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Factors influencing the outcome of non-surgical periodontal treatment: a multilevel approach

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Abstract

Aim: To investigate, by means of multilevel analysis, factors that may affect the short-term clinical outcome of non-surgical periodontal treatment.

Materials and Methods: Forty-one patients randomly assigned to two protocols of non-surgical therapy were included. The impact of different covariates on the probability of ''pocket closure'' [i.e. probing pocket depth (PPD) $\leqslant 4$ mm] was explored using a logistic multilevel model. The impact on the final PPD was explored using a continuous multilevel model.

Results: The logistic model revealed a significant impact of smoking ($p < 0.001$), presence of plaque at the site ($p < 0.001$) and location of the pocket at a multi-rooted tooth ($p < 0.001$). The model explained 44% of the total variability. Of the unexplained variance, 19% was attributed to inter-patient variability. The continuous model revealed the same factors to be significant and an additional significant impact of interactions between the covariates. The R^2 was 0.50 and the random slopes model revealed an increase in the variability of the final pocket depth with an increase in the initial PPD.

Conclusion: Smoking habits, plaque at site level and tooth type were significant factors in determining the short-term clinical outcome of non-surgical periodontal treatment.

Key words: clinical; multilevel analysis; periodontitis; plaque; randomized controlled trial; smoking

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Initial periodontal treatment aims at an effective pocket/root debridement (scaling and root planing) and the establishment of an adequate self-performed supra-gingival infection control, with the objective of reducing the bacterial load below the individual's threshold level for disease. A shallow probing pocket depth (PPD) without bleeding following probing manifests the successful outcome of the therapy. Several recent systematic reviews support the efficacy of non-surgical instrumentation, and that there may not be any major differences in treatment outcome between hand- and machine- driven instrumentation (Tunkel et al. 2002, van der Weijden & Timmerman 2002, Hallmon & Rees 2003).

A common experience, however, is that the treatment outcome of non-surgical periodontal therapy may vary not only between patients but also between various tooth sites in the individual subject (Badersten et al. 1984, Serino et al. 2001, van der Weijden & Timmerman 2002). Hence, the gain of knowledge about factors that may be responsible for such variation in treatment response would be beneficial for the selection of treatment approaches aiming at the establishment of infection control. Such factors may be related to the patient, the tooth or to the single tooth site (Axtelius et al. 1999, D'Aiuto et al. 2005, Hughes et al. 2006). However, the inherent hierarchical structure of periodontal data poses difficulties for the analysis: aggregating site data within patients using mean values runs the risk of loosing information and overestimating the standard error. On the contrary, an analysis at the tooth or site level without taking in account the dependence between teeth/sites in a patient may result in an underestimation of the standard error.

Conflict of interest and source of funding statement

The authors declare that they have no conflict of interests.

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A statistical approach that may overcome these problems is multilevel modelling, a statistical method that was originally introduced in educational research but also has been utilized in various fields of health sciences (Goldstein 1987, Rice & Leyland 1996, Snijders & Bosker 1999, Leyland & Goldstein 2001, Goldstein et al. 2002, Leyland & Groenewegen 2003). In the field of periodontology, Albandar & Goldstein (1992) applied multilevel analysis to explore in the same model explanatory factors at the subject and at the tooth site level for periodontal disease progression, determined by radiographic bone height assessments. Other authors applied this statistical method in analysis of longitudinal data on gingivitis (Müller & Stadermann 2006) disease characteristics and progression (Nieri et al. 2002, Gilthorpe et al. 2003, Tu et al. 2004a, b) and factors affecting the treatment outcome (Axtelius et al. 1999, D'Aiuto et al. 2005, Needleman et al. 2007).

In a recent publication (Wennström et al. 2005) we evaluated the clinical efficacy of a single session of full-mouth ultrasonic debridement (UD) as an initial periodontal treatment approach compared with quadrant-wise scaling/root planing (Q-SRP) with hand instruments. The results revealed no statistically significant differences between the two treatment approaches at 3 months with regard to pertinent clinical outcome variables, but it was apparent that within both approaches the treatment response varied markedly both between the patients and between tooth sites within the patients.

The aim of the present study was therefore to investigate, by means of multilevel analysis, factors that may affect the short-term clinical outcome of non-surgical periodontal treatment.

Materials and Methods

The data analysed in this report derived from a study by Wennström et al. (2005) evaluating the effect of two different approaches to non-surgical periodontal treatment. The study was conducted at two centres (Department of Periodontology, the Sahlgrenska Academy at Göteborg University, Sweden and a private dental office in Trento, Italy). Approval of the study protocol by the Ethics Committee at Göteborg University was obtained and all participating subjects provided witnessed, informed consent before the start of the study.

Briefly, 41 patients with moderately advanced chronic periodontitis were randomly assigned to be treated either with a 1-h session of full-mouth debridement (FmUD) using an ultrasonic instrument (EMS Piezon Master 400 with A+Perio-Slim tips, water coolant and power setting to 75%; EMS, Nyon, Switzerland), or with four sessions of Q-SRP with hand instruments (LM-dental, Turku, Finland). All sites with an initial PPD of $\geqslant$5 mm were included in the study. Clinical examinations were performed before treatment (baseline) and at 3 months post-treatment (four sites per tooth) and included assessments of the following:

Plaque score: Presence/absence of plaque at the cervical part of the tooth scored by running a probe along the tooth surface.

PPD: Measured with a manual Hu-Friedy PCP15 periodontal probe (Hu-Friedy Inc., Leimen, Germany) to the closest lower millimetre.

Bleeding on probing (BoP): Presence/absence of bleeding within 15 s following pocket probing.

Location of gingival margin (GM): The distance between the gingival margin and a fixed reference point on the tooth (CEJ or the margin of a restoration). A negative value was given when the gingival margin was located coronal to the CEJ.

Relative attachment level (RAL) was calculated as PPD+GM.

In addition, a full-mouth set of radiographs was obtained at baseline for recording of the presence of intra-bony defects of 3 mm or more in depth. Information about the patient's age, gender, and smoking habits (current smoker – yes/no, years of smoking, cigarettes per day) was obtained through structured interview.

One examiner (a periodontist), who was masked with respect to the treatment assignments, performed all examinations. Before the start of the study, the examiner was trained to adequate levels of accuracy and reproducibility for the various clinical parameters and indices to be used (Polson 1997). Repeated assessments were performed during the course of the study on five randomly selected subjects in order to determine the intra-examiner reproducibility. The mean difference between repeated measurements was 0.03 (SD 0.43) for PPD and 0.06 (0.65) for RAL. The reproducibility within $\pm$ 1 mm was 97% for PPD and 91% for RAL assessments. For further details regarding the original study, see Wennström et al. (2005).

Data analysis

The main endpoint for treatment success was defined as ''pocket closure'' (PPD$\leqslant$4 mm) at the 3-month re-examination. A secondary outcome variable tested in the current analysis was the PPD at 3 months.

The levels that were identified for the hierarchical analysis were the patient, the tooth and the tooth site. The database consisted of 1447 tooth sites at 771 teeth in 41 patients. The various factors associated with the three levels that were tested are given in Table 1.

Table 1. Characteristics of the patient sample

Patient related variables (level 3)	$N = 41$
Gender (male/female)	22/19
Smokers (yes/no)	20/21
Treatment (Q-SRP/FmUD)	21/20
Time for treatment [mean (SD)]	113 min. (66)
Age [mean (SD)]	49.4 years (10)
Plaque score [mean (SD)]	22.5% (14)
BoP score [mean (SD)]	76.9% (19)
Qualified sites [mean (SD)]	39% (15)
Closed pockets at 3 months (range)	62% (13–95)
Tooth-related variables (level 2)	$N = 771$
Tooth type (multi-/single-rooted)	213/558
Site-related variables (level 1)	$N = 1447$
Initial PPD [mean (SD)]	6.2 mm (1.4)
Three months PPD [mean (SD)]	4.5 mm (1.6)
Intrabony defect (yes/no)	34/1413
Position (m/b/d/l)	552/72/601/222
Plaque presence	26%
BoP positive	96%

SD, standard deviation; PPD, probing pocket depth; Q-SRP, quadrant-wise scaling/root planing; FmUD, full-mouth debridement; BoP, bleeding on probing; m, mesial; b, buccal; d, distal; l, lingual.

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Table 2. Stepwise description of model building with the outcome variable ''pocket closure at 3 months''

Variable	Empty model			Null model			Treatment				Smoking				PI_initial				Multi-rooted				Smoking+pl_initial+multi-rooted			
	value	SE	OR	CI	value	SE	OR	CI	value	SE	OR	CI	value	SE	OR	CI	value	SE	OR	CI	value	SE	OR	CI	value	SE	OR	CI
Initial PPD					−1.14	0.07	0.32	0.28 0.37	−1.14	0.07	0.32	0.28 0.37	−1.14	0.07	0.32	0.28 0.37	−1.13	0.07	0.32	0.28 0.38	−1.13	0.07	0.32	0.28 0.37
Treatment									−0.34	0.34	0.71	0.37 1.38												
									$p = 0.31$															
Smoking													−0.92	0.31	0.40	0.22 0.73									−1.12	0.31	0.33	0.18 0.61
													$p<0.001$												$p<0.001$			
PI_initial																	−0.74	0.16	0.48	0.35 0.66					−0.54	0.17	0.58	0.42 0.81
																	$p<0.001$								$p<0.001$			
Multi-rooted																					−0.96	0.16	0.38	0.28 0.52	−0.85	0.17	0.43	0.31 0.59
																					$p<0.001$				$p<0.001$			
Intercept	0.55	0.14			1.88	0.19			2.05	0.25			2.32	0.23			2.10	0.20			2.17	0.20			2.83	0.25		
Av. Prob.	63%																											
Random part																												
Patient variance	0.65	0.18			0.96	0.26			0.94	0.26			0.74	0.21			1.01	0.27			1.04	0.28			0.75	0.21		
ICC	0.17				0.22				0.22				0.18				0.24				0.24				0.19			
Varience of linear predictor					2.50				2.57				2.73				2.69				2.78				3.14			
R^2*					0.37				0.38				0.40				0.38				0.39				0.44			

*Pseudo-R^2 calculated according to Snijder & Bosker (1999).
ICC, intra-class correlation, PPD, probing pocket depth; SE, standard error; PI_initial, baseline plaque.

A statistical package specifically designed for multilevel modelling (MLwiN 2.02, ©Multilevel Models Project Institute of Education, London, UK) was used to investigate the influence of patient, tooth and site-related covariates on the outcome variables.

A logistic regression model was built to evaluate factors affecting the probability of the main outcome variable (''pocket closure''). The logit function was used to link the linear model with the probability of the binary event such that, if β is the intercept, the antilogit function of the parameter β was calculated with the formula: $[(1+\exp(-\beta))^{-1}]$ to obtain the probability of ''pocket closure'' (Snijders & Bosker 1999).

The model was applied to the data and the parameters estimated with a second-order penalised quasi-likelihood procedure implemented in the software and the significance of each covariate was tested using a Wald test. The covariates were estimated individually by adding them to the null model and testing the significance. The final model included all factors that were found significant. The intra-class correlation (ICC), i.e. the proportion of the total variance attributed to the patient level, was approximated using the formula

$$\mathrm{ICC} = \frac{\sigma_u^2}{\sigma_u^2 + \frac{\pi^2}{3}},$$

where $\sigma_u^2$is the variance at the higher levels (Snijders & Bosker 1999).

For the secondary outcome variable, PPD at 3 months, a multilevel model for a continuous variable was formulated including tests for the normality of the residuals at the different levels. Regression coefficients were estimated using iterative generalized least squares. Nested models were tested for significant improvements in model fit by comparing the reduction in $-2\mathrm{LL}$ (-2 log likelihood) with a χ^2 distribution. As the interpretation of the intercept with the value 0 mm as initial PPD has no clinical meaning, a new ''centred'' initial PPD (PPD-5) was introduced in the models.

Results

Logistic model with ''pocket closure'' at 3 months as the outcome

The stages in building the logistic multilevel model with ''pocket closure'' as the outcome event are reported in Table 2.

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The model without covariates revealed a probability of 0.63 (i.e. 63%) to obtain ''pocket closure'' (0.63 = exp(0.55)/(1+exp(0.55)) for a site following initial pocket debridement in the average patient, with a 95% CI of 0.26–0.89. Comparing these values with the raw data at the patient level (Table 1), where the mean percentage of closed pockets was 62.4% (95% CI 13–95), the model seems appropriate. The ICC showed that 17% of the variation in whether pockets were closed was due to variation between the patients and 83% due to variations between tooth sites within the patients. As the variance at the tooth level was estimated to be zero, this level was dropped from subsequent analyses.

When the initial PPD was introduced in the model, the intercept was 1.88, i.e. the probability of ''pocket closure'' 3 months post-treatment at a site with an initial PPD of 5 mm was 87% (95% CI 82–90). For each millimetre increase of initial PPD, the log odds decreased by 1.14 ($p<0.0001$). Hence, the probability of closing a 6 mm pocket was 67%, and for a 7 mm pocket 40%. The R^2 calculated according to the description of Snijders & Bosker (1999) revealed that the model explained 37% of the variability of the outcome.

Treatment type did not have a significant effect ($p = 0.31$), nor did age or gender.

The introduction of smoking (smoker/non-smoker) into the model decreased the patient-level variance from 0.96 to 0.74. Furthermore, smoking had a significant ($p<0.001$) negative impact on the chance of ''pocket closure''. The graph in Fig. 1 illustrates the probability of ''pocket closure'' for various initial PPD in smokers and non-smokers.

The patient's plaque score at baseline did not have a significant impact on the outcome of ''pocket closure'', whereas the presence of plaque at the individual tooth site had a significant ($p<0.001$) negative effect. Figure 2 depicts the probability of ''pocket closure'' at tooth sites according to initial PPD and presence/absence of plaque.

Tooth type was introduced into the model as single-rooted (incisors and premolars) or multi-rooted teeth (molars). A significantly ($p<0.001$) lower probability of ''pocket closure'' was found for a pocket located at molars compared with a pocket at single-rooted teeth (Fig. 3). The presence of an intra-bony defect had no significant effect on the outcome variable. Furthermore, no significant interactions between the various explanatory factors were identified.

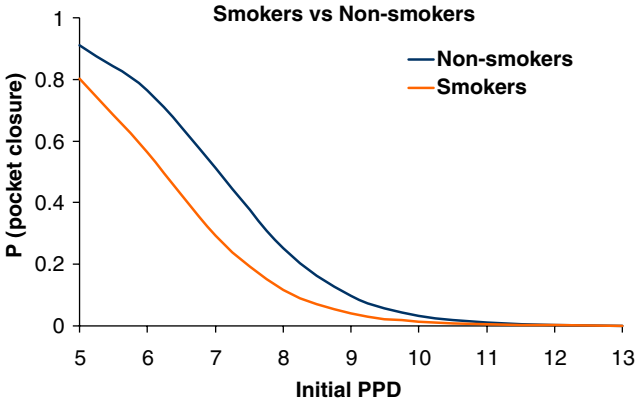

Fig. 1. Probability of ''pocket closure'' [probing pocket depth (PPD) ⩽4 mm] according to the initial PPD for smokers and non-smokers.

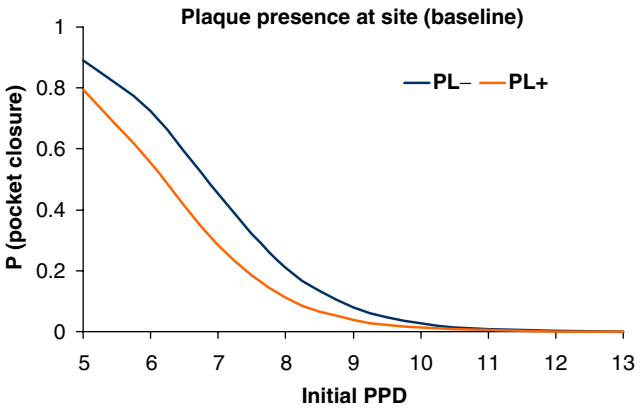

Fig. 2. Probability of ''pocket closure'' [probing pocket depth (PPD)⩽4 mm] according to the initial PPD for sites with or without plaque at baseline.

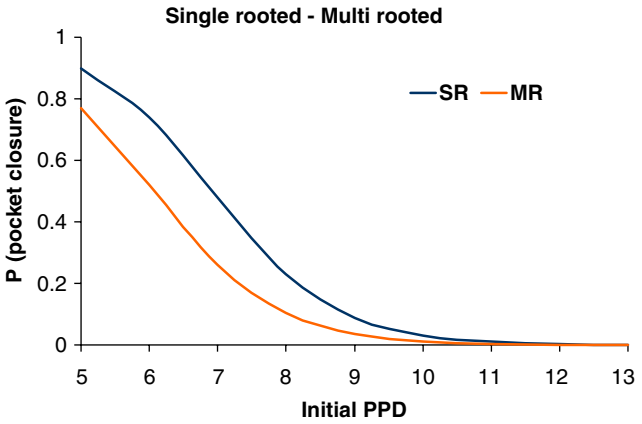

Fig. 3. Probability of ''pocket closure'' [probing pocket depth (PPD)⩽4 mm] according to the initial PPD for sites located at single-rooted and multi-rooted teeth.

The model including all the significant covariates explained 44% of the total variability (Table 2). The predicted probabilities of ''pocket closure'' in relation to different patient and tooth site characteristics are given in Table 3. The probability of achieving ''pocket closure'' 3 months after subgingival debridement at a site with an initial PPD of 6 mm was at best 84% (single-rooted tooth without plaque at baseline in a non-smoker), and decreased

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Table 3. Predicted probability of ''pocket closure'' following non-surgical pocket/root debridement in the average patient

Initial PPD	5 mm	6 mm	7 mm	8 mm	9 mm
Non-smoking					
Plaque −					
Single-rooted	94% (91–96)	84% (77–90)	63% (52–73)	36% (25–48)	15% (9–25)
Multi-rooted	88% (81–92)	70% (59–79)	43% (31–55)	19% (12–29)	7% (4–13)
Plaque+					
Single-rooted	91% (85–94)	76% (66–84)	50% (38–63)	24% (16–37)	9% (5–17)
Multi-rooted	81% (71–87)	57% (45–69)	30% (21–42)	12% (7–20)	4% (2–9)
Smoking					
Plaque −					
Single-rooted	85% (78–90)	64% (53–73)	36% (26–48)	16% (10–24)	6% (3–10)
Multi-rooted	70% (58–80)	43% (31–56)	20% (12–29)	7% (4–12)	2% (1–5)
Plaque+					
Single-rooted	76% (65–85)	51% (38–64)	25% (16–37)	10% (5–16)	3% (2–7)
Multi-rooted	58% (44–70)	31% (20–43)	12% (7–20)	4% (2–8)	1% (1–2)

Surgical pocket/root debridement in the average patient.
PPD, probing pocket depth.

markedly for greater initial PPD, presence of plaque at baseline, location at a multi-rooted tooth and/or if the patient was a smoker.

Continuous model with PPD at 3 months as the outcome

The models exploring the covariates influencing the PPD at the 3-month examination are reported in Table 4. The model with no covariates included gave a mean value of 4.4 mm for the 3-month PPD and a total unexplained variance of 2.54 (81% attributed to variation between sites, 5% between teeth and 14% between patients). The inclusion of the initial PPD led to a 42% reduction of the total unexplained variance: 42% reduction at the site level, 88% at the tooth level and 26% at the patient level.

All the factors explored in the logistic analysis were also added to the continuous model. Treatment did not have a significant effect. Smoking was a significant factor ($p<0.001$) resulting in 0.5 mm higher PPD at 3 months in smokers compared with non-smokers. Furthermore, the interaction between smoking and initial PPD was found to be significant ($p<0.05$), significantly improving the fit of the model ($p<0.05$). The negative impact of smoking on PPD reduction was therefore more pronounced for deep than for shallow sites.

Presence of plaque at the site level and tooth type and their interactions were tested and are summarized in Table 4. Age, gender, and presence of an intra-bony defect were also tested but not found to be significant and therefore were excluded from subsequent analyses.

The final model with random intercepts and fixed slopes is depicted in the last column of Table 4. Although non-significant, ''treatment'' was maintained in the model as a factor as it was the main objective of the study comparison. Plaque at the site level was also included because the interaction of this factor with initial PPD and tooth type was significant. The model represented a significant improvement in terms of fit compared with the null model, and explained 50% of the variability of the outcome variable ($R^2 = 0.50$). The ICC of 0.14 suggests that 14% of the unexplained variance was attributable to differences between patients.

No difference was detected regarding mean initial PPD when plaque presence, smoking habit or tooth anatomy were considered.

The variance components at patient and site levels were then explored with the use of random slope models. First, the slope related to initial PPD was allowed to vary randomly at the patient level, as shown in Table 5. A Wald test of the random terms (compared with a χ^2 distribution with 2 degree of freedom) confirmed their significance ($p<0.01$). The correlation between the intercept and slope was 0.19 (= 0.01/sqrt), indicating that the greatest pocket reduction for deep sites was achieved in patients with the best response for 5 mm pockets.

The final step consisted in modelling heterogeneity at the site level (Table 5). The $-2 \times$ log(likelihood) decreased significantly, confirming that the variance in final PPD was not constant but differed according to the initial PPD of the tooth site. The correlation between the intercept and the slope at the patient level was 0.83.

The plot of the function of the variances at the site and patient levels (Fig. 4) demonstrated that at both levels the variance increased with the increase of initial PPD, but maintained the proportion of the relative contribution to the total variance.

In the final model, the outcome ''PPD at 3 months'' is determined from predictors that relates to the patient (smoking – negative impact more evident in deep pockets) and the tooth site (plaque – negative impact with interaction with PPD and tooth type; location of the site – single-rooted teeth respond better than multi-rooted teeth). Eighty-six percent of the unexplained variance was attributable to site level and 14% to patient level. The graph in Fig. 5 shows the regression lines for combinations of presence/absence of the factors found significant.

Discussion

The results of the present study demonstrated that smoking habits, presence of supragingival plaque at the tooth site and location of the pocket at a molar were significant factors for an inferior outcome of non-surgical periodontal treatment. Furthermore, the initial probing depth negatively affected the predictability of the treatment outcome.

The use of surrogate variables such as PPD and relative attachment level to evaluate the clinical outcome of various treatment procedures is a common approach, because the true outcome variable to be assessed (tooth loss) is not a feasible variable in short-term clinical trials (Greenstein 2005). Given that a main goal of periodontal treatment is to establish clinically healthy periodontal conditions, manifested by shallow pockets without bleeding on probing, we defined ''pocket closure'' (PPD $\leqslant$ 4 mm) as a clinical endpoint to be evaluated. The clinical value of this variable is validated by data demonstrating (i) lower risk for disease progression in patients with non-bleeding shallow pockets (Badersten et al. 1990, Claffey 1991, Claffey & Egelberg 1995, Lang & Tonetti 2003), (ii) the effectiveness of pocket reduction in changing subgingival environmental conditions and microbial composition (Mombelli et al. 1995),

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Table 4. Stepwise description of the model-building with the outcome variable ''PPD at 3 months''

Fixed part	Empty model		Null model		Treatment		Smoking		S+S × PPD_initial		PI_initial		PI_initial × PPD_initial		Multi-rooted		Multi-rooted × PPD_initial		PI_initial × multi-rooted		All	
	value	SE	value	SE	value	SE	value	SE	value	SE	value	SE	value	SE	value	SE	value	SE	value	SE	value	SE
PPD_initial			0.75	0.02	0.75	0.02	0.75	0.02	0.69	0.03	0.74	0.02	0.70	0.03	0.72	0.02	0.66	0.03	0.72	0.02	0.52	0.04
Treatment					0.08	0.17															0.10	0.14
					NS																NS	
Smoking							0.54	0.15	0.42	0.16											0.42	0.15
							$p<0.001$		$p<0.01$												$p<0.001$	
Smoking × PPD_initial									0.11	0.04											0.20	0.04
									$p<0.05$												$p<0.0001$	
PI_initial											0.36	0.07	0.16	0.09					0.06	0.09	− 0.04	0.11
											$p<0.0001$		NS						NS		NS	
PI_initial × PPD_initial													0.16	0.05							0.12	0.05
													$p=0.001$								$p<0.01$	
Multi-rooted															0.57	0.07	0.35	0.09	0.38	0.09	0.20	0.10
															$p<0.0001$		$p<0.0001$		$p<0.0001$		$p<0.05$	
Multi-rooted × PPD_initial																	0.17	0.04			0.18	0.05
																	$p<0.0001$				$p<0.0001$	
PI_initial × multi-rooted																			0.37	0.14	0.29	0.14
																			$p<0.01$		$p<0.05$	
Intercept	4.36	0.10	3.51	0.09	3.47	0.12	3.25	0.11	3.32	0.11	3.42	0.09	3.47	0.09	3.36	0.09	3.43	0.10	3.01	0.20	3.22	0.13
Random part																						
Patient variance	0.36	0.10	0.26	0.07	0.26	0.07	0.19	0.05	0.18	0.05	0.27	0.07	0.27	0.07	0.28	0.07	0.29	0.07	0.18	0.05	0.17	0.05
Tooth variance	0.13	0.08	0.02	0.04	0.02	0.04	0.02	0.04	0.02	0.04	0.00	0.04	0.01	0.04	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.00
Site variance	2.05	0.11	1.19	0.06	1.19	0.06	1.19	0.05	1.18	0.06	1.18	0.06	1.16	0.06	1.14	0.04	1.13	0.04	1.19	0.06	1.10	0.04
ICC	0.14		0.18		0.18		0.14		0.13		0.19		0.19		0.20		0.20		0.13		0.14	
R^{2*}			0.42				0.45		0.46		0.43		0.40		0.41		0.41		0.46		0.50	
(− 2 × loglikelihood)	5265.96	842.01	4423.95	0.20	4423.742	11.52	4412.428	6.39	4406.041	25.60	4398.348	11.45	4386.894	70.31	4353.635	15.54	4338.099	13.44	4410.503	140.20	4283.749	
Refered to null model	$p=0.000$		$p=0.651$		$p=0.001$		$p=0.011$		$p=0.000$		$p=0.001$		$p=0.000$		$p=0.000$		$p=0.000$		$p=0.000$			

*Calculated according to Snijders & Bosker (1999).

PPD_initial, baseline PPD; PI_initial, baseline plaque; S, smoking; PPD, probing pocket depth; SE, standard error.

and (iii) the risk of attachment loss in sites with PPD ⩾ 6 mm (Westfelt et al. 1998).

The use of a logistic model allowed us to explore the impact of different factors on the chance of obtaining the successful treatment outcome of ''pocket closure'' (PPD ⩽ 4 mm and BoP −). Obviously the use of ''pocket closure'' as the main outcome implies the restriction of the initial sample to the sites presenting at least 5 mm depth at the baseline, but from a treatment point of view those are the sites usually requiring pocket/root debridement. The choice of this variable allowed the construction of a prediction table (Table 3) for the clinical outcome of the initial phase of non-surgical therapy. The table shows that the chance of closing a 7–8 mm pocket is markedly reduced, particularly if the patient is a smoker and the site is located at a molar. Furthermore, from Fig. 5 it can be seen that in the average patient an 8 mm pocket located at a single rooted tooth in a non-smoker demonstrating good oral hygiene was reduced to 4.7 mm at 3 months, while a pocket with corresponding initial PPD at a molar site with plaque in a smoker was reduced only to 7 mm. In other words, smoking habits, site-specific self-performed plaque control standard, as well as the location of the site in the dentition, but not the treatment approach (full-mouth UD or quadrant-wise scaling and root planing), affected the efficacy of the non-surgical treatment.

Smoking showed a negative impact, both on the probability of ''pocket closure'' and on the magnitude of pocket reduction, which corroborate data reported in recent reviews on the effect of smoking on the outcome of periodontal treatment (Labriola et al. 2005, Heasman et al. 2006). The model used to elaborate predictions suggests that the magnitude of difference in terms of the chance to obtain ''pocket closure'' was about 30% lower in a smoker. Furthermore, the continuous model revealed an interaction between smoking and initial PPD, i.e. the negative effect of smoking was more evident in initially deep pockets. Similar findings have previously been reported in studies comparing the effect of cause-related therapy in smokers and non-smokers (Kinane & Radvar 1997, Tomasi & Wennström 2004). A plausible explanation to the inferior treatment outcome in smokers was offered by Biddle et al. (2001), who suggested that the poorer response to

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Table 5. The final continuous model (dependent variable: PPD at 3 months) with random intercepts and random slopes at different levels

Predictors	Fixed slope			Random slope p level			Random slopes		
	value	SE	p	value	SE	p	value	SE	p
Initial PPD	0.52	0.04	<0.000	0.46	0.06	<0.000	0.44	0.05	<0.000
Treatment	0.10	0.14	NS	0.06	0.12	Ns	−0.05	0.11	NS
Smoking	0.42	0.15	<0.001	0.37	0.13	<0.001	0.39	0.11	<0.001
Smoking × PPD	0.20	0.04	<0.000	0.21	0.07	<0.000	0.19	0.07	<0.000
Plaque (site)	−0.04	0.11	NS	−0.03	0.10	NS	0.00	0.09	NS*
Plaque × PPD	0.12	0.05	<0.01	0.14	0.05	<0.01	0.11	0.06	NS*
Multi-rooted	0.20	0.10	<0.05	0.20	0.10	<0.05	0.18	0.08	<0.05
Multi-rooted × PPD	0.18	0.05	<0.000	0.18	0.05	<0.000	0.22	0.06	<0.000
Multi-rooted × plaque	0.29	0.14	<0.05	0.27	0.14	<0.05	0.21	0.12	NS*
Intercept (β_0)	3.22	0.13		3.28	0.11		3.37	0.10	
Random part									
Patients									
var (u_{0j})	0.17	0.05		0.10	0.03		0.09	0.03	
var (u_{1j})				0.03	0.01		0.02	0.01	
cov (u_{0j},u_{1j})				0.01	0.01		0.03	0.01	
Site									
var (e_{0i})	1.10	0.04		1.04	0.04		0.55	0.03	
var (e_{1i})							0.05	0.03	
cov (e_{0i}, e_{1i})							0.15	0.04	
−2 × loglikelihood	4283.75		p<0.000	4230.72		p<0.000	4025.13		

*The joint test was significant, $p<0.01$.
PPD, probing pocket depth; SE, standard error.

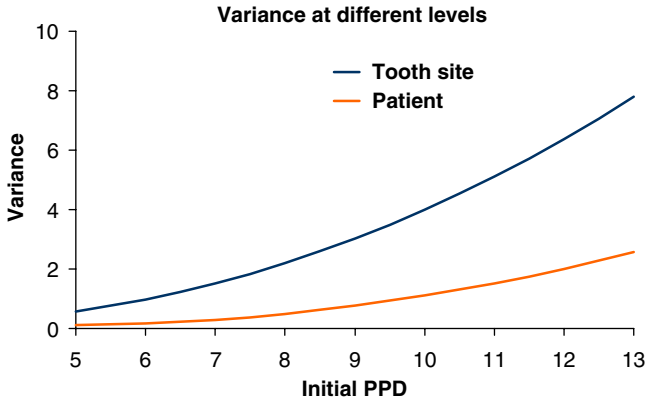

Fig. 4. Plot of the variance at tooth site and patient levels as a function of the initial probing pocket depth (PPD).

non-surgical treatment may in part be explained by reduced probe tip penetration of the tissue in smokers because of a lower degree of tissue inflammation, and a lower height of the supra-bony connective tissue portion, particularly in sites measuring 5 mm or more. This in turn would entail less potential for reduction in probing assessments as a result of successful resolution of the inflammation. Another explanation could be that the ecological environment of deep periodontal pockets in the smoker is more difficult to alter by mechanical instrumentation, an interpretation that is supported by the observation that periodontally untreated as well as treated smokers harbour a subgingival microflora that shows a higher prevalence of e.g. *Bacteroides forsythus* than non-smokers (Zambon et al. 1996, Darby et al. 2000, Boström et al. 2001, Haffajee & Socransky 2001, van Winkelhoff et al. 2001). In the interpretation of the current results, however, one has to consider the potential risk of misclassification bias of the subjects because the information on smoking habits was obtained through interview. By assessing cotinine levels in self-reported non-smokers, Wells et al. (1998) calculated the misclassification bias to be about 1% and 5.5% for regular and occasional smokers, respectively, as defined by the level of the marker.

Presence of plaque at the site level has rarely been considered as a determining factor in previous publications on the outcome of non-surgical periodontal therapy, but the plaque score has been used at the patient level instead. In the present study the aggregated variable of plaque score on the subject level was not a significant factor, but the presence of plaque at single sites was identified as significant. Hughes et al. (2006) used the plaque score on the subject level, pre- as well as post-treatment, as prognostic factors in their analysis, and found plaque not to be associated with the outcome of initial cause-related therapy in patients with generalized aggressive periodontitis (Hughes et al. 2006). In a multilevel analysis of factors influencing the 6-month clinical outcome of subgingival debridement, D'Aiuto et al. (2005) also reported a non-significant effect of the full-mouth plaque score on both the final PPD and the change in PPD. Axtelius et al. (1999), on the other hand, evaluated the influence of plaque on the tooth site level and, similar to the finding in the current study, a significant negative effect on the treatment outcome was demonstrated. In this respect it should be recognized that in our study the initial mean full-mouth plaque score was only 26%, as the patients were instructed in self-performed oral hygiene before the baseline examination. Hence, this comparatively low plaque score at the start of the study period made it feasible to explore properly the site-specific impact of plaque on the outcome variables describing treatment success.

The data analysis further revealed a poorer outcome of non-surgical therapy at sites located at molars, which is in accord with findings reported by other authors who utilized multilevel analysis in evaluations of the treatment outcome (Axtelius et al. 1999, D'Aiuto et al. 2005). In contrast to the studies referred to, however, tooth sites associated with furcation involvements were not included in the current analyses. Hence, taken together the findings indicate that the inferior treatment result commonly reported for molars is not solely due to the presence of furcation involvements, but may also be related to poorer accessibility for sub-gingival instrumentation. Furthermore, the significant interaction

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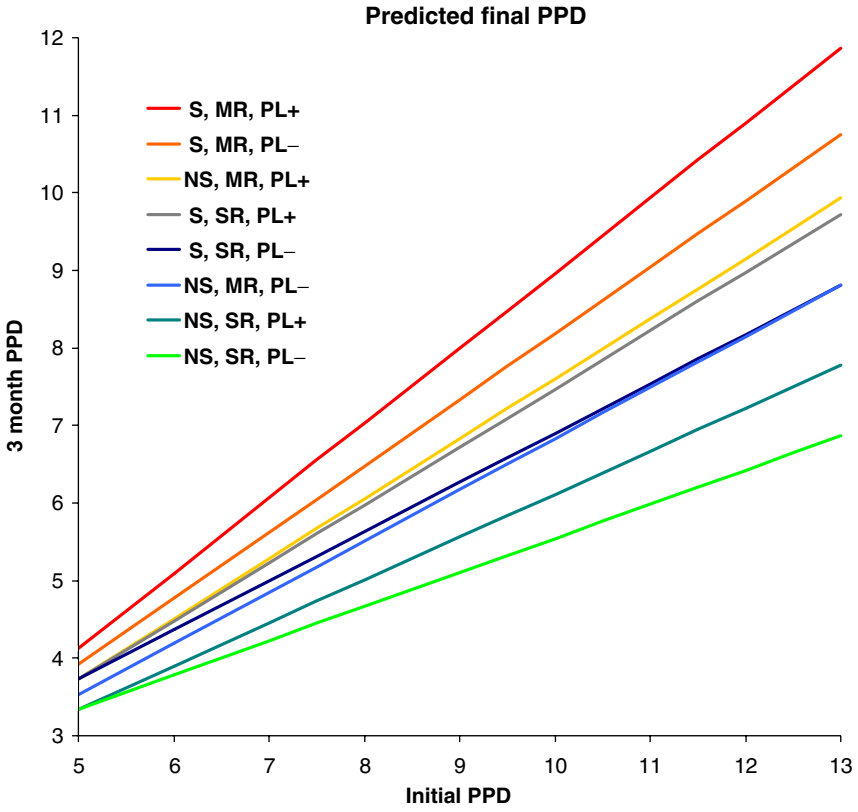

Fig. 5. Predicted final probing pocket depth (PPD) on the initial PPD for different patient and site categories (S, smoker; NS, non-smoker; SR, single-rooted teeth; MR, multi-rooted teeth; PL, presence of plaque at the tooth site).

with plaque shows that the cleaning efficiency of the patient in the posterior area is a crucial factor for pocket reduction.

Factors added into the regression models explained about 50% of the total variance in the outcome variables. It is noteworthy that 86% of the unexplained variance was attributable to intra-patient variation. Interestingly, these figures are fairly similar to those described in the recent publication by D'Aiuto et al. (2005) on multilevel analysis of the clinical outcome of subgingival debridement. Hence, these observations imply that the search for additional factors that may influence the prediction of the outcome of non-surgically performed periodontal therapy should primarily be focused on factors at the tooth site level.

The present study originally focused on the clinical feasibility of full-mouth UD as an initial approach in the treatment of the chronic periodontitis patient. The results revealed no significant difference in the clinical outcome between the two approaches. It is noteworthy, however, that the random slope model demonstrated that the predictability of the outcome, independent of treatment approach, was lower for deep pockets. From a treatment planning point of view, it would of interest therefore to evaluate if various adjunctive therapies may enhance the predictability of the treatment outcome at these particular sites.

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Clinical Relevance

Scientific rationale for the study: The understanding of which factors that determines the response to non-surgical periodontal treatment may be more adequately explored by the use of a multilevel statistical modelling.

Principal findings: Smokers presented inferior clinical healing results compared with non-smokers, especially at tooth sites harbouring plaque and located at multi-rooted teeth. The predictability of the outcome depends on the initial PPD, both on the site and patient levels.

Practical implications: The statistical models presented provide information on expected short-term clinical outcome of the pocket/root debridement and highlight the importance of self-performed infection control and smoking as important factors determining treatment success.

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