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Comparative reproducibility of three methods of radiographic assessment of alveolar bone grafting

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SUMMARY The aims of this study were to compare the reproducibility of three radiographic methods of assessing the quality of alveolar bone grafts, namely the Bergland, Kindelan and Chelsea Scales, and evaluate their application in the mixed and permanent dentitions. Additionally the use of occlusal versus periapical radiographs was assessed. Three examiners applied each scale on two occasions to the radiographs of 48 cleft lip and palate patients who had received alveolar bone grafts in 59 sites (11 had bilateral clefts). The agreement between repeated assessments by the same observer at different time points was measured by the kappa statistic, for each of the three assessors and each of the types of radiographic scale in turn.

None of the three scales was found to be more reproducible than the others (kappa statistics for intra-observer variation ranged from 0.61 to 0.70). The agreement between observers was also similar across the three radiographic scales (multiple kappa statistics for inter-observer variation ranged from 0.45 to 0.51). Likewise, neither occlusal nor periapical radiographs were found to enable greater reproducibility of assessment. Surprisingly there was a tendency to greater reproducibility in the mixed than in the permanent dentition, which suggests the outcome of alveolar bone grafting may be assessed at an earlier stage than currently adopted. The outcome of alveolar bone grafting in this group of patients was generally successful.

Introduction

The aims of secondary alveolar bone grafting in cleft palate patients are well documented (Boyne and Sands, 1976; Bergland *et al.*, 1986; Long *et al.*, 1995; Collins *et al.*, 1998) and various methods of radiographic evaluation of the success of alveolar bone grafting have been suggested. The Bergland Scale, a four-point semi-quantitative radiographic scale measuring post-operative interdental bone height has been commonly used (Bergland *et al.*, 1986). However, during use in the United Kingdom, a flaw has been described (Witherow *et al.*, 2002) whereby a bony defect can be seen at the root apex and yet the interdental bone height is normal, thereby scoring success when in fact the graft is a partial failure. As a result of this criticism, an alternative two-part scale (Witherow *et al.*, 2002) was developed. This scale assesses the position of the bone within the cleft in relation to the full length of the root surfaces adjacent to the cleft and cleft midline at eight sites (the Chelsea Scale) and also ascribes a grade to the appearance of the bony bridge across the cleft (the Chelsea Grade). Kindelan *et al.* (1997) also developed a four-point scale comparing the percentage bony infill of the cleft site using pre- and post-operative occlusal radiographs. Initially the inter-observer agreement was quite low with only fair to moderate agreement demonstrated using kappa values (Landis and Koch, 1977). However, this improved in a second study (Kindelan and Roberts-Harry, 1999) to demonstrate substantial agreement, although differently graded radiographs were re-examined and regraded.

In addition to these three scales other methods of assessment have been used. Long *et al.* (1995) measured radiographic bone contour, making a calculation for the distortion of the radiograph whilst Rosenstein *et al.* (1997) compared computed tomographic (CT) scans with periapical or occlusal radiographs. The two methods of assessment were comparable overall for a group of patients, but on an individual basis the radiographs overestimated the amount of bone covering a root surface by up to 21.4 per cent and underestimated in some by 17.7 per cent. Therefore, when the amount of bone in a cleft site is crucial for clinical purposes (e.g. placement of an implant), radiographs alone may not be totally reliable. The use of ultrasound was assessed in a porcine experimental model by Lawson and Jones (1997) and was found to be a useful adjunct to radiography but unreliable for deep cleft defects, whilst Onn (1999) used callipers to measure the amount of root surface covered by alveolar bone on radiographs. This latter approach necessitates the standardization of radiographs and this, together with alternative methods such as ultrasound or CT scanning, may not always be feasible in routine clinical work. Accordingly, despite

the limitations outlined, a simple method of assessment based on routine radiographs and of proven reproduciblity, would seem useful.

Whilst several methods for evaluation exist, there are uncertainties over their relative merits regarding validity and reproducibility and indeed, the stage of dental development at which they should be applied. For example, Bergland *et al.* (1986) stated that the interdental height cannot be assessed until eruption of the permanent canine or the fissural tooth is complete and that normal bone trabeculation of the cleft site is not established until 3 months post-operatively. Collins *et al.* (1998) took several sequential radiographs of their sample and found the bony anatomy did not change substantially 6 months post-operatively. The inability to assess the quality of a bone graft until after eruption of the permanent canine, which may be as long as 4–6 years post-operatively, is limiting. If a legitimate method of earlier assessment existed, i.e. in the mixed dentition, this would facilitate improvement in surgical technique.

The aims of this study were to:

1. Compare the reproducibility of three methods of radiographic assessment, namely Bergland *et al.* (1986), Kindelan *et al.* (1997) and Chelsea Scale and Grade (Witherow *et al.*, 2002).
2. Assess the relative legitimacy of their use in the mixed dentition.
3. Compare the usefulness of occlusal versus periapical radiographs in the post-operative assessment of the success of alveolar bone grafting.
4. Assess the outcome of alveolar bone grafting within this department and compare with published data from other units.

Subjects and methods

Forty-eight patients with either unilateral (n = 37) or bilateral (n = 11) cleft lip and palate who had received alveolar bone grafting at Queen Mary's University Hospital or latterly Kingston Hospital between 1990 and 2000 were included in the study. All patients had pre-surgical orthodontics to correct anterior and posterior crossbites. Expansion was achieved with a standard quadhelix appliance, which was removed prior to bone grafting and replaced with a transpalatal arch with extended palatal arms. Any teeth in the cleft site were removed several months prior to bone grafting. The bone grafting was performed mostly by one surgeon in the manner described by Boyne and Sands (1972), with dissection of the cleft defect to separate the nasal and palatal layers. Pre- and post-operative upper standard occlusal and post-operative periapical radiographs taken through the cleft line were obtained. The permanent canine was fully erupted in 39 cleft sites (described as the permanent dentition) whilst 20 cleft sites were awaiting the eruption of the canine (mixed dentition) at the time of final radiographic assessment. The majority of records were gathered retrospectively, with a few cases collected prospectively.

Three clinicians performed three radiographic assessments using the Bergland, the Chelsea, and the Kindelan Scales. The clinicians were not standardized in the application of the scales, in order to represent the usual clinical application. However, each was required to read publications describing each scale before use. The Kindelan Scale necessitates the use of pre- and post-operative occlusal views whereas the other two scales simply require post-operative views. Post-operative periapical radiographs were assessed using the Bergland and Chelsea Scales. The Kindelan Scale was excluded from the latter assessment due to the lack of pre-operative periapical radiographs. The radiographs of each patient were assessed against a light source using each scale and this was repeated a minimum of 4 weeks later.

Statistical analysis

The agreement between repeated assessments by the same observer at different time points was measured by the kappa statistic, for each of the three assessors and each type of radiographic scale in turn. Weighted kappa statistics were calculated for each of the Bergland, Chelsea, and Kindelan Scales, to take into account the ordinal nature of these scales; unweighted kappa was applied to the Chelsea Grade assessment. Agreement between the three observers, at each time point and for each scale, was measured using the multiple kappa statistic. The multiple kappa was calculated by averaging the three kappa statistics obtained by comparing each pair of assessors in turn (Fleiss, 1981). A kappa statistic of 0.8 indicates good agreement; over 0.6 indicates substantial agreement; over 0.4, moderate agreement; and less than 0.4, poor agreement (Bulman and Osborne, 1989).

Results

Repeatability over time: intra-observer variation

Table 1 shows the kappa statistics for repeated measurements at two time points, for each of the three assessors (HW, CN, and RE), and for each of the different types of radiographic assessment. All of these kappas were statistically significant ($P < 0.05$).

The kappa statistics for individual assessors for each of the Bergland, Chelsea Grade, and Kindelan Scales were all above 0.6, indicating substantial agreement. There was wide variation in the individual kappa statistics obtained for the various sites of the Chelsea Scale; for the occlusal radiographs, these ranged from 0.28 to 0.93,

Table 1 Intra-observer agreement. Kappa statistics for repeatability over time, all cleft sites (n = 59).

Scale	Occlusal (n = 57)				Periapical (n = 47)			
	HW	CN	RE	Mean	HW	CN	RE	Mean
Bergland	0.65	0.65	0.72	**0.67**	0.70	0.76	0.65	**0.70**
Chelsea:								
Site 1	0.32	0.87	0.75	**0.65**	0.92	1.00	0.63	**0.85**
Site 2	0.35	0.69	0.63	**0.56**	0.77	0.73	0.52	**0.67**
Site 3	0.58	0.79	0.72	**0.69**	0.77	0.72	0.37	**0.62**
Site 4	0.55	0.93	0.75	**0.74**	0.68	0.64	0.43	**0.59**
Site 5	0.28	0.75	0.69	**0.57**	0.78	0.88	0.51	**0.72**
Site 6	0.32	0.59	0.59	**0.50**	0.63	0.90	0.55	**0.69**
Site 7	0.56	0.56	0.51	**0.55**	0.53	0.86	0.52	**0.64**
Site 8	0.55	0.77	0.54	**0.62**	0.58	0.78	0.58	**0.65**
Mean	*0.44*	*0.74*	*0.65*	***0.61***	*0.71*	*0.81*	*0.51*	***0.68***
Chelsea grade	0.67	0.70	0.70	**0.69**	0.67	0.79	0.64	**0.70**
Kindelan	0.65	0.64	0.81	**0.70**				

while for the periapical radiographs the range was 0.37 to 1.00. This indicates agreement ranging from poor to excellent. However, greater variation is to be expected simply due to the measurement of eight sites for this variable, and the mean of the kappa statistics across these sites was therefore calculated; the mean kappa ranged from 0.44 to 0.81 (moderate to good agreement).

To facilitate comparison of the repeatability of different assessment methods, the kappa statistics were averaged across the three assessors. The results show relatively little difference between the performance of each of the scales, or between the occlusal and periapical measurements. The lowest average scores were obtained for the Chelsea Scale for occlusal radiographs, with some sites scoring much lower than others.

Mixed versus permanent dentition

Surprisingly, there was a tendency towards greater repeatability of the various scales among subjects in the mixed compared with permanent dentition (Table 2). For occlusal measurements, the Bergland, Chelsea Grade, and average of the Chelsea Scales produced notably higher mean kappa statistics for mixed dentition subjects, as did the Chelsea Grade periapical results. The Kindelan Scale demonstrated substantial agreement in both groups. The Bergland Scale periapical measurements appeared less repeatable for the mixed dentition, although this was largely influenced by one observer. It was not possible to test statistically the comparison of the kappa statistics for mixed versus permanent dentition.

Repeatability over time: inter-observer variation

Table 3 shows the kappa statistics for the agreement between the three observers, for each of the different types of radiographic assessment, at each time point. There was generally less agreement between observers (Table 3) than within observers (Table 1). For the Bergland, Kindelan and Chelsea Grade Scales, the lowest multiple kappa was 0.39 and the highest 0.56, indicating moderate agreement between assessments. There was greater variation in the results for the eight sites of the Chelsea Scale, as expected, with multiple kappas ranging from 0.20 to 0.69; the average kappa across these sites ranged from 0.43 to 0.56.

The individual kappa statistics were averaged across the two time points, in order to compare more easily the inter-observer variation of the different assessment methods. The average kappas of the different methods were very similar, with values between 0.45 and 0.51.

Mixed versus permanent dentition

The inter-observer variation seemed to be lower among subjects in the mixed dentition than for those in the permanent dentition (Table 4). Higher mean kappa statistics were obtained for mixed dentition subjects for the occlusal measurements of the Bergland, Kindelan, Chelsea Grade and average of the Chelsea Scales, and the periapical Chelsea Grade results. It was not possible to test statistically the comparison of the kappa statistics for mixed versus permanent dentition. These results are not independent of those presented for repeatability over time, since they use the same data, and so any 'outlier' assessments will affect both sets of results.

Comparison with other centres

In order to compare the outcome of surgery with that published by other centres, the data (CN time 1) of cases in the mixed and permanent dentition were pooled (Table 5a,b,c). The results from this centre were

Table 2 Intra-observer agreement. Kappa statistics for repeatability over time, by type of dentition.

Permanent dentition (n = 39)	Occlusal (*n* = 39)				Periapical (*n* = 31)			
Scale	HW	CN	RE	Mean	HW	CN	RE	Mean
Bergland	0.62	0.50	0.66	**0.59**	0.67	0.78	0.80	**0.75**
Chelsea:								
Site 1	0.08	0.84	0.64	**0.52**	1.00	1.00	0.78	**0.93**
Site 2	–0.06	0.30	0.19	**0.14**	0.84	0.76	0.45	**0.68**
Site 3	0.41	0.67	0.61	**0.56**	0.75	0.78	0.34	**0.62**
Site 4	0.44	0.90	0.69	**0.68**	0.65	0.62	0.37	**0.55**
Site 5	–0.05	0.79	0.64	**0.46**	0.84	0.78	0.45	**0.69**
Site 6	–0.04	0.65	0.24	**0.28**	0.78	0.78	0.63	**0.73**
Site 7	0.41	0.26	0.32	**0.33**	0.50	0.84	0.66	**0.66**
Site 8	0.47	0.65	0.43	**0.52**	0.42	0.64	0.61	**0.56**
Mean	0.21	0.63	0.47	**0.44**	0.72	0.78	0.54	**0.68**
Chelsea Grade	0.60	0.59	0.57	**0.59**	0.65	0.79	0.46	**0.63**
Kindelan	0.62	0.68	0.75	**0.68**				
Mixed dentition (n = 20)	Occlusal (*n* = 18)				Periapical (*n* = 16)			
Scale	HW	CN	RE	Mean	HW	CN	RE	Mean
Bergland	0.71	0.90	0.77	**0.79**	0.74	0.71	0.10	**0.52**
Chelsea:								
Site 1	0.71	0.90	0.77	**0.79**	0.83	1.00	0.48	**0.77**
Site 2	0.61	0.83	1.00	**0.81**	0.68	0.68	0.56	**0.64**
Site 3	0.82	1.00	0.89	**0.91**	0.84	0.60	0.43	**0.62**
Site 4	0.82	1.00	0.82	**0.88**	0.77	0.69	0.60	**0.69**
Site 5	0.63	0.71	0.77	**0.70**	0.63	1.00	0.59	**0.74**
Site 6	0.63	0.53	0.87	**0.67**	0.48	1.00	0.46	**0.65**
Site 7	0.60	0.91	0.82	**0.78**	1.00	0.88	0.28	**0.72**
Site 8	0.77	1.00	0.82	**0.86**	0.91	1.00	0.51	**0.81**
Mean	*0.70*	*0.86*	*0.85*	***0.80***	*0.77*	*0.86*	*0.49*	***0.70***
Chelsea Grade	0.80	0.86	1.00	**0.88**	0.71	0.78	1.00	**0.83**
Kindelan	0.68	0.56	0.88	**0.71**				

Table 3 Multiple kappa statistics for inter-observer variation, all cleft sites (*n* = 59).

	Occlusal (*n* = 57)			Periapical (*n* = 47)		
	Time 1	Time 2	Mean	Time 1	Time 2	Mean
Bergland	0.45	0.51	**0.48**	0.39	0.53	**0.46**
Chelsea:						
Site 1	0.50	0.69	**0.60**	0.66	0.65	**0.66**
Site 2	0.48	0.65	**0.57**	0.50	0.59	**0.55**
Site 3	0.61	0.60	**0.61**	0.47	0.38	**0.43**
Site 4	0.61	0.58	**0.60**	0.39	0.37	**0.38**
Site 5	0.35	0.60	**0.48**	0.32	0.46	**0.39**
Site 6	0.25	0.53	**0.39**	0.44	0.54	**0.49**
Site 7	0.20	0.27	**0.24**	0.26	0.35	**0.30**
Site 8	0.47	0.51	**0.49**	0.36	0.47	**0.42**
Mean	*0.44*	*0.56*	***0.50***	*0.43*	*0.48*	***0.45***
Chelsea Grade	0.48	0.47	**0.48**	0.46	0.56	**0.51**
Kindelan	0.46	0.51	**0.49**			

Table 4 Multiple kappa statistics for inter-observer variation, by type of dentition.

Permanent dentition (n = 39)	Occlusal (*n* = 39)			Periapical (*n* = 31)		
	Time 1	Time 2	Mean	Time 1	Time 2	Mean
Bergland	0.39	0.50	**0.44**	0.41	0.55	**0.48**
Chelsea:						
Site 1	0.32	0.71	**0.52**	0.78	0.62	**0.70**
Site 2	0.13	0.58	**0.36**	0.43	0.48	**0.45**
Site 3	0.59	0.61	**0.60**	0.42	0.33	**0.38**
Site 4	0.57	0.56	**0.57**	0.45	0.40	**0.42**
Site 5	0.30	0.76	**0.53**	0.37	0.56	**0.46**
Site 6	0.05	0.60	**0.32**	0.46	0.44	**0.45**
Site 7	0.05	0.21	**0.13**	0.18	0.25	**0.22**
Site 8	0.45	0.56	**0.51**	0.32	0.48	**0.40**
Mean	*0.31*	*0.57*	***0.44***	*0.43*	*0.44*	***0.44***
Chelsea Grade	0.44	0.40	**0.42**	0.41	0.48	**0.44**
Kindelan	0.43	0.45	**0.44**			
Mixed dentition (n = 20)	Occlusal (*n* = 18)			Periapical (*n* = 16)		
	Time 1	Time 2	Mean	Time 1	Time 2	Mean
Bergland	0.57	0.53	**0.55**	0.35	0.45	**0.40**
Chelsea:						
Site 1	0.70	0.70	**0.70**	0.51	0.65	**0.58**
Site 2	0.79	0.69	**0.74**	0.57	0.71	**0.64**
Site 3	0.64	0.58	**0.61**	0.54	0.49	**0.52**
Site 4	0.69	0.60	**0.65**	0.25	0.34	**0.30**
Site 5	0.40	0.61	**0.51**	0.29	0.26	**0.28**
Site 6	0.40	0.47	**0.43**	0.40	0.57	**0.48**
Site 7	0.39	0.34	**0.36**	0.49	0.55	**0.52**
Site 8	0.52	0.34	**0.43**	0.47	0.47	**0.47**
Mean	*0.57*	*0.54*	***0.55***	*0.44*	*0.50*	***0.47***
Chelsea grade	0.56	0.60	**0.58**	0.55	0.73	**0.64**
Kindelan	0.49	0.59	**0.54**			

compared with those of Bergland *et al.* (1986) (Table 5a). Those authors further divided their results into subjects who had the permanent canine erupted at the time of surgery and those who did not. Cases grafted before the eruption of the canine had a significantly higher success rate (64 per cent) than those not grafted (37 per cent). In this study the combined group had a success rate of 67 per cent. On comparing the outcome of surgery using the Kindelan Scale (Kindelan *et al.*, 1999), it is evident that this centre performed better than the mean of five units and equalled the performance of the best unit (Table 5b).

The Chelsea Scale provides more detailed information than the other scales with respect to the position of the bone within the graft. In this study it was found that the roots were more likely to be denuded in the cervical region and the tooth mesial to the graft site was more likely to be affected than the distal tooth. Five per cent of cases had a bony bridge near to the cervical region but lacked bone apically compared with 20 per cent of cases presented by Witherow *et al.* (2002) and this may be due to different surgical techniques between the two centres (Table 5c).

The Clinical Standards Advisory Group study (1998), which used the Bergland Scale, considered types I and II as a successful outcome and found that 58 per cent of cases were successful nationally. Using this criterion, 80 per cent of cases were successful in this study.

Discussion

There was little difference in the repeatability of any of the three scales assessed (either intra- or inter-observer variation), which is a little surprising given that the Chelsea Scale is more complicated than either the Bergland or Kindelan Scales. It is interesting to note that there was little difference in the results of the Bergland and Chelsea Scales when occlusal and periapical radiographs were compared, which suggests that neither radiograph is superior to the other for audit purposes. Surprisingly, all three scales were found to be generally more reproducible in subjects in the mixed

Table 5 Comparison of surgical outcome with other units.

a *Comparison of outcome. Bergland Scale*

Bergland Scale	Present study %	Bergland *et al.* (1986) %	CSAG (1998) %	Witherow *et al.* (2002) %
I	67	50		62.9
II	13	40	58	21.4
III	12	7	30	4.3
IV	8	3	12	5.7

b *Comparison of outcome. Kindelan Scale*

Kindelan Scale	Present study %	Kindelan *et al.* 1999 (mean of five units) %	Kindelan *et al.* 1999 (best of five units) %
1	64.0	51.3	63.2
2	19.5	29.5	21.1
3	15.5	19.2	15.8
4	1.0	0.0	0.0

c *Comparison of outcome. Chelsea Grade Scale*

Chelsea Grade Scale	Present study %	Witherow *et al.* (2002) %
A	59	58
B	5	20
C	12	7
D	10	3
E	5	3
F	9	9

than in the permanent dentition. This may reflect no more than random variation due to the small size of these subgroups, in particular the mixed dentition group. Alternatively this may suggest that these scales can be applied prior to the eruption of the permanent canine or fissural tooth. However, the Kindelan Scale showed equal reproducibility in both dentitions when used by single observers, but not when inter-observer agreement was assessed. Long-term follow-up of the mixed dentition group will reveal if the assessments remain the same when the canine has erupted and therefore confirm if these scales were accurately applied in the mixed dentition. Predictably, intra-observer agreement for all scales was generally substantial and therefore better than the inter-observer agreement, which was only moderate. Perhaps this suggests the application of each is rather dependent on individual interpretation of the literature and supports the need for assessors to be calibrated before using scales for research purposes. The three assessors in this study are not necessarily representative of all possible assessors, and the interpretation and application of these scales may be different amongst the broader population of clinicians. Additionally, the results will have been affected both by the quality of the radiographs, which were generally good but with some exceptions, and by the surgical outcome. A small number of radiographs were discarded or unavailable, hence the disparity between the number of cleft sites and the number of radiographs referred to in the tables. It should be emphasized that this study was limited to an assessment of the relative reproducibility of the three methods, rather than validity.

It is encouraging that the surgical outcome of alveolar bone grafting in this unit has been relatively successful. The surgery has largely been performed by one very experienced operator, which supports the argument in favour of high volume operators.

Conclusions

1. None of the three radiographic scales demonstrated superior reproducibility over the other two, either within or between observers.
2. Each scale tended to be more reproducible in the mixed than in the permanent dentition, suggesting these scales may be applicable in the mixed dentition.
3. Neither occlusal nor periapical radiographs were found to be more useful in the post-operative assessment of the success of alveolar bone grafting.
4. The results of alveolar grafting compared favourably with other published results.

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