European Journal of Orthodontics 18 (1996) 645–654

Patterns and prediction of orthodontic treatment course

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SUMMARY Most attempts at the identification and prediction of treatment-related changes and outcome in orthodontics thus far have relied upon single biometric parameters instead of employing a systemic and ecological approach. The concept of facial harmony and the availability of sophisticated multivariate statistics offer new chances for a deeper understanding of the mechanisms of change.

A longitudinal study has been conducted on approximately 500 youths aged 9–11 years, on average. Numerous parameters of cephalometric analysis, study casts, growth, treatment regimen and patient co-operation were assessed at the onset of treatment (T_0) and after 1 year (T_1) to determine treatment-related changes under therapy with removable appliances. Exploratory cluster analyses were based on five fundamental cephalometric parameters (SNA, SNB, ML–NSL, NL–NSL, NS–Ba) that establish an operational approach to harmonious facial relations (Segner and Hasund, 1991).

As a first step, analyses were restricted to 281 Class II division 1 patients selected for good co-operation by an expert rating by the first author on a three-point rating scale. They all were treated with bionators either with anterior or posterior traction. Both subgroups were studied separately.

Based on cluster analytic procedures, different patterns of change were identified for both types of appliance. A slight tendency toward harmonization of the initial skeletal relations was observed throughout all subgroups, with reactions being most obvious in the maxilla. The clusters produced for either appliance group were then screened for additional predictors of group membership by means of discriminant analysis. The findings are discussed in terms of the suitability of the methodological approach chosen.

Introduction

In his provocative essay on the 'Inappropriateness of scientific methods in orthodontics', Bookstein (1991) states that biometric research has failed to reveal universal effects of orthodontic treatment that bear scrutiny. He further points out that differences found between treatment groups usually can be attributed to differences in starting form, treatment goal, choice of appliance, or details of treatment monitoring. Consequently, he argues in favour of the subject of research shifting from 'effects' to 'associations' and for the incorporation of the social context for treatment in future research. In other words: the individual patient's reasons for seeking treatment, and aesthetic aspirations, have to be taken into account as well as the individual clinician's preferences for certain biometric indicators and certain treatment means.

Research on these subjects began at the Würzburg Department of Orthodontics and Dentofacial Orthopaedics during the 1980s. While the socio-psychological context of orthodontic treatment was the focus of interest at the start, the whole range of treatment-related processes including both clinical and social parameters was later investigated. A major longitudinal study aiming at a better understanding and prediction of the interplay of these variables has been under way for almost 3 years. In a first communication, the methodology was demonstrated in detail and preliminary findings on a subset of clinical criterion variables (Koch and Bartsch, 1996) were provided.

While single cephalometric or study cast parameters may serve as salient diagnostic indicators, the overall impression of facial shape needs to be described in terms of morphometric patterns. As early as the 1920s and 1930s, 'Gestaltpsychologie' emphasized the perceptual properties of pattern stimuli. Contemporary biometrics have provided statistical tools for analysing such structures in the form of tensor biometrics or finite-element analysis (Fine and Lavelle, 1992).

A recent approach, after the pioneering work by Solow (1966) on 'The general pattern of the cranio-facial association', was presented by Hasund *et al.* (1993) who restored to modern orthodontics the concept of facial harmony. Facial harmony is characterized by certain relations between sagittal and vertical measurements which cannot be readily derived from statistical population means. Rather, the interdependence of cranio-facial variables has to be determined by linear regression analysis in well-defined reference groups. The correlation between the SNB angle and the ML–NSL angle served as an example which showed a medium strength of –0.61 according to Segner and Hasund (1991). The value of a given parameter can thus be estimated from a number of predictor variables and provides a norm against which the actual value can be tested. The degree and quality of individual facial disharmony may now be assessed from the synopsis of these discrepancies. Segner (1989) and Segner and Hasund (1991) have supplied correlational data of five fundamental cephalometric variables (SNA, SNB, ML–NSL, NL–NSL, NS–Ba) established in 275 untreated young adults with near-ideal dento-facial relations. Based on floating norms and leading variables, the harmonious relations can be read from the 'Segner harmony box' (Figures 2 and 3) which provides a movable template framed by the tolerance limits.

The concept of harmonious relations was included in this study in accordance with the objectives of this project—studying a large number of representative skeletal and dental parameters as organized in their natural patterns in a large sample comprising subgroups of the major malocclusions in a prospective study (Koch and Bartsch, 1996).

The complexity of the relevant factors to be studied requires the application of sophisticated multivariate statistical procedures in a first step, while decision analysis may subsequently be applied to orthodontics (Kahneman and Tversky, 1982; Petrovic, 1983). Only few studies have applied such methods to the analysis of orthodontic research data (e.g. Petrovic *et al.*, 1986; Tulloch and Antczak-Bouckoms, 1987; Keeling *et al.*, 1989).

Rationale and objective

Prior to an enhanced understanding of clinical information-processing and decision-making, the issue at stake is the nature of relevant information and how clinical decisions are reached. How is the available information best used to improve the diagnostic and prognostic process? As a heuristic tool, a preliminary model of prognosis and decision in the course of orthodontic treatment was devised (Koch and Bartsch, 1996). It comprises:

1) diagnostic findings and monitored responses
2) their clinical evaluation
3) prognoses based upon (1) and (2) and their possible
4) revisions in the light of interim results
5) decisions based upon (1)–(3) and their possible revisions in the light of interim results
6) treatment measures derived from (4) and their possible revisions.

To follow the course of orthodontic treatment and the determinants of its outcome and to be able to assess clinical judgement requires a sufficient body of clinical data. The aims of the study were to examine: (i) a large number of representative skeletal and dental parameters; and (ii) a large sample of subsets comprising homogeneous subgroups of the major malocclusions.

Subjects and methods

From the model suggested above, the design of a major study has been derived (Figure 1). The total study group comprised more than 400 children most of whom were between aged 9–12 years. This sample was drawn from the clientele of the practice of the first author (Table 1). The records available encompassed cephalometric and study cast parameters, parameters of growth and functional status, and the clinical assessment of patient compliance. Separate analyses were run for different classifications (e.g. Angle classes), stages of skeletal growth, and treatment approaches (Table 2).

Thus far, the results gathered at the start of treatment and interim data obtained after one year of treatment were analysed. In this report,

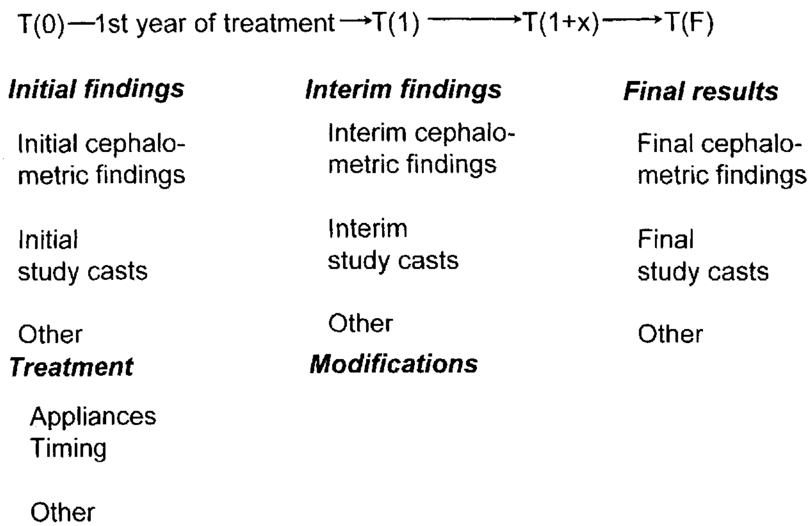

Figure 1 Design of the prospective study (modified after Koch and Bartsch, 1996).

we focus on Class II division 1 cases, while all other types of malocclusion are excluded from analysis. They were selected for at least a sufficient degree of treatment co-operation. The remaining patients ($n = 281$) were assigned to two groups depending on the type of their appliance, bionators combined with anterior traction ($n_A = 199$), and bionators with posterior traction ($n_P = 82$). Both groups were treated separately in all analyses to follow.

In order to statistically predict individual patterns of change, cluster analysis is the tool of choice (Kirkwood, 1988). Cluster analysis is highly recommended, whenever little is known about the structure of the data. Agglomerative hierarchical cluster analysis was combined with subsequent k-means procedure, so as to obtain a restricted number of homogeneous subgroups which optimally discriminate between one another. As a measure of similarity Euclidean distances were computed between the z-standardized variables (Everitt, 1980).

In contrast to the clinical parameter approach described elsewhere (Koch and Bartsch 1996), identical criteria were employed in this study at the start of the treatment and after 1 year, so both initial and interim findings could be entered simultaneously into the same cluster analysis. This gives clear evidence of the degree of respective change.

The aim was to study not only the grouping pattern of the sample, but also to identify additional initial findings discriminating between the clusters. These variables might account for different types of the treatment course, as well as being used for predictors in the future. In terms of statistics, it was the intention to distinguish between several mutually-exclusive groups the members of which are known, and to identify the variables that are important for distinguishing among the groups. Discriminant analysis is the technique commonly used to investigate this set of problems (Fisher, cited by Lachenbruch, 1975; Hand, 1981). Linear combinations of the independent ('predictor') variables serve as the basis for classifying cases into one of the groups. What is of major importance to clinical relevance is that discriminant analysis allows eliminating redundant predictors in favour of a sparse, yet powerful set of variables. This report is restricted to those Bergen analysis parameters (Hasund, 1976) which have not been utilized to establish the harmonious relations.

Preliminary findings

A couple of subgroups representing unique 'harmony' patterns of cranio-facial relations behaving differently during the first year of treatment were identified. Depending on the selection criteria, various cluster solutions were tested regarding the kind of extra-oral traction, skeletal age and appliance-age interactions (Table 2).

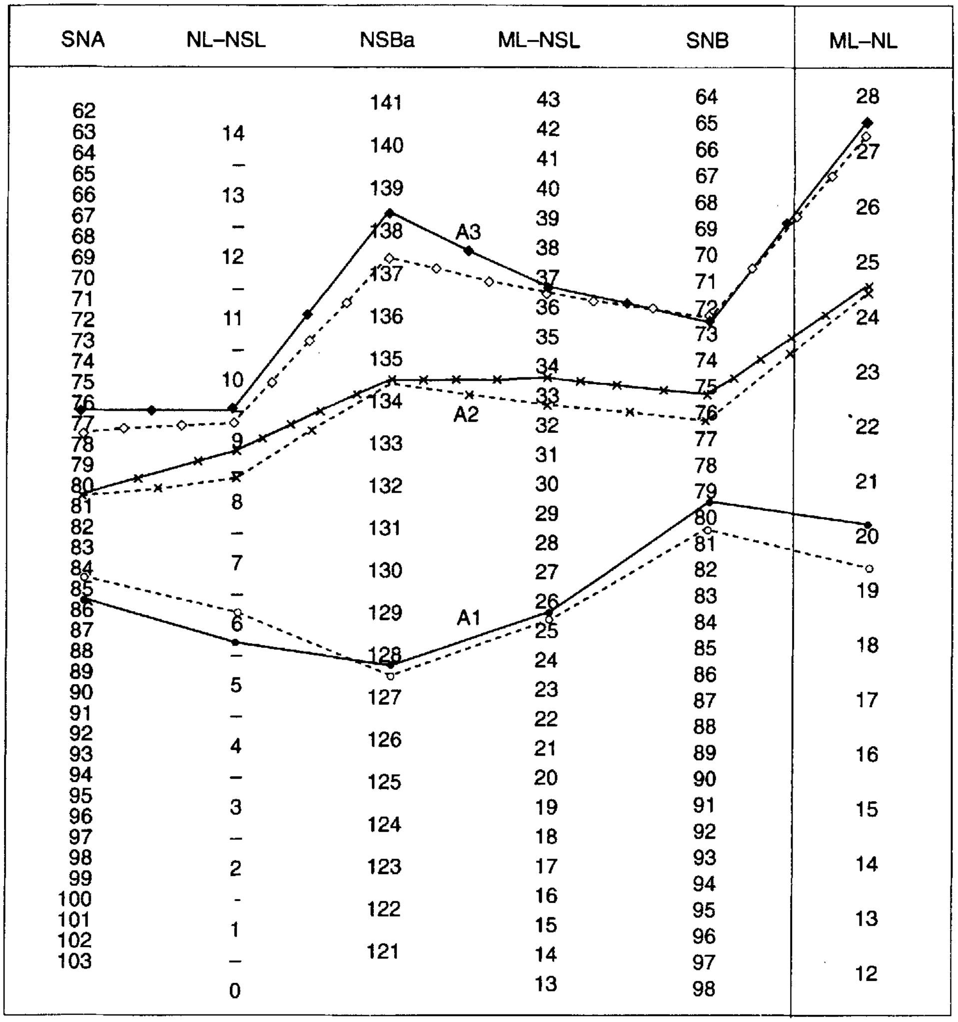

Figure 2 Harmony box of initial and 1-year findings in patients with anterior traction (three-cluster solution). A straight horizontal line represent a maximum degree of facial harmony.
Lower level: Cluster A1 ($n=46$)
•———• Initial findings
•- - - - - -• 1-year findings
Medium level: Cluster A2 ($n=139$)
x———x Initial findings
x- - - - - -x 1-year findings
Upper level: Cluster A3 ($n=14$)
◆———◆ Initial findings
◆- - - - -◆ 1-year findings

In view of the variety of classification results, we shall focus on the three cluster solutions emerging for patients wearing headgear either with anterior or with posterior traction. These findings are especially suited to demonstrate the methodological approach, in that they do not imply more than two subgroups (unlike the classification for skeletal age) and produce significant statistical differences between both the clusters (1 versus 2 versus 3) and the measurement points (T_0 versus T_1) respectively.

The findings for the anterior traction subgroup are given in Table 3 and Figure 2, those for the posterior traction subgroup are pre-

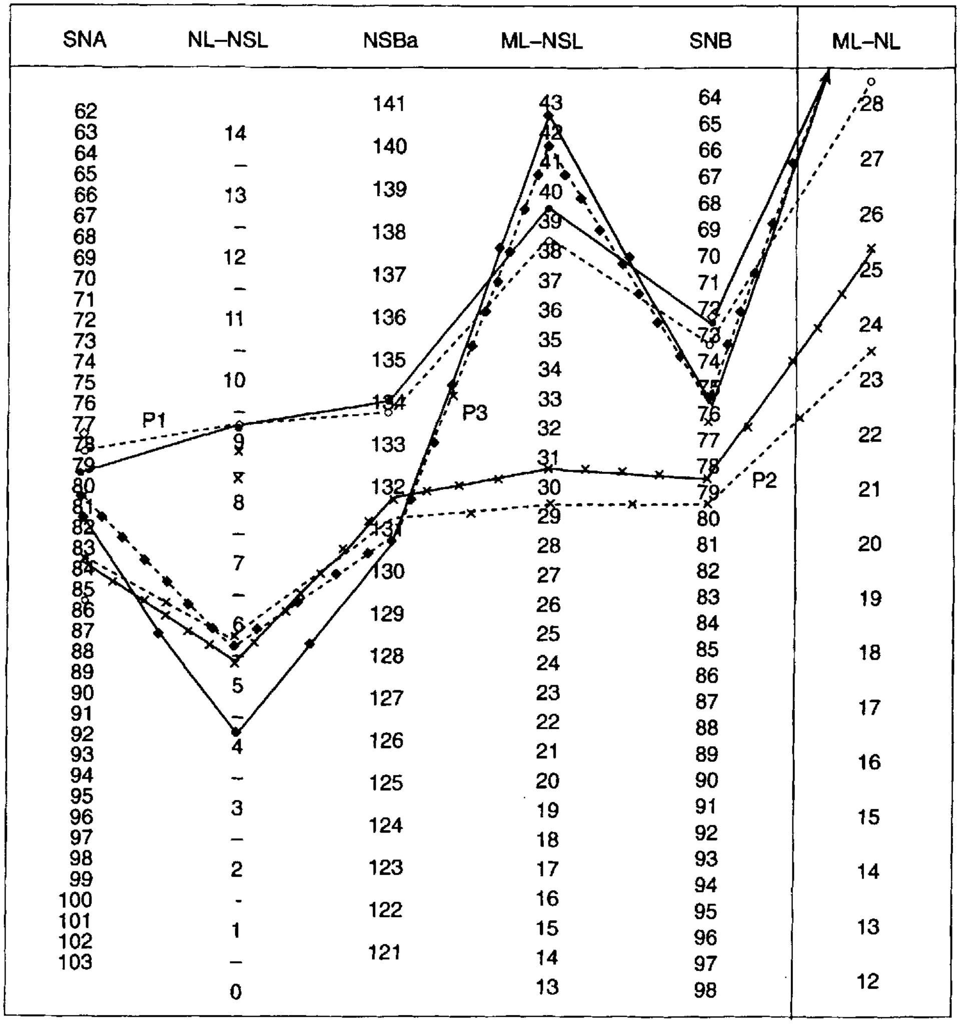

Figure 3 Harmony box of initial and 1-year findings in patients with posterior traction (three-cluster solution). A straight horizontal line represents a maximum degree of facial harmony.
Upper level: Cluster P1 ($n = 35$)
•———• Initial findings
•- - - - -• 1-year findings
Lower level: Cluster P2 ($n = 32$)
x———x Initial findings
x- - - - -x 1-year findings
Medium level: Cluster P3 ($n = 15$)
◆———◆ Initial findings
◆- - - -◆ 1-year findings

sented in Table 4 and Figure 3. Generally, a trend towards more harmonious relations was observed during the first year of functional orthodontic treatment. Whether to apply a bionator with anterior or posterior traction, is not dependent on the 'harmonious relations', so both groups behave in a similar way. This finding is in line with the assertion made by Bookstein (1991) that different facial types respond alike to specific treatment interventions.

The orthopaedic forces were primarily applied to the maxilla which implied mandibular reaction to only a minor degree. Hence, as

Table 1 Patient sample.

Class II division 1 patients	281
Sex	
Male	151 (53.7%)
Female	130 (46.3%)
Age	
Median	11.05 years
Mean	11.10 years
SD	1.65 years
Appliance	
Bionator with anterior traction	199 (70.8%)
Bionator with posterior traction	82 (29.2%)

Table 2 Data analysis.

Selection of parameters	
Cephalometric parameters	
Bergen cephalometric analysis (Hasund, 1976)	
Structural analysis	
Study cast parameters	
Carpus radiographs	
Functional status	
Patient compliance rating	
Kind of appliance (extra-oral traction)	
Selection of cases	
Grouping for appliance	Class II division 1 Bio + anterior traction versus Bio + posterior traction
Grouping for skeletal age	Stages derived from carpus radiographs (PP2, S, MP3cap a.s.o.)
Statistical analysis	
Cluster analysis on harmonious relation parameters (T_0, T_1)	separately (a) on total study group (b) by appliance subgroup (c) by skeletal age subgroup
Discriminant analysis between 'harmony' clusters	(d) by subgroup combined for appliance and skeletal age

expected, indicators of the sagittal and vertical position of the maxilla changed most obviously.

The more dysharmonious relations were found at the beginning, the more marked reactions were observed after 1 year. A similar finding has been noticed once before, when the mode of action of cervical headgear was studied in four groups of Class II division 1 patients differing by their patterns of facial harmony (after Hasund). In this earlier study patients presenting unharmonious facial relations responded more strongly to extra-oral forces than did patients presenting rather harmonious relations (Koch, 1985). It might therefore be suggested that: (i) single parameters will change under treatment resulting in a more harmonious cranio-facial pattern; (ii) primary harmonious relations are less amenable to therapeutic improvement than primary dysharmonious patterns; (iii) unique predictors of discrete harmonization patterns were identified by means of discriminant analysis.

Discriminant analysis yielded a sparse set of initial cephalometric predictors of the anterior traction cluster solution (A1 to A3). The variable set comprises in order of their predictive power: (i) the facial axis; (ii) the PFH/AFH ratio and the rough values of PFH and AFH; (iii) facial convexity; (iv) overjet; (v) $\underline{1}$–NL; (vi) $\underline{1}$–NS, and (vii) ANB. These parameters combined allow a 'hit rate' of 85.9 per cent (compared with 33.3 per cent chance) for the prediction of cluster membership in the sample studied (Table 5).

A somewhat different set of predictor variables emerged for the posterior traction cluster pattern (P1 to P3). They encompass: (i) the Björk sum angle; (ii) SN–PG; (iii) Tgo–Gn; (iv) Pg–NB; (v) facial convexity; (vi) PFH/AFH ratio; (vii) $\underline{1}$–ML, (viii) 1–NB; (ix) ANB; and (x) facial axis (Table 4). This set of parameters yielded a correct classification of 87.8 per cent (compared with 33.3 per cent chance) of the criterion clusters (Table 6).

The means predictor values for each group are presented in Table 7. The selection of the variables to be included in an analysis is crucial, so if important parameters are omitted, poor or misleading results may result (Romesburg, 1984). On the other hand, some of the predictor variables (e.g. ANB) are geometrically dependent upon classification parameters (e.g. SNA, SNB) and, thus, do not represent true 'predictors' in a logical sense. However, we feel this approach may contribute to a better understanding of the determinants of change under treatment.

Conclusions

At the moment, it is difficult to give a serious interpretation of these findings that have been

Table 3 Results of cluster analysis for anterior traction subgroup (final cluster centres).

	Parameters			
Cluster	SNA2	SNB2	ML _ NSL2	NL _ NSL2
A1	84.8432	80.4432	25.5135	6.0405
A2	80.7140	76.1225	32.9411	8.4070
A3	77.1750	72.2250	36.4750	9.3500
Cluster	ML _ NL2	NS _ BA2	SNA1	SNB1
A1	19.4324	127.6595	85.0432	79.8865
A2	24.5442	134.2411	80.6713	75.2814
Cluster	ML _ NSL1	NL _ NSL1	ML _ NL1	NS _ BA1
A1	25.8243	5.7432	20.0892	127.8676
A2	33.6287	8.9140	24.7140	134.3202
A3	36.8500	9.6750	27.5750	138.3750
Cluster	Number of cases			
A1	46			
A2	139			
A3	14			
Total	199			

Table 4 Results of cluster analysis for posterior traction subgroup (final cluster centres).

	Parameters			
Cluster	SNA2	SNB2	ML _ NSL2	NL _ NSL2
P1	78.6441	73.2000	38.3647	9.3065
P2	83.5233	79.1900	29.4333	5.9429
P3	80.5000	75.9533	41.8400	5.7154
Cluster	ML _ NL2	NS _ BA2	SNA1	SNB1
P1	28.4559	133.8441	79.4500	72.8563
P2	23.6138	131.2267	83.4387	78.4065
P3	37.0667	130.8733	81.4429	75.7786
Cluster	ML _ NSL1	NL _ NSL1	ML _ NL1	NS _ BA1
P1	39.4813	9.2500	30.2250	134.0219
P2	30.8677	5.4645	25.4000	131.8645
P3	42.9000	4.1143	31.7786	130.6071
Cluster	Number of cases			
P1	35			
P2	32			
P3	15			
Total	82			

Table 5 Results of discriminant analysis for clusters of anterior traction subgroup.

Step	Parameter entered	Wilks' Lambda	Significance
1	F _ ACHS1	0.78182	0.0000
2	PFHAFH1	0.69865	0.0000
3	PFH1	0.65548	0.0000
4	AFH1	0.63532	0.0000
5	F _ KONV1	0.61842	0.0000
6	OVERJ1	0.60635	0.0000
7	O1 _ NL1	0.59193	0.0000
8	O1 _ NS1	0.54347	0.0000
9	ANB1	0.53016	0.0000

Table 6 Results of discriminant analysis for clusters of posterior traction subgroup.

Step	Parameter entered	Wilks' Lambda	Significance
1	BJ _ RK1	0.41167	0.0000
2	SN _ PG1	0.27691	0.0000
3	TGO _ GN1	0.24834	0.0000
4	PG _ NB1	0.22567	0.0000
5	F _ KONV1	0.20565	0.0000
6	PFHAFH1	0.18412	0.0000
7	U1 _ ML1	0.17027	0.0000
8	U1NB _ M1	0.14934	0.0000
9	ANB1	0.14066	0.0000
10	F _ ACHS1	0.13296	0.0000

Table 7 Significant predictors of harmony clusters.

Parameter	Cluster	*P*	Anterior traction (A)	*P*	Posterior traction (P)
Facial convexity		0.048		0.012	
	1		4.77		6.20
	2		4.21		4.16
	3		4.58		5.66
ANB		0.034		0.011	
	1		4.93		6.59
	2		5.25		4.90
	3		4.99		5.65
PFH/AFH		0.0002		0.014	
	1		18.52		58.86
	2		55.18		54.57
	3		24.09		54.09
Facial axis		0.0001		0.0001	
	1		89.95		87.12
	2		92.52		92.64
	3		85.65		86.21
Overjet		0.0003			
	1		8.48		
	2		6.94		
	3		7.26		
$\underline{1}$-NS		0.021			
	1		75.72		
	2		75.17		
	3		78.42		
$\underline{1}$-NL		0.016			
	1		69.03		
	2		66.91		
	3		71.57		
SN–PG				0.0001	
	1				73.35
	2				78.96
	3				75.89
Björk Angle				0.0001	
	1				407.47
	2				398.67
	3				411.72
PG–NB				0.017	
	1				0.95
	2				1.15
	3				0.20
1–ML				0.005	
	1				96.91
	2				99.84
	3				88.17
TGO–GN				0.003	
	1				74.88
	2				78.26
	3				80.71
1–NB				0.005	
	1				6.13
	2				5.73
	3				6.64

unparalleled in orthopaedic or orthodontic treatment reports. The so-called 'harmonious relations' approach is, thus far, an unprecedented attempt to combine, by means of a mathematical function, skeletal parameters which mainly describe the sagittal and vertical positions of the maxilla and the mandible towards the structures of the skull. In contrast to some other approaches such as the Steiner analysis (Steiner, 1960), the aim of this concept is not to determine the conditions most favourable for treatment, but rather to represent an 'ecological' approach to the study of treatment-related changes.

Furthermore, the linear regression approach can readily be extended to additional skeletal and dento-alveolar variables, e.g. the position of the lower incisors (Hasund *et al.*, 1993). By this means, a forecast of ideal dento-alveolar compensation appears possible. Naturally, the accuracy of prediction depends upon the availability of a data set large enough to generate robust models which may be applied to samples other than ours (Hirschfeld and Moyers, 1971). This has thus far been a major drawback of the 'funnel approach' used in our study, but should be overcome by a larger data set. In the further course of this project, we shall extend our approach by the study of various malocclusions and additional clinical data.

On the basis of the basic research outlined above, it is hoped to advance the development of a decisional expert system for the operational analysis in orthodontics (Brown *et al.*, 1971; Sims Williams *et al.*, 1987; Mackin *et al.*, 1991; Koch and Keß, 1995). The approach thus far has concentrated upon narrow-scale clinical models of prognosis (such as the Steiner analysis) and intervention decisions, while individual and subjective treatment goals still await consideration. The concept of facial harmony in combination with a large body of empirical data (Hirschfeld and Moyers, 1971) promises to amplify this approach into a comprehensive system without sacrificing the tried and tested tools of objective biometric research (Patrick, 1979; Weinstein *et al.*, 1980).

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