 week prior to orthognathic surgery;
T2 between 1 and 2 weeks after surgery;
T3 between 4 and 5 weeks after surgery;
T4 as close to 6 months post-surgery as possible.

Following the results of Study 1, all readings for the osteotomy patients were taken using the 'hand-held' technique to apply the probe, using the fixed orthodontic bracket for accurate and consistent location.

Results

Study 1

To examine the relative stability and reproducibility of reading with the Laser Döppler Flowmeter, right and left maxillary central incisor blood flows, measured as Relative Perfusion Units (RPU's), are shown in Tables 1 and 2. The serial recordings are presented as: R1 = 1st week; R2 = 2nd week; R3 = 3rd week. Table 1 shows the results for group A (where the probe was 'hand-held' using the brackets as locators), whilst Table 2 shows similar results for group B (where the probe was located with the 'custom-made' splint). Different groups of patients were used for each exercise.

Figure 1 illustrates most clearly the relative stability over time of the readings of mean blood flow when using the two

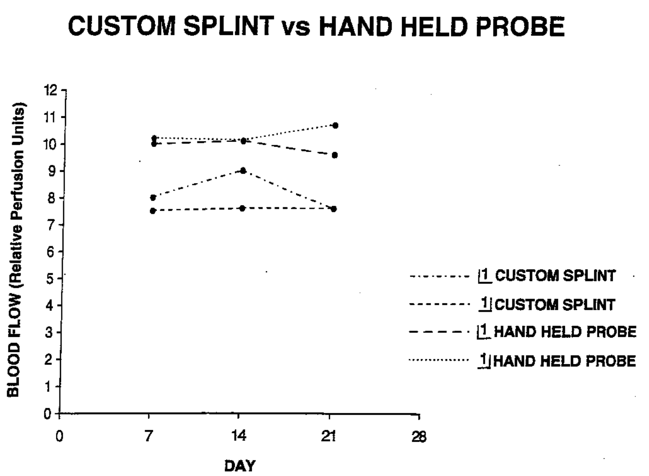

FIG. 1 Comparison of two different techniques of placing LDF probe against labial surface of maxillary incisors.

different techniques for positioning and holding the probe against the labial surface of the two incisors.

In Table 3 (a,b) the outcome of the statistical analysis of these results is presented. Separate two-way analyses of variance were performed for both groups for both upper central incisors. To give an indication of the variability of the readings over time with the two techniques of positioning the probe the *F*-ratios given in Table 3a show the systematic variation, and the standard deviations of reproducibility (S.D.) in Table 3b show the random variation. This suggests that the variation was a little increased with the custom splint technique (S.D. = 1·91/1·39) in comparison with the hand-held/bracket-located approach (S.D. = 0·96/1·07). This difference in variability and reproducibility between the two techniques was judged to be of marginal significance within the context of the main study: there was no clear evidence that either technique was superior to the other in measuring pulpal blood flow with the LDF.

TABLE 1 *Group A: Hand-held probe—serial readings of blood flow (readings for right/left maxillary incisors at R1 – first week, R2 – second week, R3 – third week)*

Subject	R1	R2	R3
1	14·7/11·9	13·7/12·6	15·0/11·9
2	8·6/8·1	6·3/9·1	9·2/8·3
3	7·0/6·8	9·0/7·5	7·4/8·2
4	4·8/6·2	4·4/5·9	5·3/5·5
5	11·9/12·9	11·4/13·2	11·2/10·8
6	13·2/15·4	13·8/12·9	14·7/14·5
7	7·7/6·6	6·4/7·9	9·9/7·4
8	12·0/10·7	14·3/12·1	15·1/12·5
9	10·2/11·8	11·1/9·7	9·8/8·4
10	11·3/9·1	11·2/10·3	10·1/8·9

TABLE 2 *Group B: custom-made splint held probe—serial readings of blood flow (presented to same format as previous table)*

Subject	R1	R2	R3
1	3·7/4·5	5·5/6·5	3·8/5·0
2	9·7/11·7	9·0/12·2	6·5/8·5
3	5·5/7·0	5·2/7·0	6·5/7·0
4	5·0/9·7	7·2/10·0	5·7/7·7
5	12·2 /10·7	11·5 /11·7	8·2/8·5
6	9·5/12·5	8·0/11·0	11·7/9·7
7	8·0/7·5	11·2/7·5	11·5/15·5
8	8·7/7·5	7·0/4·3	9·5/4·5
9	0·8/0·7	0·9/0·9	0·9/0·9
10	11·7/9·2	12·0/ 10·5	12·7/9·0

TABLE 3 *(a) Analysis of variance for repeated blood flow measures. F ratios (2 and 18 df) testing for systematic variation over time*

	Upper right central	Upper left central
A: Hand-held probe	0·62	1·13
B: Custom splint-held probe	0·21	0·10

TABLE 3 *(b) Random variation over time presented as pooled standard deviations*

	Upper right central	Upper left central
A: Hand-held probe	0·96	1·07
B: Custom splint-held probe	1·91	1·39

Study 2

Table 4 shows the blood flow perfusion recorded for the two maxillary incisors at times T1 (presurgery); T2 (1–2 weeks post-surgery); T3 (4–5 weeks post-surgery); and T4 (16–26 weeks post-surgery) in those patients that received a Le Fort I osteotomy.

Table 5 shows the serial blood perfusion readings for the maxillary incisors in a similar format to Table 4, but for the seven patients that had a sagittal split mandibular osteotomy only.

The data for the blood flows from the surgical patients in Study 2 was found to be skewed when plotted. This being the case, for the purposes of hypothesis testing, the values for relative perfusion units were transformed to a $\log_{10}$ scale so that the data would approximate a more normal distribution. Due to the nature of the data a two-way analysis of variance (ANOVA) was performed first, in order to compare the four time points on an 'equal footing'. This suggested highly significant differences for the Le Fort I group of patients over time. No significant differences were found for the much smaller group of patients that had received a mandibular osteotomy. Simple paired sample *t*-tests were then performed to present the statistically significant differences between the pre-operative readings and each of the serial post-operative readings. The results of the statistical analysis are summarized in Table 6, mean values and standard deviations for the blood flow in each tooth are also included in this table.

A Wilcoxon matched pairs signed Ranks test on the original untransformed data gave very similar results.

The overall tendency was for the pulpal perfusion reading to increase for both central incisors immediately after surgery then to be followed by a steady decline until at T4 (approximately 6 months after surgery) there was a significant fall compared with the original pre-surgical reading. Figure 2 graphically illustrates this change in the average blood flow of the upper incisor pulps over time, presenting a comparison of the mean perfusion for both the maxillary and mandibular osteotomy patients.

TABLE 4 *Blood flow in Le Fort I osteotomy patients (shown for right/left maxillary incisors. T1 = presurgery, T2 = 1–2 weeks post-surgery, T3 = 4–5 weeks post-surgery, T4 = 16–26 weeks post-surgery)*

Patient	T1	T2	T3	T4
1	10·7/11·7	8·8/8·3	9·1/8·7	9·7/9·2
2	9·0/10·2	13·0/10·3	10·2/12·6	4·1/3·8
3	6·6/7·0	5·8/11·1	9·1/11·1	4·3/6·1
4	9·0/9·0	13·7/12·8	7·8/8·2	5·4/6·6
5	10·8/11·0	8·5/7·6	6·8/9·1	6·0/6·6
6	11·4/13·4	15·2/14·9	14·9/15·4	6·0/6·8
7	12·2/10·1	15·1/12·3	15·4/11·1	11·7/9·8
8	8·3/6·5	12·4/12·3	10·1/8·9	7·9/4·1
9	11·5/8·8	11·7/12·0	12·8/9·1	10·1/7·9
10	14·2/14·8	14·3/15·2	14·0/10·2	13·8/15·4
11	8·6/7·9	12·4/9·6	11·5/9·8	6·2/8·1
12	12·8/10·7	13·7/12·9	13·9/11·2	9·8/9·8
13	10·3/11·5	9·4/12·1	11·9/12·7	8·6/10·1
14	11·3/10·8	15·7/12·5	13·2/12·8	9·2/8·6
15	5·3/5·9	8·1/7·0	7·1/9·0	5·3/5·6

TABLE 5 *Blood flow in mandibular osteotomy patients. (results presented in similar format to previous table for comparison)*

Patient	T1	T2	T3	T4
1	14·2/15·0	16·1/14·6	15·8/16·2	13·2/16·5
2	7·8/6·4	8·2/7·8	8·5/7·4	8·4/6·1
3	8·2/7·6	9·1/7·0	8·7/8·2	8·9/7·1
4	8·9/4·7	10·3/5·1	8·5/4·9	9·4/3·9
5	9·4/9·9	9·6/10·3	9·3/10·2	10·1/9·7
6	13·4/13·7	8·6/6·8	9·7/13·1	12·6/13·9
7	9·5/7·2	10·1/7·8	9·9/6·7	10·2/6·5

TABLE 6 *Mean values (with standard deviations) of blood flow recordings from T1–T4. Included is the statistical significance of changes in incisor blood flow over time when compared to original presurgical perfusion recording*

Blood flow recording	Maxillary osteotomy 1/	Maxillary osteotomy /1	Mandibular osteotomy 1/	Mandibular osteotomy /1
T1 Mean (S.D.)	10·1 (2·3)	9·9 (2·4)	10·2 (2·5)	8·3 (2·9)
T2 Mean (S.D.)	11·8 (2·9)	11·4 (2·4)	10·3 (2·4)	7·5 (1·6)
t-value	–2·41	–2·1	–0·12	0·52
P-value	0·03	0·05	0·9	0·62
T3 Mean (S.D.)	11·2 (2·6)	10·7 (2·0)	10·6 (2·6)	8·4 (2·9)
t-value	–1·73	–1·34	0·22	–1·28
P-value	0·1	0·2	0·83	0·22
T4 Mean (S.D.)	7·8 (3·4)	7·9 (3·0)	10·4 (1·8)	7·9 (3·2)
t-value	4·41	3·49	–1·22	1·28
P-value	0·001	0·004	0·27	0·25

Discussion

Study 1: Performance and Validity of Laser Döppler Flowmeter

It is important to realize that at the time this study was performed (Buckley,1994) that the LDF instrument being applied was working at its operational limit of sensitivity when measuring pulpal blood flow. For this reason, it was judged important to first test and evaluate the instrument in the clinical conditions it would face when measuring blood flows for maxillary osteotomy patients before moving on to the main study. Therefore, time was committed to validating and, where necessary, calibrating the instrument (study 1) prior to its application to the surgical patients (study 2). The authors would maintain that this is an

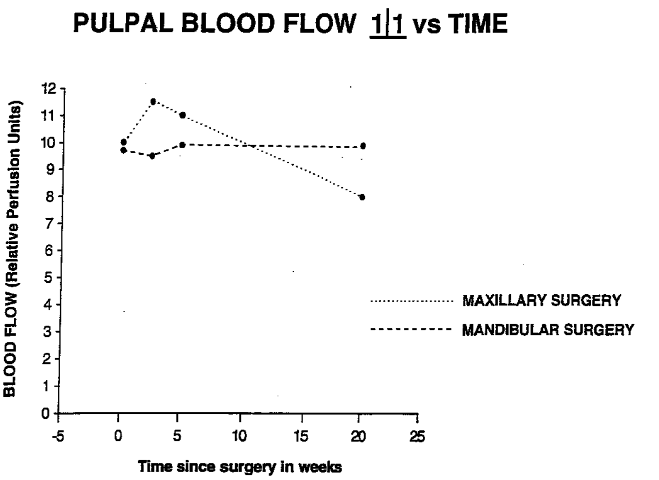

FIG. 2 Change of pulpal blood flow in maxillary incisors over time following surgery (average of means for right/left incisors).

important regimen to follow in other studies when similar instruments are applied within the dental environment, since the readings can be very prone to artefacts. The limitations of the technique can be classified under the following headings:

1. Movement artefacts.
2. Spatial variations.
3. Temporal variations.
4. Noise from adjacent tissues.

Movement Artefacts. These are caused by relative movement between the measurement probe and the tooth; an example of this might be related to an 'energetic swallow'. However, with experience, such artefacts of any significance, can be identified from the reading as an irregularity on the continuous plot. They can then be eliminated in the selection of a typical sample of flux which is to be used to reflect the mean blood flow.

Spatial Variation. Research by Ramsay and his co-workers (1991) suggests that readings from the LDF of pulpal blood flow will vary with the location of the probe on the labial tooth surface and its angulation to the prismatic structure of the enamel. The main problem would appear to be in the vertical plane and is termed spatial variation. This effect is very difficult to quantify and so particular attention was paid in the current study to consistent vertical positioning when using the two techniques of holding the probe.

Temporal Variation. On occasion, readings taken at the same location on the same tooth, apparently under similar conditions, will vary from visit to visit (Ramsay *et al.*, 1991). This is termed temporal variation and is again difficult to quantify. However, if care is taken to keep the conditions constant and the patient/reading is allowed time to settle before the sample of flux is taken, this problem can be minimized and, in any event, should be insignificant within the context of the larger changes that might be expected in the blood flow of patients receiving surgery.

'Noise' from Surrounding Tissues. This is related to the contribution to the blood flow reading from the surrounding tissues. It is possible that the gingivae can make a significant contribution to the apparent pulpal recording, Amess and co-workers (1993, 1994) have suggested that this might constitute as much as 20 per cent. The problem comes from the background 'noise', particularly from lips and tongue, and is difficult to either control or quantify, although the custom splint may provide some shielding. In the current study, care was taken to keep surrounding tissues away from the probe, but in any event, such 'noise' should have been a constant in the serial readings and would probably have moved in sympathy with the changes in pulpal blood flow. It is accepted that other techniques are available which may reduce the contribution of the surrounding tissues to the flux reading more consistently than the techniques employed in the current study (Hartmann *et al.*, 1996). However, it is not possible to apply such techniques in a study of this nature since a fixed appliance and orthodontic archwire limit the ability to use rubber-based location splints. Encouragingly, other researchers in this field have successfully employed a technique similar to that described in the current study (Anderson *et al.*, 1995).

In summary, after assessing the operational evaluation exercise performed in Study 1 it was felt that most sources of variation could be either minimized and/or would have little significance in the context of the likely serial change to be recorded in the main study (2). The results of Study 1 would confirm the view that the Laser Döppler Flowmeter is a useful clinical research tool and, in particular, could be expected to perform reasonably consistently under the clinical conditions to be experienced in the main study.

Study 2 : The Changes in Blood Flow Following a Le Fort I Osteotomy

In this part of the study, 15 consecutive patients receiving a Le Fort I osteotomy to a standardized protocol (Eales *et al.*, 1995), had consecutive recordings of blood flow taken immediately before surgery (T1) and at approximately 1, 4, and 24 weeks after surgery (T2, T3, T4). The recordings were made as close to target times as patients would allow and in any event within a few days for T1–3, and between 4 and 6 months for T4.

As well as patients who had received a maxillary osteotomy it was felt that it would be useful to collect a group that had received a mandibular osteotomy only, to allow for some examination of any physiological effects on the maxillary perfusion/pulpal blood flow of surgery in a different jaw. It was the intention to collect a similar sized group of patients as for those receiving a maxillary procedure. However, this proved difficult within the time constraints of the study since far fewer single jaw mandibular procedures are performed in the unit than was previously the case. In the event, seven patients were collected, sufficient to indicate that the physiological effect was probably not important, in that the mandibular control group showed no statistically significant mean change in maxillary blood flow as measured at the central incisor pulps over the post-operative period (Figure 2).

Some criticism may be levelled at the study with regard to the technique employed for LDF probe positioning in the surgical cases. However, the fixed bracket location system proved to be both accurate and flexible for use in the clinical environment. In the authors' opinion, this proved a far more practical method than attempting to construct and consistently locate a custom splint to fit around the fixed appliance for the serial readings. A further and, arguably, more valid criticism may be made regarding the control of 'noise' from the immediate surrounding tissues. Certainly, such an effect routinely occurs in this type of study and is probably impossible to eliminate or even accurately quantify in clinical research of this type. However, it should be borne in mind that the local tissues in this study largely form part of the osteotomized segment and, thus, their perfusion would be influenced in a similar manner to that recorded via the dental pulps. Since the 'noise' would largely be in sympathy with the blood flow recorded through the pulp the effect is of less relevance to the results of the current study.

Examining the readings in Tables 4 and 5 it is immediately apparent that there was a high variability in the maxillary central incisor pulpal perfusion over time, both between and within subjects. In neither case was this unexpected and it reflects the findings in most of the similar studies reviewed earlier. As part of this individual variability during the post-operative period some patients' dental pulps recorded hyperaemia over the post-operative period, whilst others experienced ischaemia. Generally, there was a tendency for the perfusion of the pulp to increase immediately after surgery. However, over the 4–6-month period post-surgery the mean pulpal perfusion showed a significant reduction in those patients that had received a Le Fort osteotomy. This was not found to be the case in the mandibular osteotomy patients. Ramsay *et al*. (1991) made a similar finding when they examined Le Fort I osteotomy patients, although it would appear that the overall reduction in pulpal perfusion was greater in the present study.

The clinical implications of such findings are unclear. There are two possible causes for the longer term reduction in blood flow:

(1) it may reflect a general reduction in the perfusion of the entire maxillary complex following the trauma of the osteotomy;
(2) it could reflect a reduction in the size of the pulp chamber with later secondary dentine formation.

Regarding maxillary perfusion, Nelson and co-workers (1977) recorded a significant drop in the perfusion of the maxillary complex of primates in the first hour after surgery, whilst others, taking readings in the operating theatre on human subjects with LDF systems (Dodson and Bays, 1997), found the perfusion of the gingivae to be significantly reduced immediately after surgery. Neither study looked at blood flows in the longer term. An increase in pulpal blood flow immediately after surgery was recorded in a number of subjects in the current study. Similar changes in maxillary perfusion has been noted using various recording techniques by other workers (Bell, 1975; Ramsay *et al*., 1991) and has been termed 'compensatory hyper-vascularization'. It has also been noted specifically in the pulps (Sugg *et al*., 1981; Ramsay *et al*., 1991), although the time at which it appeared seems to vary in these studies. On the other hand, some workers have noted more general maxillary ischaemic episodes immediately after osteotomy (Indresano and Lundell, 1983; Quejada *et al*., 1986; Meyer and Cavanaugh, 1976), although the research of Nelson and co-workers (1977) would suggest that not all tissues in the 'osteotomized' segment experience the same magnitude of ischaemia. Having said this, other researchers also have recorded instances of significant pulpal ischaemia following osteotomy, at least in the shorter term (Meyer and Cavanaugh, 1976; Ramsay et al, 1991).

In the current study there were individual examples of both increased and decreased pulpal perfusion immediately after maxillary surgery, but generally there was a significant tendency towards an immediate increase in pulpal perfusion. However, this was not maintained and later serial readings showed a steady decline in the measured blood flow (Figure 2). This general tendency for the pulpal perfusion to gradually reduce could be related to a genuine longer term reduction in the pulpal blood flow and/or local maxillary perfusion. It could also be related to a reactive reduction in the size of the pulp chamber with associated secondary dentine formation. This latter phenomenon has been observed previously in a similar situation (Vedtofte *et al*., 1989), although only definitely observed in 2·3 per cent of cases 28 months after surgery.

The clinical significance of the findings of the current study is unclear. Certainly, there is great individual variability in pulpal perfusion in response to surgery. However, this study would seem to indicate that in the majority of patients receiving a Le Fort I maxillary osteotomy a reduction in pulpal blood flow is likely to occur and will probably be a long-term effect. In most patients this may not be of great significance. However, if the blood supply to the pulp has been compromised previously, perhaps by an earlier traumatic episode, then one is more likely to see loss of vitality and discoloration of the incisors after surgery.

Conclusions

The Laser Döppler Flowmeter is a useful and valid means of recording the blood perfusion of the dental pulp. In particular, it is valid to apply the LDF to examine changes in pulpal blood flow in patients that have received orthognathic surgery, whilst accepting that some of the recorded change may be related to a sympathetic alteration in local maxillary soft tissue perfusion.

A technique for the hand positioning of the LDF probe around fixed orthodontic brackets is described. This technique facilitates the taking of more rapid serial recordings in the clinical environment, and provides results of similar consistency to that experienced when a customized splint is used to position and retain the measuring probe.

The Le Fort I osteotomy appears to result in an initial rise in blood flow, as measured via the maxillary central incisor pulps, immediately after surgery; this may constitute a form of hyperaemic inflammatory response. Subsequently, there is a statistically significant reduction in the perfusion of the pulp (in comparison with the presurgical value), which has still not recovered 4–6 months after surgery.

It may be wise to warn patients that are to undergo a Le Fort I osteotomy procedure that this type of blood flow change may occur and can, very occasionally, contribute to a loss of vitality and discoloration of the maxillary incisor teeth resulting in a need for root canal therapy.

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