Comparison and reliability assessment of "p distance" with conventional lower incisor measurements. A Long term cephalometric study

Vasantha Kumar Srinivasan B.D.S, M.S

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Dedication

To my parents, Mr. Srinivasan Arumugham and Mrs. Kalavathy Rengaswamy and to my sister Dr. Kavitha Srinivasan.

For your love and affection, and to your continued support, financial and moral. Without you, I would not be here.

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Declaration

CANDIDATE CERTIFICATE

This is to certify that the candidate carried out the work in this thesis in the Orthodontic Department, University of Sydney and has not been submitted to any other University or Institution for a higher degree.

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Abbreviations

FMIA	Frankfort Plane Mandibular Plane Incisor Axis Angle
FMA	Frankfort Mandibular Plane Angle
IMPA	Incisor Mandibular Plane Angle
NB	Nasion B Point
SNA	Sella Nasion A Point
SNB	Sella Nasion B Point
ANB	A Point Nasion B Point
L1	Lower Incisor
Po/Pog	Pogonion
SNI	Sella Nasion Lower Incisor tip
FH	Frankfort Horizontal Plane
H angle	Holdaway angle
H line	Holdaway line
VTO	Visual Treatment Objective
ANS	Anterior Nasal Spine
PNS	Posterior Nasal Spine
PP	Palatal plane
MP	Mandibular plane
p Distance	Proposed new measurement for lower incisors

1. Introduction

1.1 The Relevance of the Mandibular Incisor in Orthodontics

Although great emphasis is placed on measurements taken from the lower incisor crown and the lower incisor inclination in orthodontics, it is difficult to obtain reliable reference points regarding the lower incisor on lateral cephalometric radiographs. The purpose of this study was to compare and assess the reliability of “p distance” with conventional lower incisor measurements using lateral cephalometric radiographs over a long period of time.

If the lower incisor position and inclination are incorrectly determined, it adversely effects the treatment planning of patients as well as the scientific validity of orthodontic research.

2. REVIEW OF THE LITERATURE

2.1 THE RELEVANCE OF MANDIBULAR INCISORS IN TREATMENT PLANNING FOR PATIENTS

The mandibular incisor position is of critical importance in orthodontics. The main purpose of orthodontics can usually be defined as the creation of the best balance between occlusal relationships and dental and facial aesthetics. Stability of the result as well as the long-term maintenance of the dentition is also critical (Proffit, 2000). The lower incisors have a central role to all these goals.

The mandibular incisors function with the maxillary incisors:

- in the cutting of food (the moving blades)
- in the production of distinct speech and
- in maintenance of a good appearance by supporting the lower lip
- By fitting their incisal edges against the lingual surfaces of the maxillary incisors, they also help to guide the mandible posteriorly in the joint during the final phase of closing before the posterior teeth contact. (Woelfel, 1990)

The mandibular incisors are, however, limited in the range that they can be moved orthodontically as their alveolar support over basal bone, especially in an antero-posterior dimension, is the least of all teeth (Alexander, 1986).

Much attention has been focused on the antero-posterior position of the lower incisors, from the point of view of its effect on the profile of the lower face, and the stability of the treated result. These considerations determine the desired incisor position, from which extraction and anchorage requirements are evaluated, and remaining tooth movements planned.

The trend in this modern world is towards the greater use of fixed appliances, which afford very precise movements of the lower incisors. In the light of this, a collation of the various methods available for determining the planned position of the lower incisors is presented, and a brief appraisal of each is given.

Different opinions regarding the optimum position of the lower incisors are held.

2.2 RELEVANCE OF MANDIBULAR INCISOR POSITION IN THE SCIENTIFIC VALIDITY OF ORTHODONTIC RESEARCH

Cephalometric Analysis of Lower Incisors:

2.2.1 Tweed, 1954

Tweed believed that the diagnostic triangle concept was his most important contribution to clinical orthodontics (Tweed, 1969). This was evolved over many years from observation of changes achieved in tooth and in particular, lower incisor position which gave rise to desirable facial aesthetics.

In a cephalometric analysis of a sample of 100 non-orthodontically treated patients selected for good profile aesthetics, Tweed found a mean value of the Frankfort plane-mandibular plane incisor axis angle (FMIA) of 69°. In addition, many cases exhibited a compensatory relation between the mandibular incisor-mandibular plan angle (IMPA) and the Frankfort-mandibular plane angle (FMA)(Tweed, 1954).

These three angles form the 'Tweed triangle', which was presented as a diagnostic aid in order to position the lower incisors for optimal facial aesthetics by attempting to achieve a FMIA in the order of 65°. Given a relatively constant FMA, the third angle, IMPA is altered by treatment mechanics to give the ideal FMIA.

The 'prognosis' tracing is constructed by moving the mandibular incisor axis about the apex so that an angle of 65°-70° is made with an extended Frankfort plane. This principle was later modified by Tweed (Tweed, 1966) to consider vertical skeletal discrepancy; the desired FMIA for FMA angles of 30° upward is 65°, whilst the FMIA goal increases to 72° when the FMA is 20°, and is further raised progressively to a maximum of 80° for FMA angles below 20°. Tweed also stated that in about 25 per cent of cases where mandibular growth was considered unfavourable (i.e. mainly downward, with an increasing ANB angle), attainment of the FMIA goal of 65° was impossible. Such cases were therefore considered to be of poor prognosis.

The method is limited to angular measurements and assumes that only tipping movements about the apex are possible. It could also be argued that the Frankfort plane is an inappropriate reference line with which to assess the antero-posterior position of the lower incisor.

2.2.2 Steiner, 1953, 1959

Steiner's analysis considers the position of the lower incisors in relation to the cephalometric Nasion-B point (NB line), and is measured angularly (mean 25°) and linearly (mean+4mm). The prognosticated lower incisor position however is individualized according to the patient's projected dental base discrepancy as measured by the angle ANB, and the relative prominence of the bony chin.

The desired lower incisor position is determined from measurements ANB, L1-NB (angle and distance) and NB-Pogonion (distance). A range of values for incisor position with varying ANB angles has been presented by Steiner and is known as the 'acceptable compromises'.

If the predicted ANB angle at the end of treatment is smaller or larger than 2°, the appropriate acceptable compromise model is used to determine the 'ideal' position. The prognosis model is further modified by the NB-Po distance, which according to Holdaway's ratio (Holdaway, 1956) should be the same as the L1-NB distance.

An assessment for the relative change in A point to B point during treatment is made; about 2° reduction in ANB can be expected resulting from some backward remodelling of A point and forward growth at B point. In addition it is anticipated that further bone deposition at the chin will give rise to an increase of NB-Po of about 1 mm.

Using the 'chevron' diagrams from the Steiner analysis form the presenting problem is depicted schematically, and the incisors 'moved' as dictated by the acceptable compromise for a 3° ANB. The modification to lower incisor position to concur with the predicted NB-Po distance is then made, and the upper incisor is positioned accordingly.

The corresponding measurements of the acceptable compromise and NB-Po modification are averaged to arrive at the overall treatment goal. This is then compared with the presenting problem to give an indication of the required incisor movements.

This method therefore assumes that no single mean position is appropriate and takes into account the guiding effect of the ANB angle and chin conuration. The possible effect of vertical skeletal relationship, however, is not considered.

Steiner points out that the prognosis model should be further individualized according to the patient's age, sex and growth pattern although it is not clear how this should be achieved.

2.2.3 Ricketts, 1960

Downs (Downs, 1956) first utilized a line drawn from A point-Pogonion (A-Po) as a reference line to relate the lower incisor position antero posteriorly, and this has been incorporated by Ricketts into an overall cephalometric analysis. This analysis has been used over many years to produce a data base forming the basis of a computerized growth prediction and treatment planning service.

Ricketts' studies of stable cases and consideration of aesthetic lip relationships led him to advocate positioning the lower incisor at 22° and at +1 mm (i.e. slightly ahead) to the A-Po line as a clinical objective. The acceptable range was given as ±2.5mm. Ricketts also found that in untreated individuals the mean position of the lower incisor with respect to A-Po changes very little with growth (Ricketts, 1981). The relative position of A point is influenced by treatment, however, and the position of Po relative to A point is also growth dependent. Account must therefore be taken of these factors when estimating the direction and degree of movement required.

Clearly therefore the projected incisor A-Po position can be dependent on movements of the lower incisor or the A-Po line or both, and it may be that a backward movement of A point in response to upper incisor retraction is sufficient to place the lower incisor in ideal relation to A-Po without its movement in relation to the symphysis. Obviously if some forward movement at Po relative to A point is anticipated through growth, the amount of incisor retraction to achieve this would be somewhat less. Since the A-Po line is intended to represent the anterior-most extensions of the maxilla and mandible, this method arguably compensates for dental base discrepancy. It would appear particularly applicable to the clinical situation as it can be used in the absence of an accurate growth prediction or complete Ricketts analysis in giving an indication of the permitted direction (or perhaps more usefully the direction not permitted!) of lower incisor movement.

2.2.4 Mills, 1968

The method of treatment planning advocated by Mills on the basis of a series of surveys in the mid 1960's has been widely adopted by the orthodontists around the globe. Analysing the lower incisor position using the cephalometric SNI angle (I = tip of lower incisor), Mills showed that whether proclined or retroclined by treatment, the lower incisors tended to return to their original position once all appliances were removed (Mills, 1966, Mills, 1967).

Comparing these samples with control groups and cases where the lower first premolars had been extracted but no other treatment applied to the lower arch, he concluded that the lower incisors occupy a narrow zone of stability, presumably influenced by the lower lip and tongue. The average amount of successful proclination or retroclination was 1-2mm.

Thus, the position of the lower incisor at the start of treatment is also the treatment objective. This position is therefore used as a base from which to plan treatment (Mills, 1968).

This is however qualified by certain exceptions; in those cases where it is apparent that the lower incisor is prevented from taking up its true position of balance, e.g. when 'trapped' lingually by a very deep overbite or 'swapped' with the upper incisors in a class III relationship, then a small amount of movement in the appropriate direction can be expected to remain stable.

Whilst this conservative approach is obviously foolproof in terms of relapse, many clinicians have shown cases where much greater amount of lower incisor movement than recommended by Mills have been achieved without significant relapse and with a concomitant aesthetic improvement (e.g. Ricketts). Moreover the effect of bodily or apical movement was not fully evaluated by Mills as the lower incisors were moved by tilting in the majority of cases.

2.2.5 Hasund, 1980

Hasund's analysis of lower incisor position is essentially an evolution of Steiner's analysis which introduces the 'floating norm' concept by modifying ideal incisor position to take account of the skeletal A-P discrepancy and chin prominence as guiding variables.

In a previous study, (Hasund and Ulstein, 1970) on Norwegian adults, concluded that account must also be taken of the mandibular inclination (ML-NSL), Hasund and co-workers have analysed Norwegian (Hasund and Boe, 1980) and German (Janson and Hasund, 1981) samples of adults with Class I occlusion and harmonious profiles with a view to refining the floating norm concept to cover a variety of facial types.

The following cephalometric variables were measured:

- ANB angle
- ML-NL angle;
- 'Nordeval' (N) angle (the angle made by a tangent to the bony chin through B point and the mandibular line);
- L1-NB distance.

Linear correlation coefficients were calculated between L1-NB and the three guiding variables ANB, ML-NL and N angle. The coefficients were applied to a multiple regression analysis and an equation found for the lower incisor position according to the guiding variables.

For a Norwegian population this was:

Y (L1-NB mm) = 0.47 ANB + 0.11 ML-NL + 0.06 N angle – 2.40

And for a German population this was:

Y = 0.47 ANB+0.11 ML-NL+0.09 angle-4.21

If applying the equation in treatment planning, the guiding variables as they appear at the end of treatment should be used. Therefore an estimation of the effects of growth and treatment on the variables-especially ANB-is required.

Since the multiple correlation coefficient for the guiding variables accounts for about 40 per cent of the variation in L1-NB and Hasund states that further modification to the prognosis is required according to the individual character of the malocclusion, a somewhat unwieldy equation would appear to be of dubious value to the clinician.

Nevertheless, the Hasund method does represent a more elaborate and statistical attempt at individualizing the ideal lower incisor position when compared with Steiner's original model.

2.2.6 Holdaway, 1983

Holdaway derived his soft tissue analysis in an attempt to improve the facial balance of a proportion of cases treated to Tweed incisor goals, having concluded that a single hard-tissue measurement was inappropriate.

The technique is based on Holdaway's experience and analysis of treated cases over many years of practice, and whilst the incisor position cannot be assessed in isolation from the total analysis, a brief description is given for completion.

The analysis consists of 11 measurements, intended to give an impression of harmony and balance for a given facial pattern. They are derived from a standard cephalometric tracing of hard tissue structures and the profile outline using the following lines:

- Frankfort horizontal (FH);
- Facial plane (N-Po);
- Soft tissue facial plane (N'Po');
- Tangent to vermilion border upper lip perpendicular to FH;
- Holdaway line (tangent to soft tissue chin and upper lip).

The parameters of particular interest in incisor position are the hard tissue convexity (A-NPog) and the Holdaway Angle, the angle between the H-line and the soft tissue facial plane. The lower lip should fall just on the H-line.

The H-angle is a measure of upper lip support and will be influenced by mechanical repositioning of upper incisors; the appropriate H angle depends on the bony convexity at A point, and Holdaway's observations on faces with good lip esthetics in various types dictates that his be 'set' at an angle equivalent to the convexity plus 10°.

The upper incisors are moved in order to optimize the H angle and lip sulcus depth and remove lip strain; the required lower incisor movement is determined from the appropriate upper incisor movement. Holdaway (Holdaway, 1984) advocates use of a visualized treatment objective (VTO) based on a growth prediction, when necessary, which incorporates an improved soft tissue profile with appropriately repositioned incisors.

The VTO can then be superimposed on the original tracing to give an assessment of the incisor movements required. It could however be argued that whilst the method undoubtedly prognosticates the optimum esthetic position of the lower incisors, stability does not necessarily arise as a result.

2.3 DISCUSSION

Another opinion is that of Alexander whose key objective is to treat a patient with the face proportionately balanced, consistent with his particular skeletal pattern. In keeping with this basic objective, Alexander makes his case diagnoses with particular emphasis on the position of the mandibular incisors in regard to the patient's profile (Alexander, 1986).

According to Lenz in an article *Incisal Changes and orthodontic stability*, Nanda and Burstone list three concepts regarding ideal position and angulations of the incisors for stability that differ from those traditionally accepted (Lenz and Woods, 1999). These three concepts are:

- the so-called cephalometric normal values for the incisors are the most stable, and yet stability can and does exist outside these norms;
- the original positions of the mandibular incisors before treatment are the most stable positions and correcting any malocclusion may move the incisors into unstable positions;
- There is only one stable position for the mandibular incisors.

Given the widespread use of lower incisor positioning formulae in treatment planning, there are very few evaluations of the clinical effectiveness of these methods reported in the literature.

Tweed himself has published many of his case reports, and has made his results available to others for evaluation. e.g. (Stoner et al., 1956, Wylie, 1955). It would seem that application of the Tweed triangle was successful for the majority of his treated cases, but led to a worsening of facial esthetics in a minority. Tweed has attributed this to the inappropriateness of the 65°+FMIA goal in patients exhibiting certain growth patterns (Tweed, 1966), whilst Holdaway (Holdaway, 1983) felt that failure to take into account soft tissue morphology was responsible.

Anderson (Anderson et al., 1973) evaluated 70 cases treated to the Tweed philosophy and found that the lower incisors had been moved lingually with respect to N-Po line 2-3mm. A concomitant improvement in lower facial profile (as assessed by the esthetic plane and H angle) was observed. No significant change was evident on re-evaluation 10 years out of retention, although comparison of these findings with a control sample was not made.

Steiner's analysis, though widely used, is largely unchallenged in the literature with respect to incisor positioning. Servoss (Servoss, 1973) has attempted to discover the origin of the acceptable compromises on which the analysis is based. He has suggested that they were derived from a geometric procedure involving the manipulation of various angles whilst maintaining the angle of the upper incisors to the NB line constant, and has questioned the biological validity of such a geometric model.

Ricketts' A-Po line has been evaluated by Williams (Williams, 1969) who, without any statistical analysis of his findings, felt that the A-Po line is the key to lower incisor positioning, in achieving lip balance and stability. He suggested however that the angular relation of the lower incisor to A-Po line is less important than the crown position. Thompson (Thompson, 1974), assessing results of cases treated with the Begg Appliance found that the lower incisors consistently approached the A-Po line during treatment.

A number of cases treated by Ricketts have been examined by Schulhof (Schulhof et al., 1977) who concluded that the maxilla is important when determining the incisor position, and that A-Po is a useful reference line in respect of both lip harmony and incisor stability, although angular measurements to A-Po were not considered. In an evaluation of a small number of treated cases showing a considerable esthetic improvement, Lindquist (Lindquist, 1956) observed that application of the Tweed, Steiner and A-Po line methods arrived at different incisor prognoses, and concluded that, whilst linear measurements were more successful than angular measurements, no method or formula was ideal.

Mills' investigation was conspicuous in being based on treated cases rather than a collection of mean values for 'ideal' untreated samples. His conclusion that the lower incisor position is largely immutable has been supported by Hixon (Hixon, 1972) who felt that the only value of cephalometric analysis of lower incisor positioning lies in ensuring that it is not changed as a result of treatment. Riedel (Riedel and Brandt, 1976) lent further weight to this concept, and also pointed out that lingual movement by the amount that would occur normally as a result of facial growth changes should remain stable.

Schulhof, however, on the basis of results achieved by Ricketts has rejected the theory that the labio-lingual position of the lower incisor should be maintained as presented, although it was stressed that careful consideration of individual patients' musculature is essential, and that indiscriminate incisor movements should be avoided. Brenchley (Brenchley, 1980) has shown cases where the incisors were moved by treatment towards the A-Po line only to relapse later, but pointed out that skeletal and soft tissue morphology was extreme, and growth unfavorable in each case.

Whilst many clinicians feel that lower incisor position is influenced more by soft tissue than skeletal factors, it is still unclear whether moving the lower incisors into more 'normal' relationships will bring about a favorable change in soft tissue pattern. Posen (Posen, 1976) measured the strength of the peri oral musculature and found that this correlated with the position of the incisors. He observed that a change in the oral environment due to a more normal denture position was accompanied by a change in the peri oral musculature to more normal readings, especially in class II division 2 incisor patterns.

The problems of relying on cephalometric points and planes distant from the area of interest, e.g. SN line, Frankfort plane, have been highlighted by many authors. Bjork (Bjork, 1955) has shown that S and N points can undergo considerable movement with growth independent of other cranial structures. Hussels and Nanda have detailed factors which affect the accuracy of the ANB angle skeletal assessment, and it would seem that this is a relatively poor measure of antero-posterior discrepancy. The validity of lower incisor prognosis measurements involving S and N points, and ANB angle, is therefore questionable.

Tracing and superimposition errors have also been well documented (Gravely and Benzies, 1974) and can be responsible for reduction in accuracy of formula based assessments. The use of 'VTO's' and growth predictions in general have fallen into some disrepute recently, and have been reviewed by Houston (Houston, 1979).

Hixon (Hixon, 1972) has warned against the trend of applying increasingly complicated cephalometric measurements to a biological system; this is relevant to lower incisor position, where individual variation and the uncertain effects of growth and treatment can render the most elaborate analysis worthless.

It is widely accepted that the position of the lower incisors is of clinical importance in treatment planning. The methods of arriving at a projected incisor position in the treatment goal have been described.

From a review of the literature their various limitations are clear; most rely heavily on various cephalometric points, lines and planes which are themselves subject to variation and errors in identification, and are in some cases remote from the area of interest. Growth and the response to treatment are still not completely predictable and further limit the value of prognosis.

On the other hand, they are only intended as a guide to incisor positioning, and their value probably lies in establishing an objective of treatment which assists the orthodontist in attaining a degree of consistency in treatment results.

To this end, the A-Po line is probably the most useful adjunct to treatment planning; unlike many other reference lines it is closely related to the structures influencing lower incisor position and the modifying effects of treatment and growth can be clearly visualized. Moreover it is uncomplicated by the need for extensive analysis or accurate measurement. It would seem wise, however, to adopt a cautious approach in the light of Mills's work and avoid planning an excessive movement of the lower incisors.

Nevertheless, it is considered of sufficient importance to investigate further the relationship between treatment planning goals and the incisor position actually achieved. A sample is therefore being collected to establish mean and range values for the various parameters concerned with lower incisor position appropriate to a British population. These will then be applied to a series of well treated cases, out of retention, in an attempt to assess more fully the clinical value, if any, of the methods described.

3. RADIOGRAPHIC PRINCIPLES AND CEPHALOMETRY

3.1 INTRODUCTION

Cephalometry originates from craniometry where anatomists recorded various dimensions on dry skulls. In classic Cephalometry, measurements of the head were taken from bony landmarks as located by palpation through adjacent soft tissue. The technique to produce a lateral head film by Pacini in 1922 evoked the standardization of cephalometric lateral radiographs of the skull for use in orthodontics by Broadbent and by Hofrath in 1931 (Athanasiou, 1995). Radiologic cephalometry is thus the recording of bony landmarks (as well as dental and soft tissue landmarks) on a radiograph of the skull.

The most commonly used radiograph is a lateral head radiograph with a classical cephalometric analysis involving the construction of lines and planes on the anatomical landmarks to form a reference system. Cephalometrics is to a large degree "applied geometry" (Moyers, 1988). Points are precisely located spots that relate to specific landmarks and are located on a tracing of a cephalometric radiograph. A plane is determined by joining two points with a straight line.

Analyzing cephalometric head films serves as a valuable treatment planning and treatment assessing tool. Cephalometrics is essential in the diagnoses of facial disharmony and the planning and evaluation of orthodontic treatment. The use of lateral cephalometric head films are therefore one of the routine procedures in any orthodontic practice (Jacobson, 1995).

Although cephalometric analysis "is only one of many diagnostic tools used to determine the type and focus of therapy for an individual", it is one of the more objective tools to compare pre and post treatment results in a quantifiable way. It is therefore important to be as exact as possible in cephalometric when tracing, measuring and comparing different radiographs and landmarks (McNamara, 1984). Cephalometrics is unfortunately prone to certain common errors. To accurately interpret and apply cephalometrics it is important to realize the influence and potential of different possible sources of error:

- **Errors of projection** –"standard errors" of the recording procedure where the object as imaged on the radiographic film is subjected to magnification and distortion.
- **Errors in landmark identification** – the validity and reproducibility of the landmark will influence the consistency of conclusions drawn from cephalometric data. (Reliability is sometimes used to encompass both validity and reproducibility.)
- **Measurement errors** – operator mistakes while reading measurements. The influence of measurement errors of this kind is not addressed in the research project as computational methods greatly enhance accuracy in this regard.

3.2 ERRORS OF PROJECTION: MAGNIFICATION AND DISTORTION

3.2.1 Magnification:

X-ray beams are not parallel with all the points of the object to be examined with resultant magnification. The difference between image size and object size illustrates that the further the target (x-ray tube) is from the object (patient), the less will be the magnification. Secondly, the closer the object is to the film (the shorter the object-film distance), the less will be the magnification.

The ideal of zero magnification is difficult to attain in practice. To minimize magnification a long target-film distance and a short object-film distance are required. The resultant standardized distances for orthodontic lateral cephalometric radiographs are: target to object distance of 150cm and the object to film distance as close as the film could be placed against the lateral of the patients head (± 9-15cm) (Proffit, 2000). The latter implies that the amount of magnification might differ from patient to patient because the target-film distance may differ from 150+9 =159 to 150+15=165cm. If serial cephalograms of the same patient are to be compared it is important to keep the target film distance constant.

Orthodontists routinely perform measurements on films that are translated into clinical treatment, which may or may not accurately reflect true dimensions. Magnification of the image of the object should always be taken into consideration. Systematic error will arise if no compensation is made between measurements from models and radiographs with any allowance for the radiographic enlargement. The same invalid conclusion will be made if measurements from two different studies are compared without knowing whether the degree of magnification was the same. As already mentioned different objects (depending on their position according to the mid-sagittal plane) will be magnified differently.

The degree of decompensation and the surgical shift cannot be directly applied from the lateral cephalometric radiograph to the model or the patient. Measurements should always be mathematically corrected for comparison.

To ease the calculation of magnification on a lateral cephalometric radiograph a ruler is usually provided on the head holder of the cephalometric unit in the mid-sagittal plane. This ruler can be used with common mathematics to calculate the degree of magnification and is usually in the region of 8% magnification of image to object.

3.2.2 DISTORTION

The image of the face and skull that the lateral cephalometric radiograph provides is a two dimensional image of a 3-dimensional object.

Most landmarks used for cephalometric analysis are located in the mid-sagittal plane (Sella, Nasion, ANS, PNS, A-point, B-point, Pogonion and upper/lower incisors) at the standardized 150cm target-object distance. The ruler that enables calculation of magnification is also in the mid-sagittal plane.

Other landmarks (Porion, Articulare, Condylion, Gonion and dental landmarks like molars and occlusal plane) are all located on both sides of the mid-sagittal plane. The implication is the landmarks in different sagittal planes are unevenly magnified and distorted with different degrees of magnification on either side of the mid-sagittal plane.

Linear distances will be foreshortened on the objects closer to the film and *vice versa* for objects further from the film. Furthermore, these bilateral structures on both sides of the mid-sagittal plane do not superimpose on a lateral cephalometric radiograph. The fan of the x-ray beam expands as it passes through the head, causing a divergence between the images (and different magnifications) of all bilateral structures (except those along the central beam).

The greater the distance between the bilateral structures, the more the difference in magnification and divergence. That explains why the lower central incisors will be closely superimposed and equally magnified on a lateral cephalometric radiograph, while the lower wisdom teeth will not be superimposed exactly and will be differently magnified (although being in the same ipsi-lateral positions and of the same size).

Phelps and Masri specifically investigated distortion in the lower incisor area on lateral cephalometric radiographs and conclude that no real distortion could be manifested in their study and that the lateral cephalometric radiograph can be used with confidence to analyze the lower incisor area (Phelps and Masri, 2000).

3.3 ERRORS IN LANDMARK IDENTIFICAITON

3.3.1 Validity (accuracy)

Validity in epidemiological studies refers to "accuracy with which a measurement is representative of the true value, i.e., does the value accurately reflect what it is supposed to be measuring (Nelson, 1999) (the term accuracy may also be used in this sense). In cephalometrics, for instance, are sella and nasion valid end points for the anterior cranial base? Another example: it is generally accepted that A-point is remodeled when the upper central incisors are moved. A change in ANB angle cannot therefore be taken to show that orthodontic treatment has affected jaw relationships. Is A-point a valid point to indicate the anterior border of the maxilla? Simplistic conclusions that are incorrect may be drawn if certain landmarks are interpreted without caution (Houston, 1983). This unreliability leads to inaccuracy regarding cephalometric interpretation.

In a study by Tng et al. in 1994, the validity of commonly used skeletal and dental landmarks were comprehensively evaluated (Tng et al., 1994). Steel markers were placed in the true anatomical positions on dry skulls, lateral cephalometric radiographs with and without the steel markers were taken and the true anatomical position compared to the analyzer-registered landmarks. Many landmarks were found to be invalid along one or both the x and y-axis. The landmarks are estimated on the lateral cephalometric radiographs therefore differed from the true anatomical landmarks that the examiner wanted to measure and might be misleading.

In general the dental landmarks have poorer validity than the skeletal landmarks. The upper incisor edge is generally estimated forward (0.6mm) of the true landmark, thereby tending to procline the teeth. Upper incisor apex is estimated lower (-1.0mm) than the true point. The lower incisor edge is estimated forward (0.5mm) of the true landmark and is made difficult to locate by the overlapping images of upper incisors. Lower incisor apex is estimated backwards (-1.1mm) of the true point. The combination of lower incisor tip estimated forward and apex more backward tends to procline the teeth and increases the lower incisor angulation. The lower incisor to mandibular plane angular differences between cephalograms with and those without the steel ball markers have a standard deviation of 4.0 degrees.

Although this study of Tng et al. refers to the "validity" of the landmarks, it should rather be the "reproducibility", as the apex of the lower incisor is a valid landmark to define the apex of the lower incisor! Houston is of the opinion that "many cephalometric landmarks have been defined for convenience of identification and reproducibility, rather than on grounds of anatomic validity" (Houston, 1983) and justly asks in this regard whether nasion and sella are valid end points for anterior cranial base? Furthermore, point A is accepted to remodel when the upper incisors are moved, but A-point is regarded as an indicator of skeletal jaw relationship! Using the lower incisor apex to the lower incisor edge is also a valid plane to assess the long axis on sagittal radiographs of the relevant tooth. It may, however, be very unreliably (un-reproducible) located on a lateral cephalometric radiograph. As no better alternative landmarks are available, these variables are not necessarily rejected as invalid, but it must be recognized that in certain instances they may be misleading.

3.3.2 REPRODUBILITY (reliability):

Reliability is defined in epidemiological studies as the precision with which a measurement is reproducible within the same or different observers (Nelson, 1999). Reproducibility is used as a synonym in cephalometrics and encompasses the precision or closeness of successive measurements of the same subject (Houston, 1983). Cohen ascribes the main source of cephalometric error to uncertainty in landmark identification (Cohen, 1984). This leads to an element of subjectivity in determining landmark position. Hagg et al. states that the major source of variability in landmark determination is related to the observer's opinion of the landmark location (Hagg et al., 1998). In the presence of soft tissue, the standard deviations of all variables increased in a previous related study by the same authors – the distance, for instance, from the incisal tip of the lower incisor to the A-Pogonion line shows a four-fold increase in its standard deviation with the soft tissue present. This study also concludes that incisor tip for lower and upper incisors on dry skulls are about 4 times more reproducible (expressed by 95% confidence interval) than the lower and upper incisor apices.

Reliability of the lower incisor may be compromised by any of the following

- Superimposed images of adjacent structures are major factors in the poor reliability of landmarks such as lower incisor apices.
- the lower incisors (and even the lower canines) are sometimes basically in the same line if viewed from lateral (sagittal dimension)
- the most prominent incisors may also be the lateral incisors rather than the central incisors and it is not possible to differentiate between them on cephalograms.

3.4 Conclusion

In relation to the lower incisor landmarks, the influence of possible cephalometric errors can be summarized as follow:

Magnification: the amount of magnification may differ from patient to patient, because the target-film distance may vary from 150+9 = 159 to 150+15 = 165cm. The ruler that enables calculation of magnification is in the mid-sagittal plane as well that positively influences the estimation of the magnification effect on the incisors.

Distortion: Phelps and Masri conclude that no real distortion could be manifested in their study that specifically investigated distortion in the lower incisor area on lateral cephalometric radiographs and is of meaning that the lateral cephalometric radiograph can be used with confidence to analyze the lower incisor area (Phelps and Masri, 2000).

Validity: the lower incisor apex and the lower incisor edge are valid landmarks to assess the long axis of the lower incisor as they anatomically represent the true points to be considered.

Reproducibility: the reproducibility of the lower incisor edge is much better (4 times according to Hagg et al.) than the reproducibility of the lower incisor apex (Hagg et al., 1998).

4. ANATOMY OF THE LOWER INCISORS

4.1 INTRODUCTION

The anatomy of the lower incisors is important as a general knowledge of the usual length of a tooth and the expected rate of taper perceived from the visible portion of the crown and root are often used for projection of the apex that is obscured by superimposed surrounding structures (Jacobson, 1995).

An in-depth review of the anatomy of the lower incisors is also relevant to this study to validate templates, crown-root angulations, labial surface inclinations and labio-lingual variations in crown proportions.

Although Woelfel mentions that there is more uniformity of shape in the mandibular incisor teeth than in other teeth, it is clear from this and other studies that variation, especially in tooth length, occurs within the norm (Woelfel, 1990). Taylor mentions that there is a considerably range of variation within the "lower incisor group" (Taylor, 1978). These include length and breadth dimensions, as already mentioned, but also differences in curvature of outline and bends or curves of the roots. The relevant differences will be discussed in more detail.

4.2 GENERAL DIMENSIONS

Carlsen finds a mean length of 22mm with variations from 19 to 28mm for the lower central incisor (n=140) in a study of extracted Danish teeth and a mean of 24mm for the lower incisor laterals (n=160) with a minimum of 17mm and a maximum of 26mm. The crown-root index for both the central and lateral is 1.3 (Carlsen, 1987).

4.3 ROOT CURVATURE

Although a slight bend of the root to the distal (when viewed from the front) is not an uncommon finding especially on the lower central incisor, bends that start abruptly are rarely encountered. This is in contrast to the upper incisor teeth that are in close proximity to the nasal floor (Harris et al., 1993). Bends of apical root area to the labial or lingual are seldom encountered.

The apex of the root is thus encountered in the line of the long axis of the tooth in the sagittal dimension.

4.4 SUMMARY

A summary of relevant anatomical features of the lower central and lateral incisors includes the following:

- mean lower incisor length:22mm, with variation from 16.9 to 28mm
- mean lower incisor labio-lingual dimensions:6mm, with variation from 4.8-7.4mm
- labial surface inclination varies
- the apex is in line of the long axis (sagittal view) of the tooth.

5. DIFFERENT METHODS CURRENTLY USED TO DETERMINE LOWER INCISOR INCLINATION

5.1 INTRODUCTION

The pros and cons of different methods to determine lower incisor inclination (for example: clinical assessment, study model analysis and analysis on lateral cephalometric radiographs) are discussed in this chapter.

5.2 CLINICAL ASSESSMENT OF LOWER INCISOR INCLINATION

The inclination of the incisors can clinically be described as normal, proclined or retroclined. This assessment is usually done relating the incisors to the occlusal plane, profile or lower mandibular plane. These planes are not stable and can be altered with treatment.

Secondly, direct measurements are difficult clinically which implies comparison to other patients (or for the same patient pre and post treatment) a subjective and non-scientific observation. Clinical description of inclination is, although important, subjective.

5.3 STUDY MODELS ASSESSMENT

Jacobson explains why plaster casts cannot be used routinely to ascertain incisor inclination (Jacobson, 1995). The inclination of the incisors can be very deceptive as they are related to the artistic portion of the study model base. The angle to which the plaster base is cut is not necessarily in accordance with the degree of incisor inclination in the mouth.

Neither the inclination nor the extent of the antero-posterior jaw dysplasia or the degree of labial (or lingual) inclination of incisor teeth can be determined from a set of study models.

Richmond et al. describes a method of assessing incisor inclination to overcome the above-mentioned shortcomings (Richmond et al., 1998). An instrument, the "tooth inclination protractor" (TIP) was developed to relate the incisor angulations specifically on study models. The tooth inclination protractor records the crown inclination to the occlusal plane. The authors point out that assessment of the crowns to the occlusal plane may be variable especially in the lower arch where problems may occur with a deep curve of spee. Although the occlusal plane variability does not seem to be a factor in reliability, it may cause a problem with validity when comparing the lower incisor to the occlusal plane and mandibular plane in pre- and post-treatment comparisons because the reference planes undergo changes during treatment.

It was found that the TIP consistently under-scores the lateral cephalometric radiographic determined maxillary incisor angulations by 10.46 degrees and consistently over-scores the lower mandibular incisor angulation by 2.57 degrees. The implication is that the study models measurements are adapted to cephalometric values (that are not perfect either!) and is therefore not ideal and rather unscientific.

It can be concluded that determination of incisor inclination on study models is still unreliable, mainly due to the lack of a stable plane to relate to. The study model base as well as the occlusal plane is prone to undergo immeasurable and inconsistent changes.

5.4 LATERAL CEPHALOMETRIC RADIOGRAPH ASSESSMENT

The most common method used to analyze the position of these teeth is by using lateral cephalometric radiographs. Common cephalometric measurements used in relation to the lower incisor are the following:

- lower incisor tip to N-B line (linear measurement)
- lower incisor tip and pogonion to N-B line (linear relationship)
- lower incisor tip to A-Po (linear measurement)
- lower incisor to N-B angulation (incisor inclination derived)
- lower incisor to mandibular plane angulation (incisor inclination derived)
- lower incisor to upper incisor angulation (incisor inclination derived)

The lower incisor long axis is compared to another plane (e.g. mandibular plane) to obtain an angle. Two different reference planes are thus used and the angle between the two is measured to determine the inclination of the lower incisor. The inaccuracies of both planes (and the landmarks used to determine the planes) increase the margins of error. The observed error for a given measure is thus a function of:

- the magnitudes of estimating error for the landmarks it interrelates,
- the separation distances among those landmarks, and
- the directions from which the line segments connecting the landmarks intercept their envelopes of error(Baumrind and Frantz, 1971)

Chan et al. explained the influences of landmark error in an article *Effects of cephalometric landmark validity on incisor angulation,* confirming that in the instance of the lower incisor inclination based on the mandibular plane as reference plane, the major contributing factors to error are the dental and not the skeletal landmarks(Chan et al., 1994)

The lower incisor is usually traced according to specific landmarks to determine the long axis of the tooth. Different landmarks to interpret the lower incisor axis are to trace from:

- incisor edge to apex,
- incisor edge parallel to the labial surface,
- incisor edge to the middle of the symphysis and
- the incisor edge through the middle of the tooth crown.

5.4.1 Tracing from incisor edge to incisor apex

When the incisor inclination is determined by locating and connecting the incisor tip and apex, the superior landmark (incisor edge or tip) is defined as the "incisal edge of the most prominent mandibular central incisor"; the inferior landmark defined as the "the root apex of the most anterior mandibular central incisor"(Jacobson, 1995). As already proved in the literature review on cephalometric landmarks, the lower incisor edge is a relatively reliable landmark. Correct location of the apex should be determined as accurately as possible if lower incisor inclination is determined from the apex as the inclination of the lower central incisor can play a vital role in cephalometric diagnosis, and ultimately, the treatment of the patient's malocclusion. The lower incisor apex, however, is found to be unreliable with deviations in the antero-posterior as well as the vertical dimensions.

More evidence proving the unreliability of the lower incisor apex as cephalometric landmark is found in an article *Precision in cephalometric landmark identification* (Stabrun and Danielsen, 1982). Stabrun and Danielsen find that the apex inferior was not located with confidence by the observers in 75% of the cases. Two observers recorded the relevant landmark on 100 cephalograms twice and in two categories for each observer: I- both assessments judged as uncertain; II- both assessments judged as certain. Recordings in which the two registrations differed (26 for observer A and 25 for observer B) were excluded.

The recordings of the first recording were all placed in the origin and the points represent the deviations compared with the other series. They illustrated the variability in double registrations for observer A and B of apex inferior when both the observers were judged uncertain and secondly when both registrations were judged certain.

Minor errors in incisor apex location; however have a vast adverse influence on the accuracy of the incisor inclination. If the study by Tng et al. is used as an example of the lower incisor apex location it would have influenced the determination of the long axis of the tooth.

Phelps and Masri indicate that a 3mm deviation in the location of the apex buccally or lingually would cause an error of 8°(Phelps and Masri, 2000). This study concludes "the lack of certainty in locating apex inferior in 75% of cases should be taken into account when using the axial inclination of the lower incisor in diagnosis and treatment planning".

In summary, the literature overview clearly indicates the highly unreliable indicators and analysis for lower incisor inclination and its position. We can also conclude that lower incisors have been analysed in reference to variables present in different parts of the skull which have lead to contrasting values based on the individual's facial shape and structure.

5.4.2 Tracing from incisor edge parallel to labial surface

The unreliability of locating the lower incisor apex led to some orthodontists overlaying the template on the labial surface of the crown to trace the relevant tooth.
This method is unreliable as the inclination of this surface is inconsistent and quite often poorly defined due to "noise" from adjacent superimposed structures.

5.4.3 Tracing to the middle of the symphysis

Phelps and Masri in a recent article *Location of the apex of the lower central incisor* state: " Of the common lateral cephalometric landmarks, the apex of the lower central incisor is perhaps the most difficult to accurately locate"(Phelps and Masri, 2000). This study used 38 complete skulls (aged 16-39 years; mean 22.8) to define the radiographic anatomy surrounding the true apex. Metallic markers were placed in the socket apex of the lower central incisor.

Measurements from the markers to the lingual and labial symphyseal borders determined that the true location of the lower central incisor apex is most often found in an approximate 60:40 ratio from the external labial outline of the symphysis at the apical level. In 9 skulls the marker ball was located lingual to the centre of the symphysis with an average deviation of 0.28mm.

The study of Phelps and Masri concludes that the apex of the lower central incisor should be located “slightly forward of halfway from the lingual to the labial surface of the symphysis at the apical level” on a cephalometric radiograph.

Chan et al., however, report in their study on cephalometric landmark validity that they found the lower incisor apex very close to the buccal plate in a few instances.(Chan et al., 1994). A point of criticism is that although an antero-posterior estimate to locate the lower incisor apex is suggested, the length of the lower incisor varies and this influences the height at which the middle of the symphysis should be determined. It is furthermore important to keeping mind that the study by Phelps and Masri was performed on unclaimed (patients assumed never been orthodontically treated) skulls.

The effects of treatment tend to specifically move the apices while aligning the incisal edges. Fuhrmann highlights the effects of orthodontic tooth movement in the symphyseal area and mentions that the loss of thin bone plates may be induced by force of orthodontic tooth movement(Fuhrmann, 1996b, Fuhrmann, 1996c). Fuhrmann also mentions that the labio-lingual diameter is commonly overestimated on cephalometric radiographs in comparison to objective measurements(Fuhrmann, 1996a). It is critical to take this into consideration before treatment commences. The anatomy of the symphysis is classified by Mulie and Ten Hoeve in three types of symphysis.

In the study by Mulie and Ten Hoeve it was found that the apices of the lower incisors were orthodontically moved “through the dense cortical plate and are now lingual to their bony structure" in type III symphysis(Mulie and Hoeve, 1976). An explicit example of the results in a case of a narrow and high symphysis, pronounced sagittal incisor movements and derotation during routine orthodontic treatment with a fixed appliance can lead to progressive bone loss of lingual and labial cortical plates.

5.4.4 Tracing from incisor edge through the midpoint of the crown

Athanasiou states that "the midpoint on the bisection of the apical root width can be used" to determine the long axis of the tooth(Athanasiou, 1995).

The routine use of this method is currently troubled by difficulty in locating the crown of a specific lower incisor because of:

- super-imposed structures, adjacent teeth (the lateral incisors) are in the same sagittal lane and often impossible to differentiate from the central incisors on a lateral cephalometric radiograph. In deep bite cases the upper incisors (and upper canines) in extreme instances) tend to obscure lower incisors.
- If the lower incisors are rotated they will not project in a true lateral image. Measurements will also be compromised, as the measurements from lower incisor edge should be taken from the mesio-distal centre of the incisor edge.

These factors negatively influence the accuracy of this method.

5.5 COMPUTED TOMOGRAPHY

Computed tomography can be used to exactly locate the lower incisor apex, but it is impractical for day-to-day use because of the cost involved. It is however, a very accurate research tool that could be used to validate other common methods of locating cephalometric landmarks.

5.6 CONCLUSION

Current methods applied to determine lower incisor inclination can be summarized as follows:

- Clinical assessment is subjective and it is impossible to describe inclination with clinical assessment in a quantified, measurable way.
- Analyzing lower incisor inclination on study models is either subjective or impractical
- The various methods of determining the inclination of the lower incisor on a lateral cephalometric radiograph have also been proofed unreliable, mainly because the lower incisor apex cannot be reliably located.
- The only method to exactly define lower incisor inclination is with CT – scans, but it is impractical for routine use.

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7. MANUSCRIPT

Comparison and reliability assessment of "p distance" with conventional lower incisor measurements.
A Long term cephalometric study

Comparison and reliability assessment of "p distance" with conventional lower incisor measurements. A Long term cephalometric study

V K Srinivasan
BDS., M.S
Postgraduate Student,
Discipline of Orthodontics
Faculty of Dentistry
University of Sydney

A Darendeliler
BDS, MDSc
Course Coordinator
Discipline of Orthodontics
Faculty of Dentistry
University of Sydney

P Petocz
PhD
Associate Professor
Department of Statistics
Macquarie University

M A Darendeliler
BDS, PhD, Dip Orth., Certif. Orth., Priv.Doc
Professor and Chair
Discipline of Orthodontics
Faculty of Dentistry
University of Sydney

Address for correspondence:
Professor M. Ali Darendeliler
Discipline of Orthodontics
Faculty of Dentistry
The University of Sydney
Level 2, 2 Chalmers Street
Surry Hills NSW 2010 Australia
Phone +61 2 93518314
Fax +61 2 9351 8336
Email: adarende@mail.usyd.edu.au

Abstract

The aims of this study were divided into two parts. The first part was to compare the proposed "p distance" with conventional lower incisor measurements (angular and linear). The second part was to investigate the reliability assessment of landmark location error using Dahlberg's formula.

The patient material comprised of 36 subjects (17 males and 19 females). They were selected retrospectively from a patient pool of 275 patients who were treated successfully (good buccal relationship, normal overjet and overbite) with fixed appliances (extraction and non extraction) between the years of 1997-1998 at the Department of Orthodontics, University of Sydney, Australia.

The patients were examined at three time points. T1 (Before treatment), T2 (After treatment), T3 (5 years after treatment). The mean age of the patients at T1 was (15.5±2.61 years), at T2 (17.8±2.37 years) and at T3 (22.5±2.51 years).

Pearson's correlation (r) was used to assess the interrelation between the incisor variables. Correlation was determined as weak ($|r|<0.3$), moderate ($|r|=0.3-0.7$) and strong ($|r|>0.7$). Results indicate that "p distance" had moderately correlation with L1- MP. The overall method error for "p distance" was 0.13mm, which is smaller than for the other variables. We conclude that "p distance" is a much more reliable lower incisor measurement than other conventional measurements in subjects during active growth period. "p distance" can be located and measured more accurately than L1-A Pog, L1-N Pog, L1-MP and L1-OP.

Keywords: Lower incisors, Stability, Relapse, Symphysis width, "p Distance"

Introduction

The relative position of the lower incisors to their supporting bone is an important feature that is related to case analysis, post treatment stability, and harmony of the facial profile. Various norms describing the position of the lower incisors have been proposed and are used to predict the stability of treatment results [1-4].

The mandibular incisors are, however, limited in the range that they can be moved orthodontically as their alveolar support over basal bone, especially in an antero-posterior dimension, is the least of all teeth [5]. Movement beyond the alveolar housing in the antero-posterior dimension may lead to bone loss or periodontal anomaly. It is therefore a consensus in orthodontic clinics that the displacement of lower incisors, especially the adjustment of labio-lingual torquing and tipping, be well planned and conducted in a restrictive manner.

There are many linear and angular measurements to relate and define lower incisor position, but there are no measurements which are constructed using a combination of the above. Therefore, the aim of the present investigation was to evaluate a newer measurement called the "p distance" in comparison with conventional linear and angular measurements with respect to its reliability and clinical significance.

"p Distance":

In 1997, Darendeliler[6] proposed a new measurement called the "p distance" which is the distance between the intersection point of the mandibular incisor long axis on a perpendicular line constructed ½ (half) way between B (B point)-Me (Menton) and the posterior border of the symphysis (Figs. 2&3).

Conventional measurements

L1-A Pog : The distance from the incisal edge of the lower incisor to the A-Pog line [7,8,9] (Fig.1).

L1- N Pog: The distance from the incisal edge of the lower incisor to the N-Pog line (Fig.1).

L1-MP : The inner angle between the long axis of the lower incisor to the constructed mandibular plane [2] (Fig 1)

L1-OP : The inner angle between the long axis of the lower incisor to the constructed occlusal plane[10] (Fig 1).

Subjects

The patient material comprised of 36 subjects (17 males and 19 females). They were selected retrospectively from a patient pool of 275 patients who were treated successfully (good buccal relationship, normal overjet and overbite) with fixed appliances (extraction and non extraction) between the years of 1997-1998 at the Department of Orthodontics, University of Sydney, Australia.

The patients were examined at three time points. T1 (Before treatment), T2 (After treatment), T3 (5 years after treatment). The mean age of the patients at T1 was (15.5±2.61 years), at T2 (17.8±2.37 years) and at T3 (22.5±2.51 years).

Cephalometric Analysis

Lateral cephalograms were obtained using a standardized technique with a fixed focus-midsagittal plane distance of 155cm and a constant midsagittal plane distance of 10cm. All roentgenograms were taken with the teeth in habitual occlusion. All head films were of high quality.

One author (VS) traced all lateral radiographs of T1, T2, T3, on a tracing table with a magnifying viewer (2 x) to facilitate the identification of the skeletal structures and reference points. The cephalograms were traced twice using a 0.003 matte acetate paper with a 0.5mm HB pencil. T1, T2 and T3 radiographs from each patient was traced during the same session. All landmarks (including the main five incisor variables: p distance, L1-A Pog, L1- N Pog, L1- MP, L1- OP) were calculated twice and the mean was used for calculation. The second tracing was performed approximately one month after the first tracing.

Statistical Analysis

Means and standard deviations were calculated for all cephalometric variables at the three times of examination (T1, T2 and T3). Statistical analysis was undertaken using the Statistical Package for the Social Sciences for Windows (SPSS Version 12.0, Chicago, IL, USA). Significance was determined at $P < 0.001$(***) and $P<0.01$ (**), and $P<0.05$ (*); $P \geq 0.05$ was not considered significant (NS). Pearson's correlation (r) was used to assess the interrelation between the incisor variables. Correlation was determined as weak ($|r|<0.3$), moderate ($|r|=0.3-0.7$) and strong ($|r|>0.7$).

The reliability of the different lower incisor measurements was assessed by method error calculations. The size of the combined method error (ME) in locating the reference points, and measuring the variables was assessed upon double registrations of all 36 subjects. The formula of Dahlberg (1940) was used in the calculation:

$$ME = \sqrt{(\sum d^2/2n)}$$

where *d* is the difference between registrations of a pair and *n* is the number of double registrations.

Results:

The mean and standard deviations of the five variables investigated at T1, T2 and T3 as well as during the periods T1-T2, and T2-T3 are shown in Table 1. The interrelation between the variables is shown graphically on Fig.4. "p distance" had no correlation with L1- A Pog ($r=0.07$, $P<.465$) and L1- N Pog ($r=0.07$, $P<.446$) but was moderately correlated with L1- MP ($r= -0.44$, $P<0.000$) and weakly to L1- OP ($r=0.27$, $P<0.004$). L1- A Pog was moderately correlated to L1- N Pog ($r=0.55$, $P<0.000$) and weakly correlated to L1- MP ($r=0.20$, $P<0.037$) and was not correlated to L1- OP ($r=0.13$, NS). L1- N Pog was moderately correlated to L1- MP ($r=0.24$, $P<0.011$) and weakly correlated to L1- OP (r=-0.20, P<0.037). L1- MP had strong negative correlation to L1-OP (r=-0.71, P<0.000).

The method error calculation of the five variables at T1, T2 and T3 as well as during the periods T1-T2 and T2-T3 along with overall analysis (T1+T2+T3) are given in Table 2. The method error for "p distance" at T1 is 0.04mm, at T2 it is 0.08mm and at T3 it is 0.10mm. The overall method error for "p distance" is 0.13mm, which is smaller than for the other variables.

Discussion:

The purpose of this study was to compare and assess the reliability of conventional lower incisor measurements with "p distance" over an extended period of time. The subjects were retrospectively collected, and the two most commonly used angular (L1-MP, L1-OP) variables along with the two most commonly used linear (L1-APog, L1-NPog) variables that are used to analyse the position of lower incisors in modern cephalometrics were assessed in relation to "p distance". A reliability assessment was performed to identify the extent of landmark location errors of the five variables being investigated. In modern orthodontics, the focus has been on the mandibular arch, the assumption being that the lower arch is the key to stability or relapse[11].

From T1 to T2, "p distance" had marginally significant change, whereas L1-A Pog, L1-N Pog, L1-MP and L1-OP had no significant change. This shows that "p distance" had consistently changed from T1 to T2 in all subjects, whereas the other angular and linear variables exhibited changes that were inconsistent and were highly variable between individuals. This is supported by the initial proposal of "p distance" as the ideal lower incisor measurement[6], due to its reliability only on the symphysis, whereas the conventional measurements changed considerably based on changes in associated dental and skeletal structures. It must also be remembered that the "p distance" was postulated as the only measurement that would not be influenced by any malocclusion[6].

The consistent "p distance" changes from T1 to T2 compared to changes of conventional lower incisor variables can be explained by the fact that, the subjects could have grown between those time points (T1 to T2), as T1 subjects were younger and in midst of their growth spurts, leading to changes in skeletal and associated dental landmarks progressing towards T2. Due to growth changes, all lower incisor measurements changed in a highly variable fashion with high individual variability except "p distance", which is influenced only by the symphysis, and was found to be more consistent in its changes during growth spurts/periods.

However, in assessing the changes between after treatment and five years after treatment (T2 to T3), "p distance" did not change consistently, only L1-N Pog changes were marginally significant. We attribute this to a variety of factors, including the possibility of late adolescent growth spurt involving changes in nasion or pogonion[12-15]. The other factor could be, the landmark location error difference of L1-N Pog was found to be higher than the other linear and angular variables from T2-T3 difference. There is also the possibility of mandibular rotation after pubertal growth spurt[16] which could have influenced the position of pogonion in relation to lower incisor and nasion. Other reasons could be excessive protrusion and subsequent up righting of incisors [17,18]. In our study the mean of "p distance" is mildly negative at end of treatment, this was due to the fact that the subject pool had severe malocclusion with severe crowding and proclined lower incisors to start with, and were proclined much further to achieve an acceptable occlusion. It would also be ideal to have more patients with positive "p distance" at before treatment and analyse their changes to negative "p distance" subjects. By including much younger subjects, it would be easier to eliminate the inactive growth phase and analyse the changes of all the variables during active growth period.

At five years after treatment (T3), the relapse that had occurred, lead to slightly increased negative "p distance". This could be related to previous studies which discussed the same phenomena with the use of different measurements[19-21]. It must be recognised that a negative "p distance" could also mean that the lower incisor could be placed behind, or in front of the N Pog or A Pog line.

"p distance" is negatively correlated to L1-MP and positively correlated to L1-OP. This confirms the fact that when lower incisors are proclined, L1-MP increase and L1-OP decrease. This is consistent with previous studies[22]. L1- A Pog is positively correlated to L1- N Pog, this shows that the majority of subjects had lower incisors behind L1-N Pog and L1- A Pog and any change in inclination had similar changes in both measurements. L1- A Pog did not show any major correlation to any other variable, it could have been due to the fact that, A point changes depending on upper incisor angulation which in turn is influenced where the lower incisors finish during treatment. It could also have been influenced by the retention regime that was employed which would have controlled the position of the lower incisor crowns[23]. It is also important to note that the method error analysis results indicate that “p distance” can be located with increased reliability than other conventional lower incisor measurements at individual time points, and also when assessed in an overall (T1+T2+T3) situation. We attribute this to the simple fact that, less the number of landmarks that are associated in measuring a variable, landmark location error would be minimal. In this case, “p distance” used symphysis only for its value, which is much closer to the lower incisor in comparison to the other variables we investigated, which involved skeletal and dental landmarks that were placed in different planes and positions farther away from the lower incisor.

Conclusions:

Based on the results of our study we can conclude that “p distance” identifies the position of the lower incisors more accurately than other conventional measurements in subjects during active growth period. “p distance” can be located and measured more accurately than L1-A Pog, L1-N Pog, L1-MP and L1-OP as its landmark location error is much lesser than other conventional lower incisor variables.

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Table 1:
Cephalometric records before treatment (T1), after treatment (T2) and 5 years after treatment (T3) in 36 subjects treated with fixed appliances

Variables	T1		T2		T3		T1-T2			T2-T3		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	value	Mean	SD	value
"p distance" (mm)	-0.6	1.66	-1.3	2.34	-1.5	2.10	0.7	1.67	2.6,*	0.2	1.85	0.6
L1- A Pog (mm)	2.9	2.34	2.8	2.54	3.5	2.47	0.02	2.54	0.05	-0.7	2.06	-2.0
L1 – N Pog (mm)	5.3	2.64	4.9	3.12	4.2	2.88	0.4	2.40	1.03	0.6	1.41	2.7,*
L1 – MP (°)	94	5.78	95.6	9.32	96	8.69	-1.5	6.04	-1.5	-0.5	5.05	-0.6
L1 – OP (°)	67.9	6.92	67.4	8.14	66.7	7.06	0.4	4.60	0.5	0.7	4.87	0.9

*. Significance at the 0.05 level

Table 2: Method error analysis investigation of 36 subjects treated with fixed appliances for assessing the reliability of the different incisor variables

Variables	T1	T2	T3	T1-T2	T2-T3	T1+T2+T3
"p distance" (mm)	0.04	0.08	0.10	0.04	0.02	0.13
L1-A Pog (mm)	0.21	0.26	0.16	0.05	-0.10	0.38
L1-N Pog (mm)	0.18	0.17	0.17	0.01	0	0.30
L1-MP (°)	0.41	0.48	0.50	-0.07	-0.02	0.82
L1-OP (°)	0.23	0.31	0.36	-0.08	-0.05	0.53

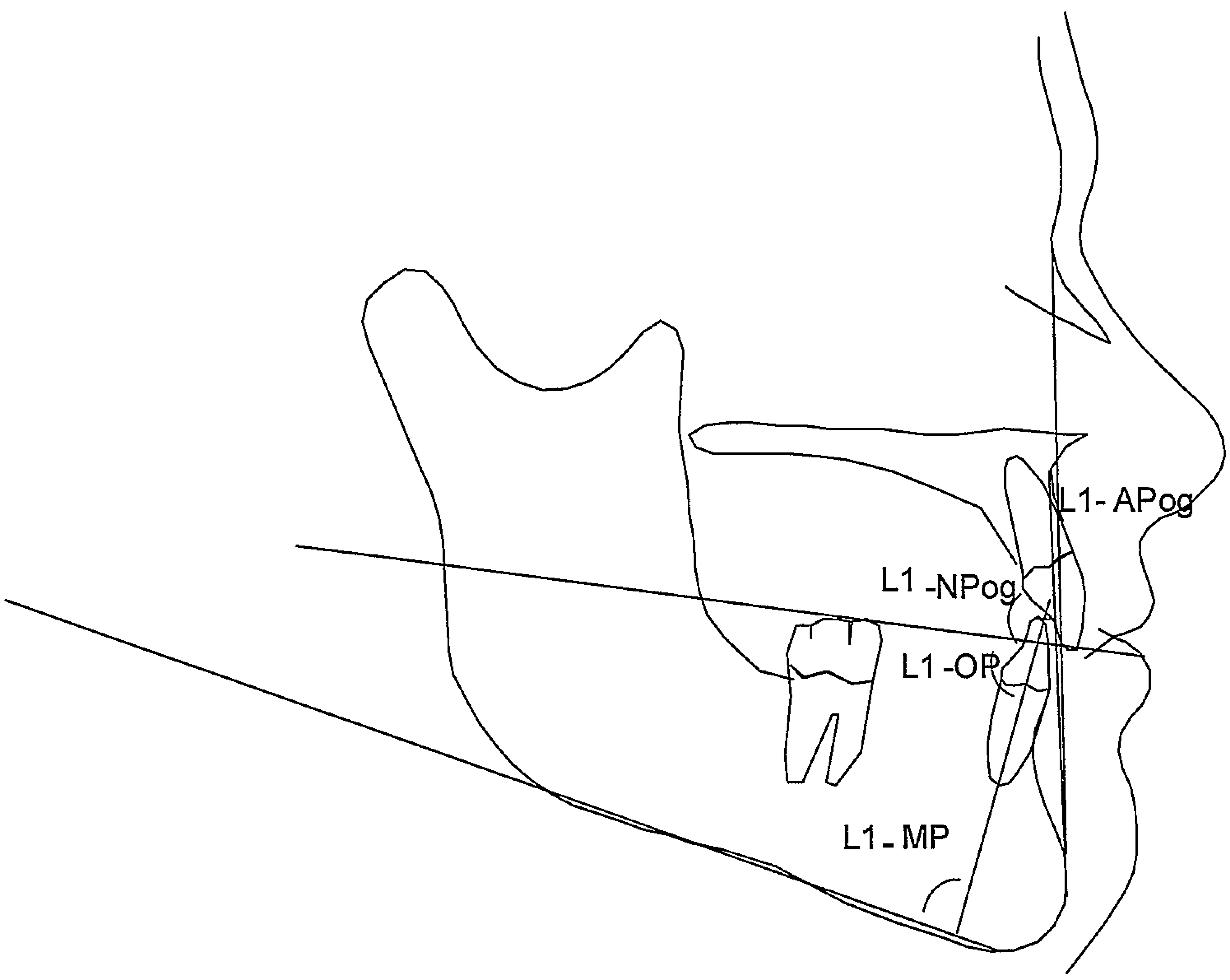


Figure 1: Conventional angular (L1 – MP, L1- OP) and linear (L1- N Pog, L1- A Pog) measurements used to identify lower incisor position on a lateral cephalogram

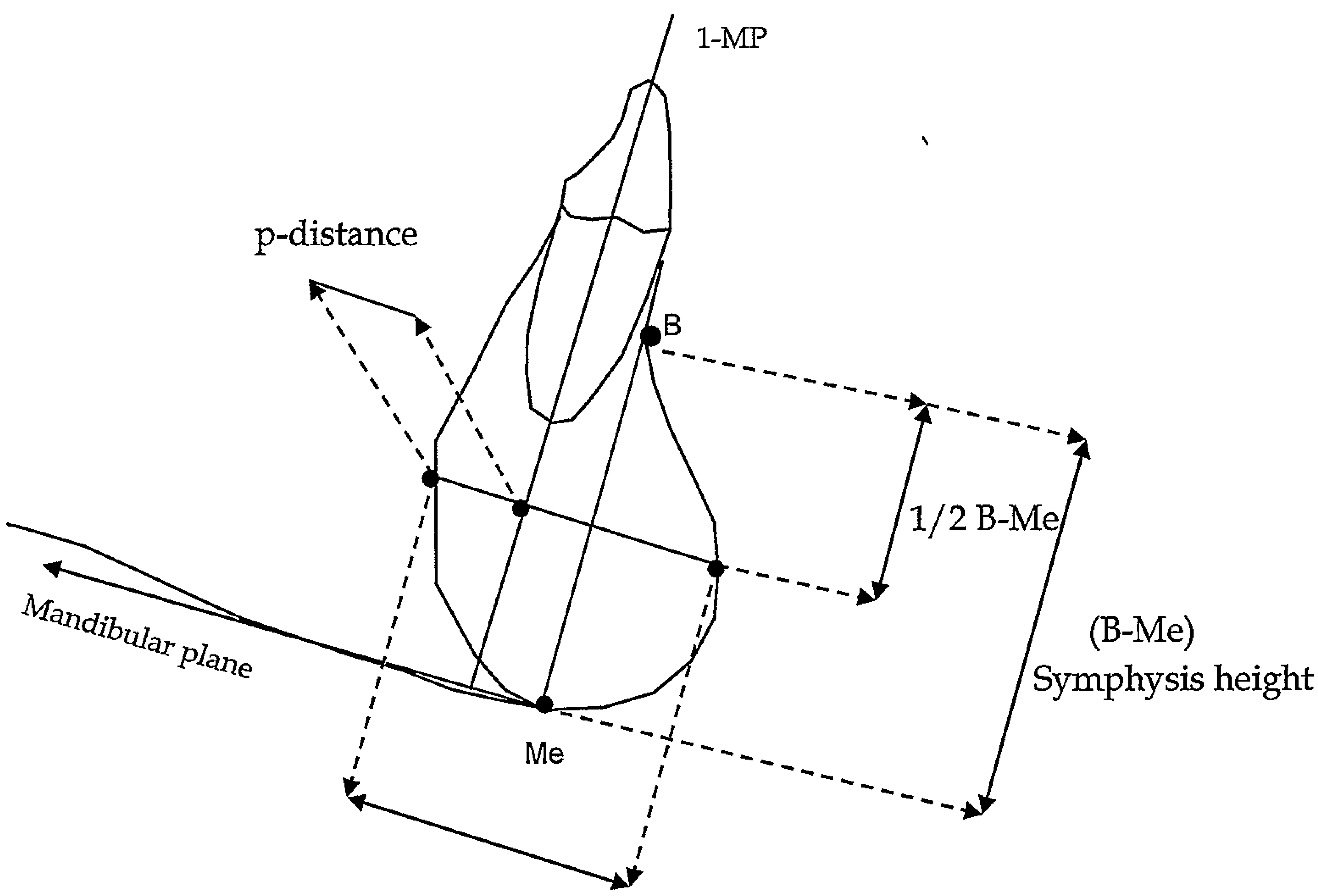


Figure 2: Illustration of construction of "p distance" (positive "p distance")

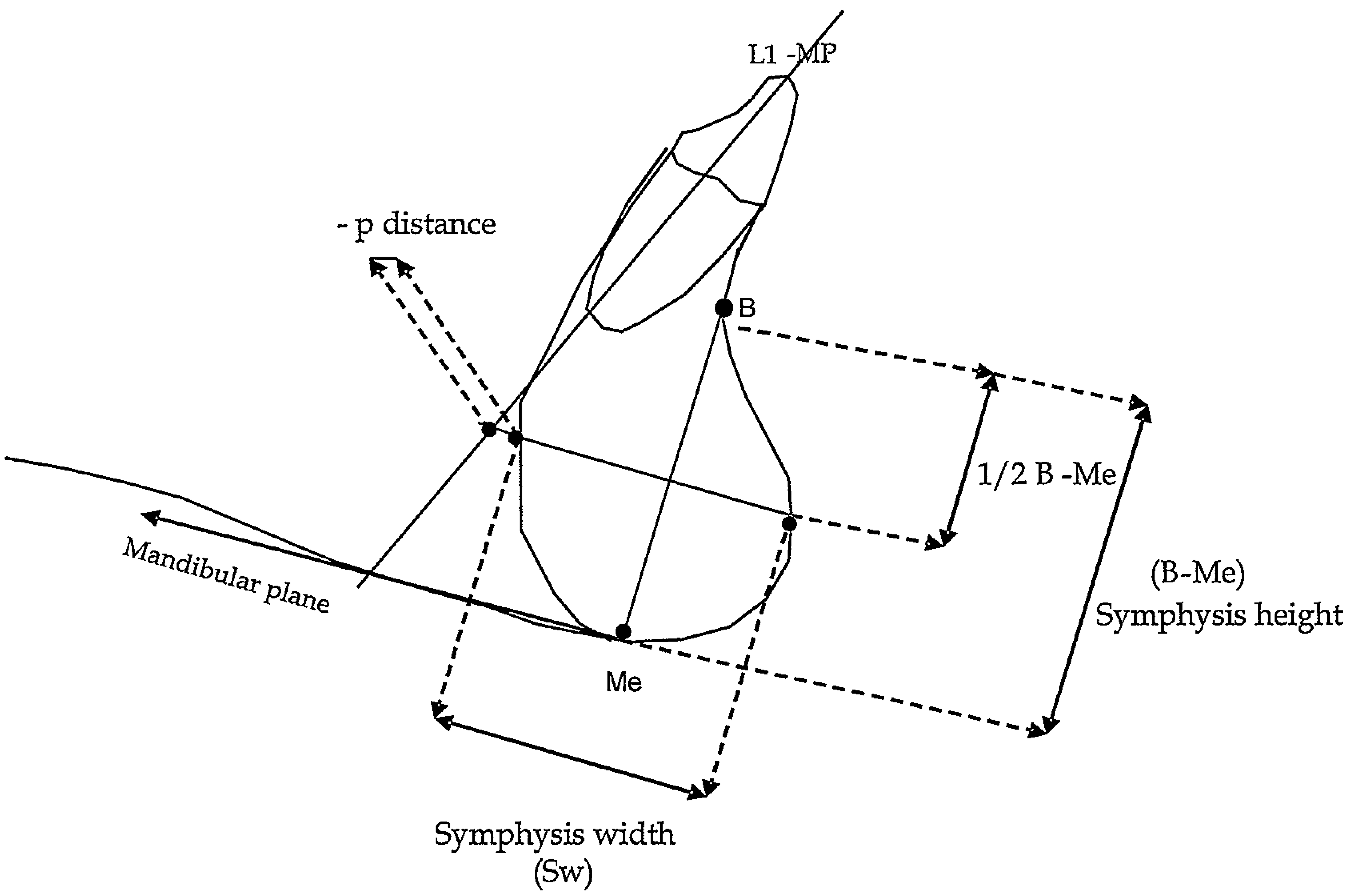
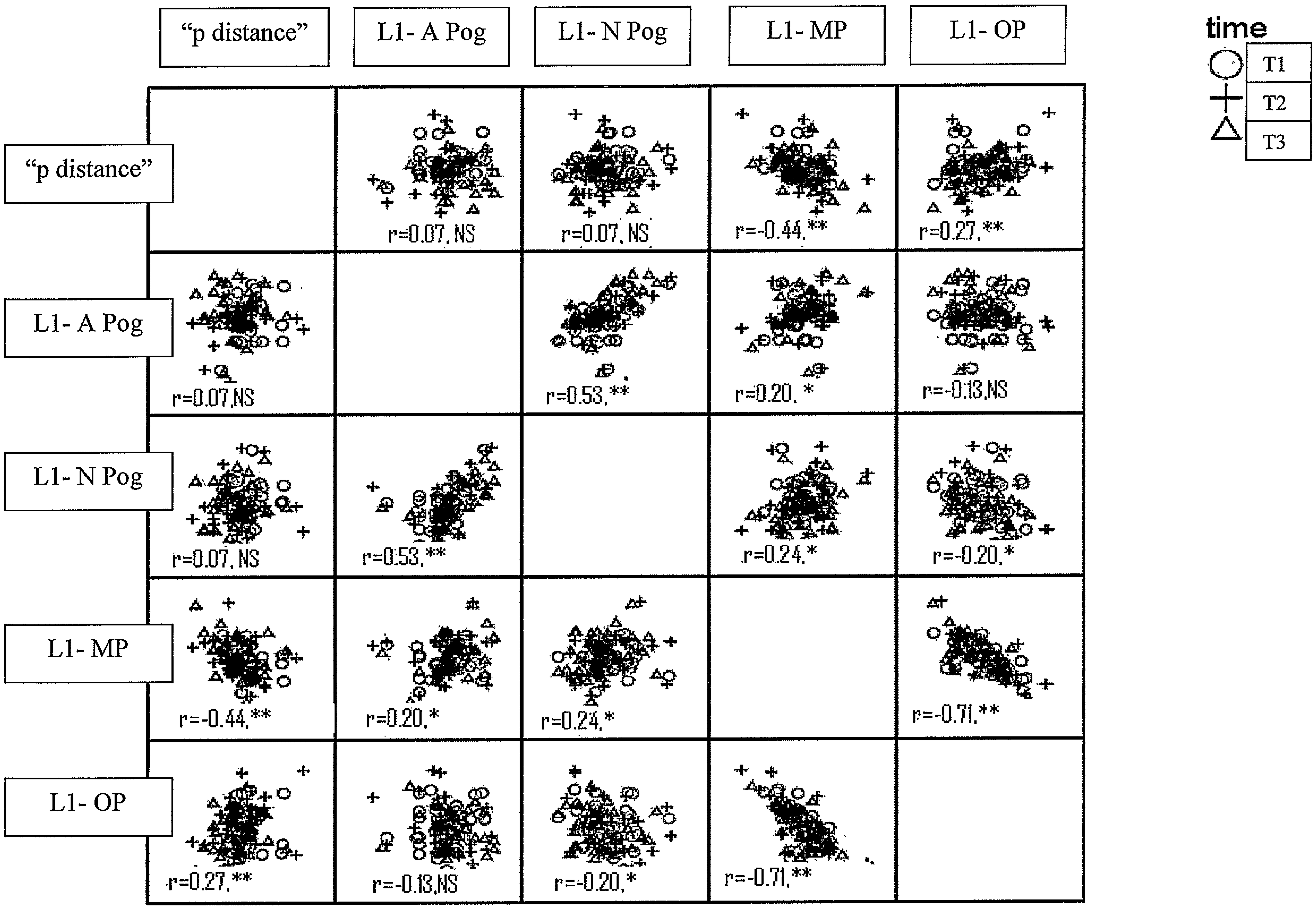


Figure 3: Illustration of construction of "p distance" in case of proclined lower incisor (negative "p distance")



**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

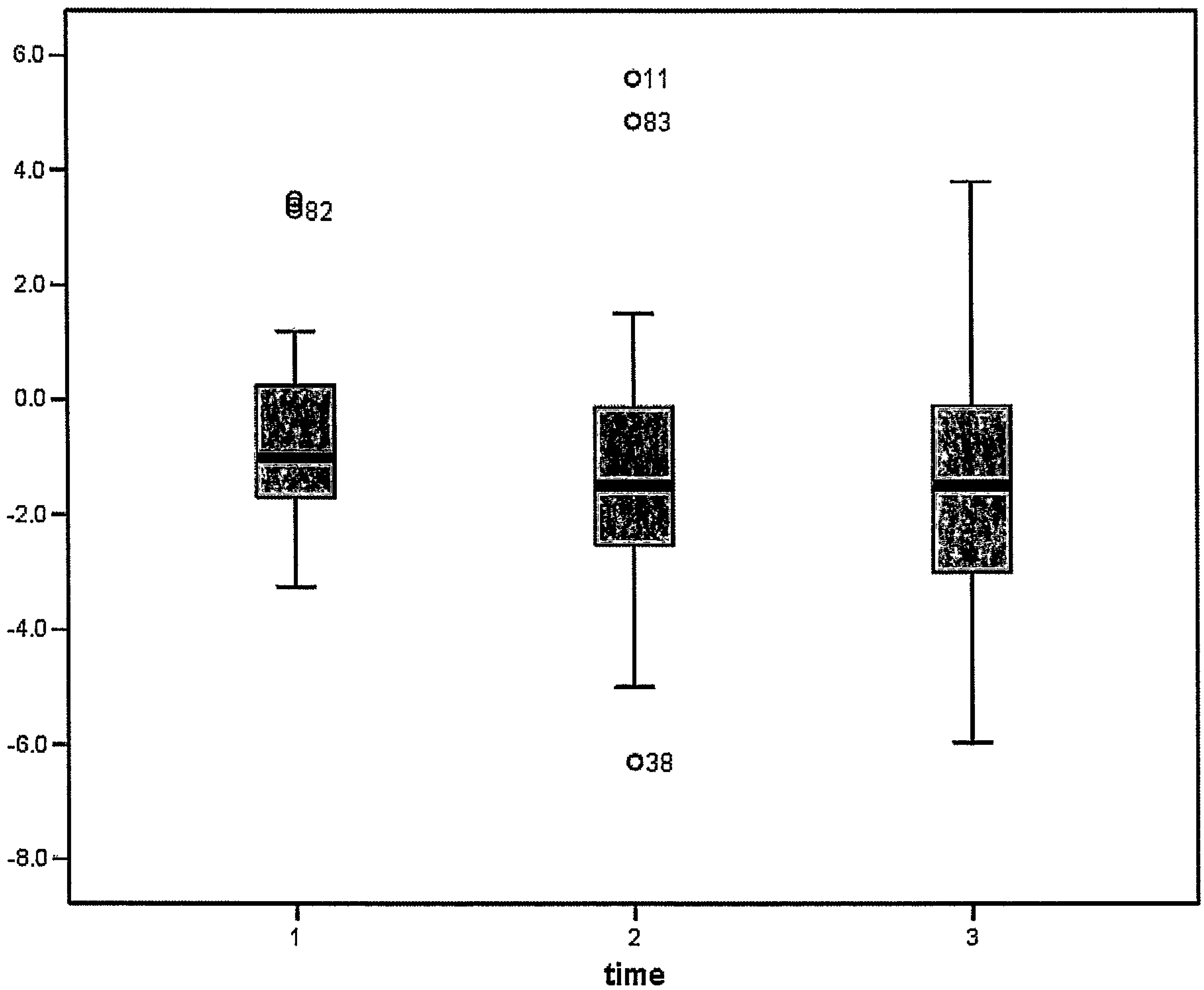
8. Future Applications:

1. Our study had three time points, out of which the first one (T1) was the only one time point which consisted of subjects who were close to active growth period. It would be ideal to include at least one other time point with subjects that are still around the active growth period. This would enable us to compare subjects between growth periods and identify if lower incisor variables had any relationship between each other.
2. Our subjects were not identified or selected based on age, sex or malocclusion. Since, "p distance" changes based on lower incisor position, it would be ideal to recruit more subjects and group them based on initial malocclusion and sub divide them based on sex.
3. Newer technologies have evolved in recent times. We used lateral cephalometric radiographs to identify landmarks. This is a two dimensional study. By utilizing three dimensional radiographic techniques like Cone Beam CT (Newtom), landmark identification would be more accurate and changes could be correlated in three dimensions.
4. Every case could be treated differently and different malocclusions need different treatment mechanics. In our study, we did not relate changes to treatment results. It would be ideal to include treatment results and analyze the effect of treatment on lower incisor position.

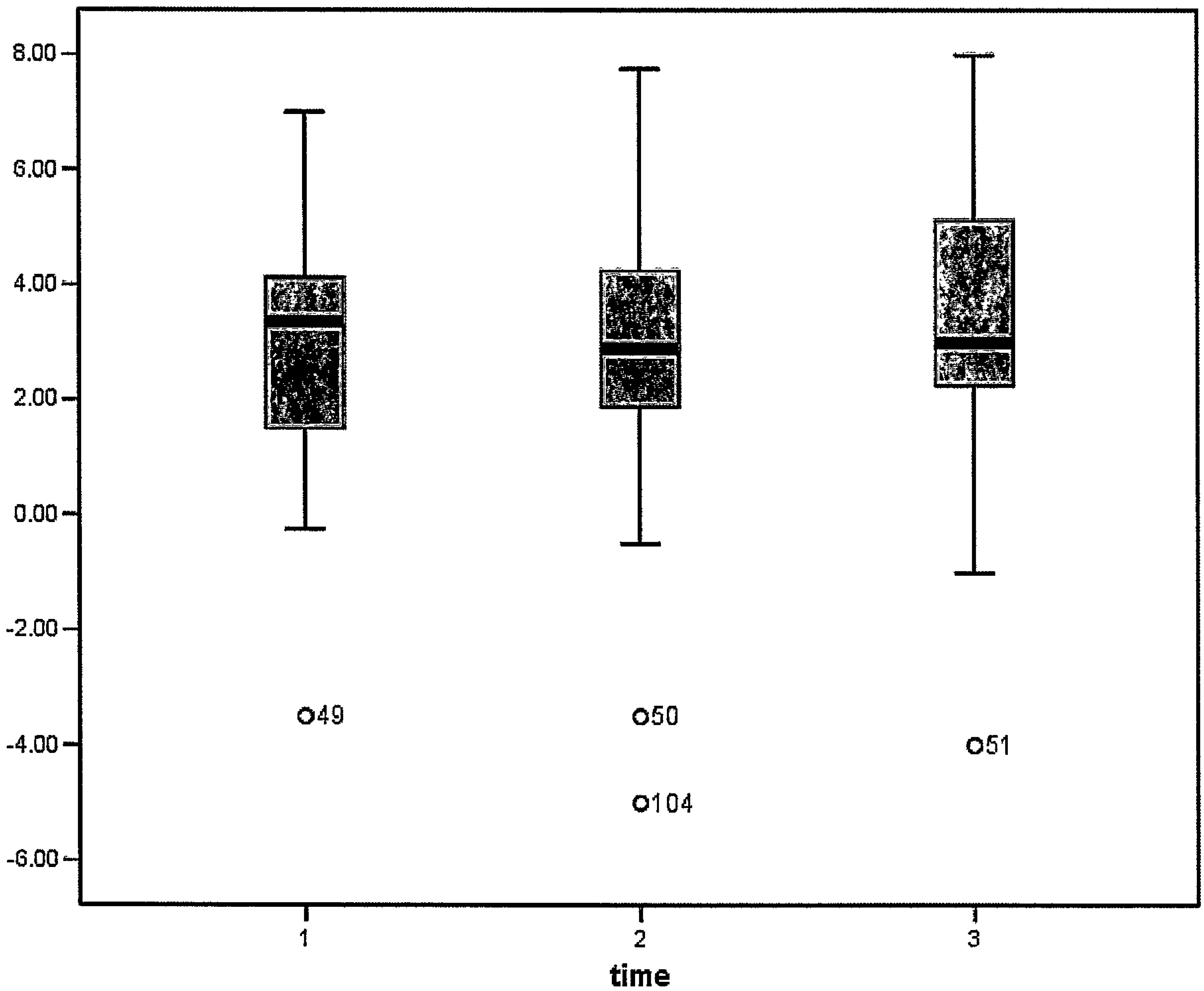
9. Appendix 1:

Box Plots of all five variables at different time points

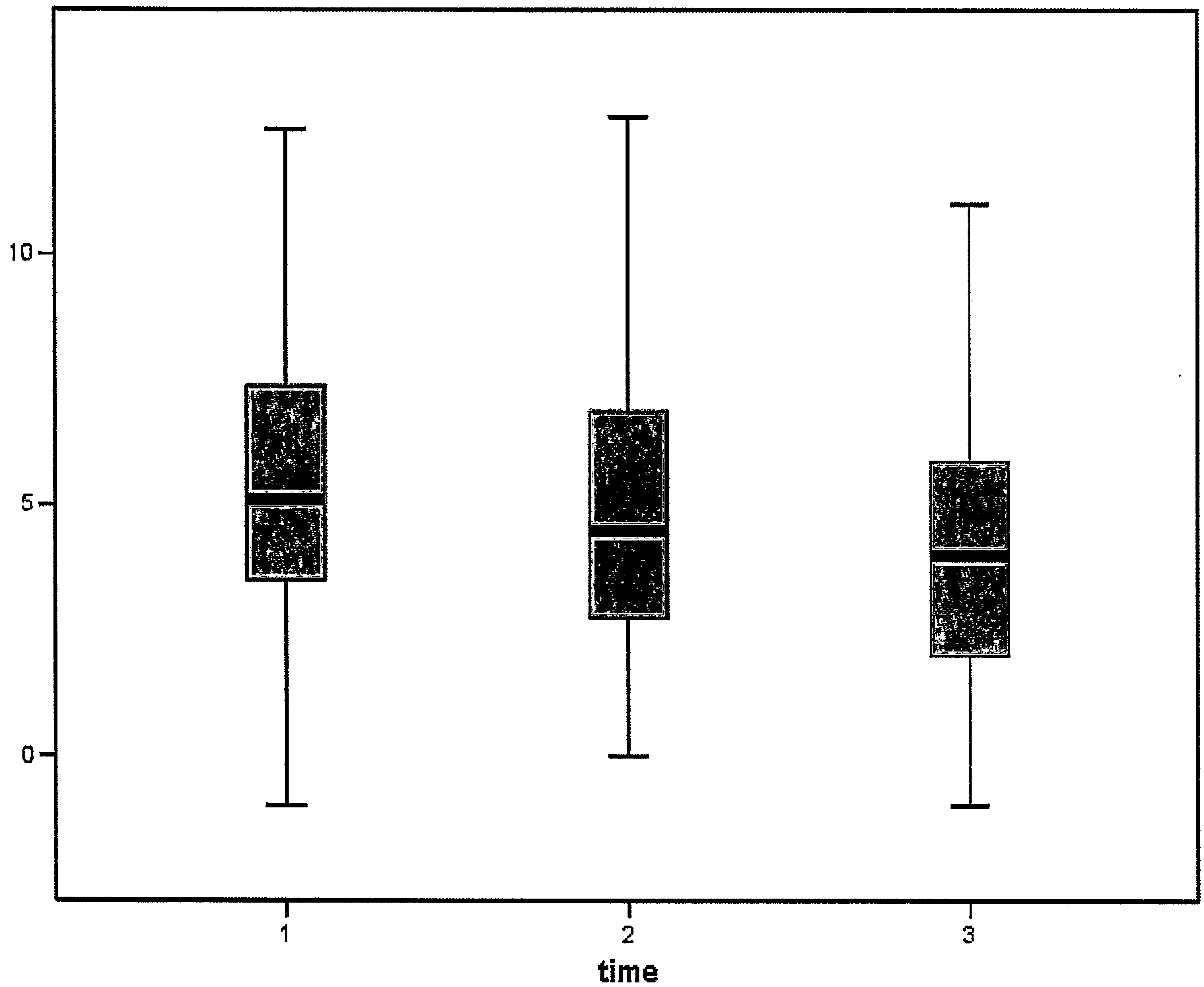
1. "p distance"



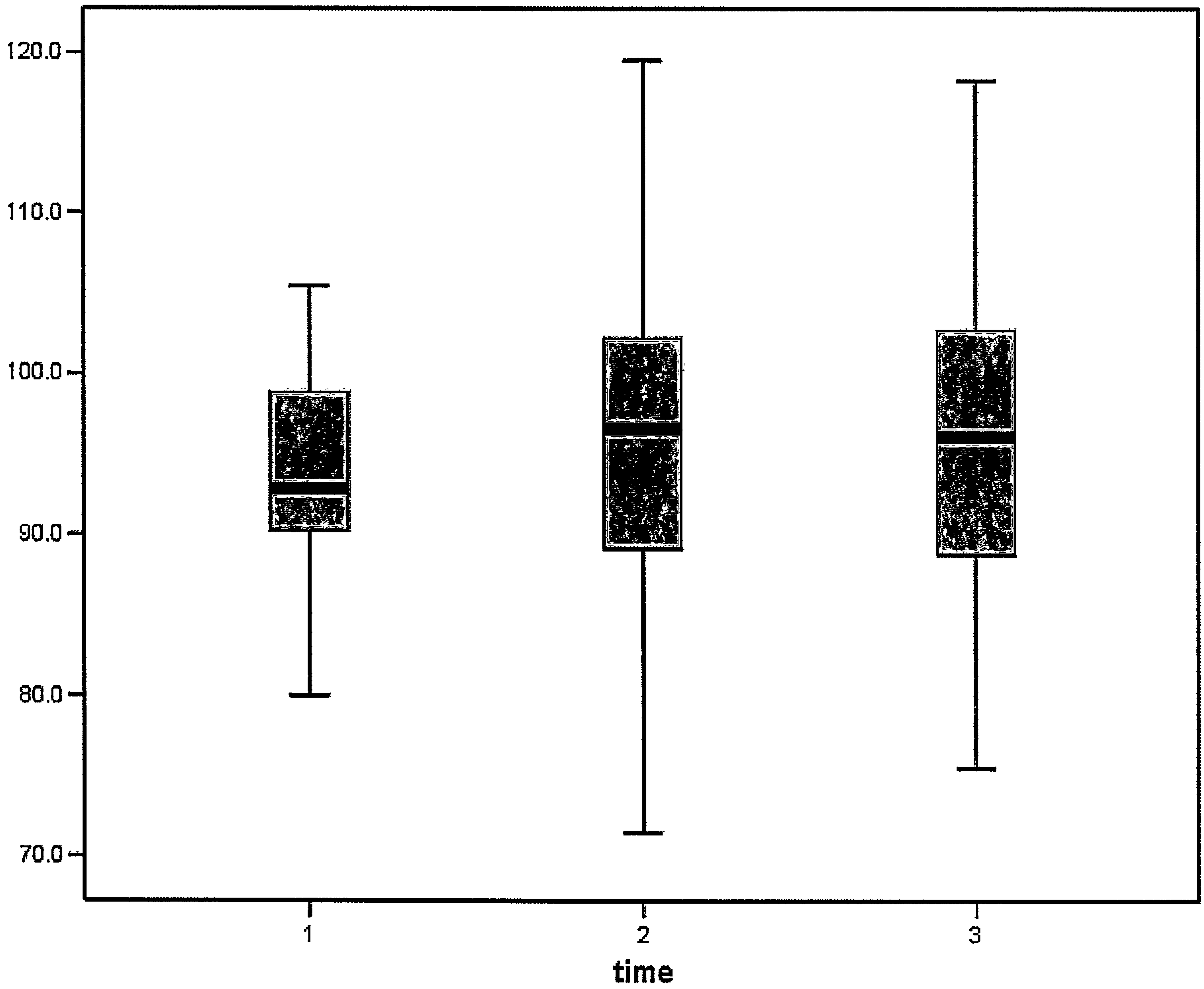
2. L1-A Pog



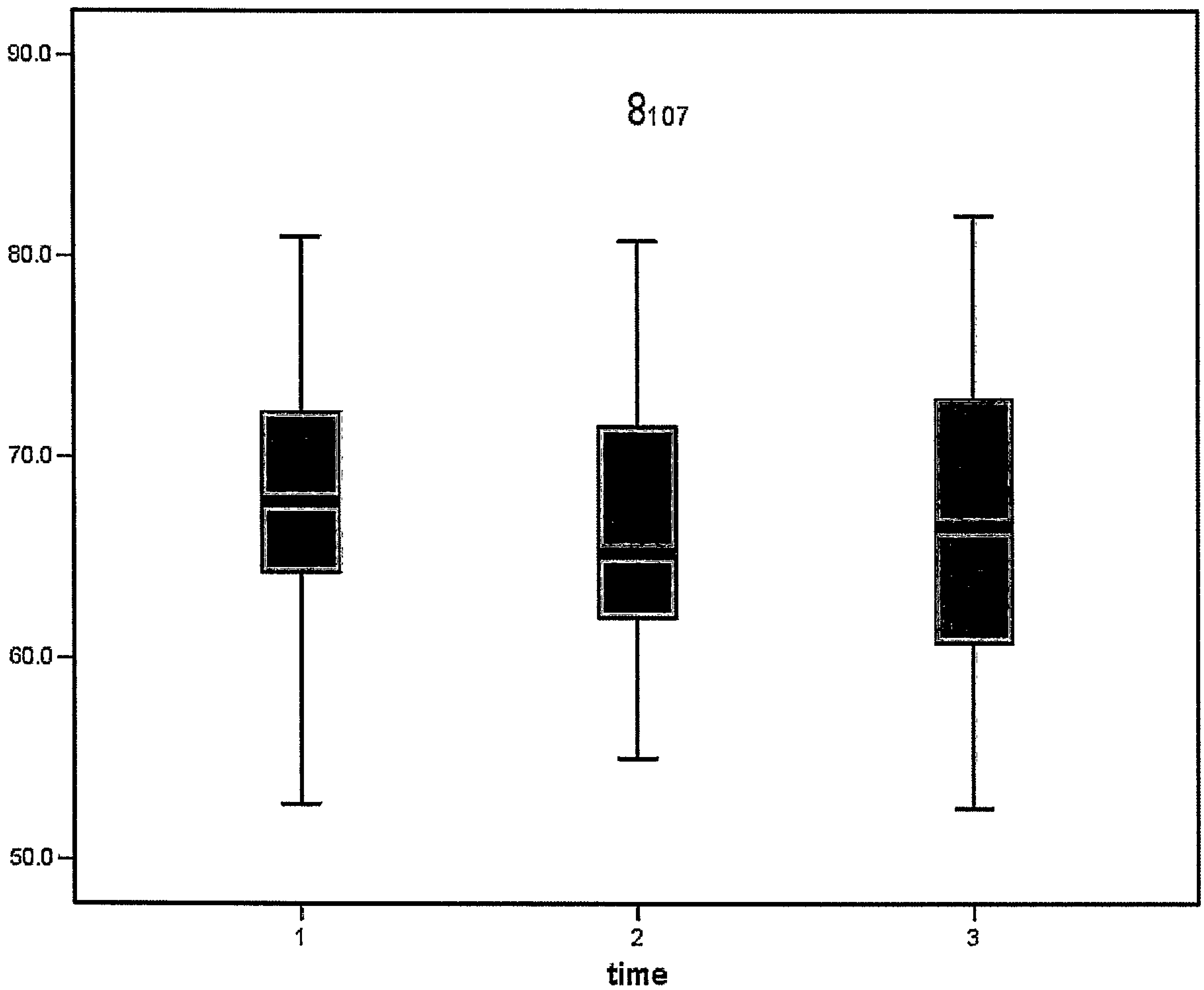
3. L1- N Pog



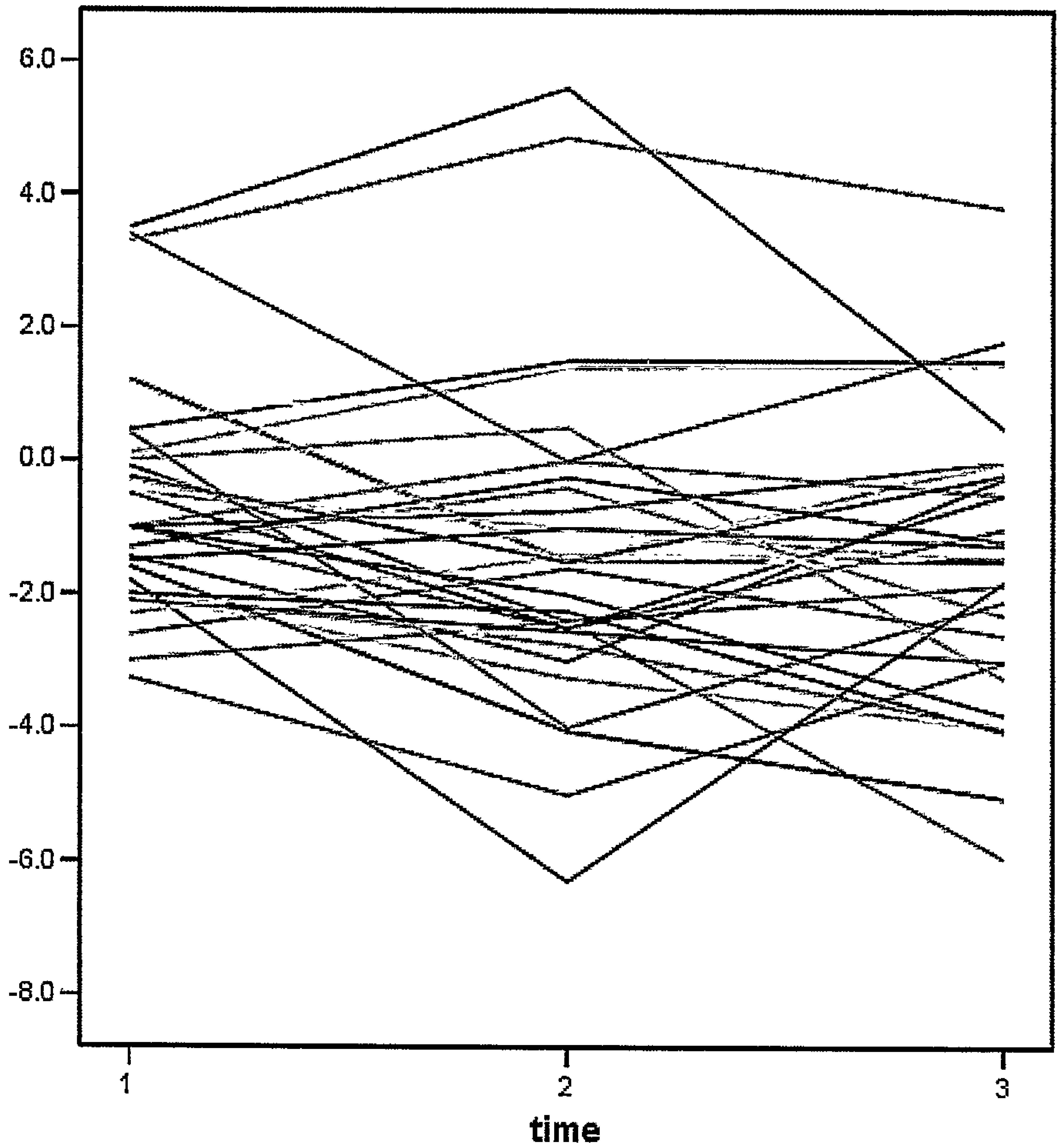
4. L1- MP



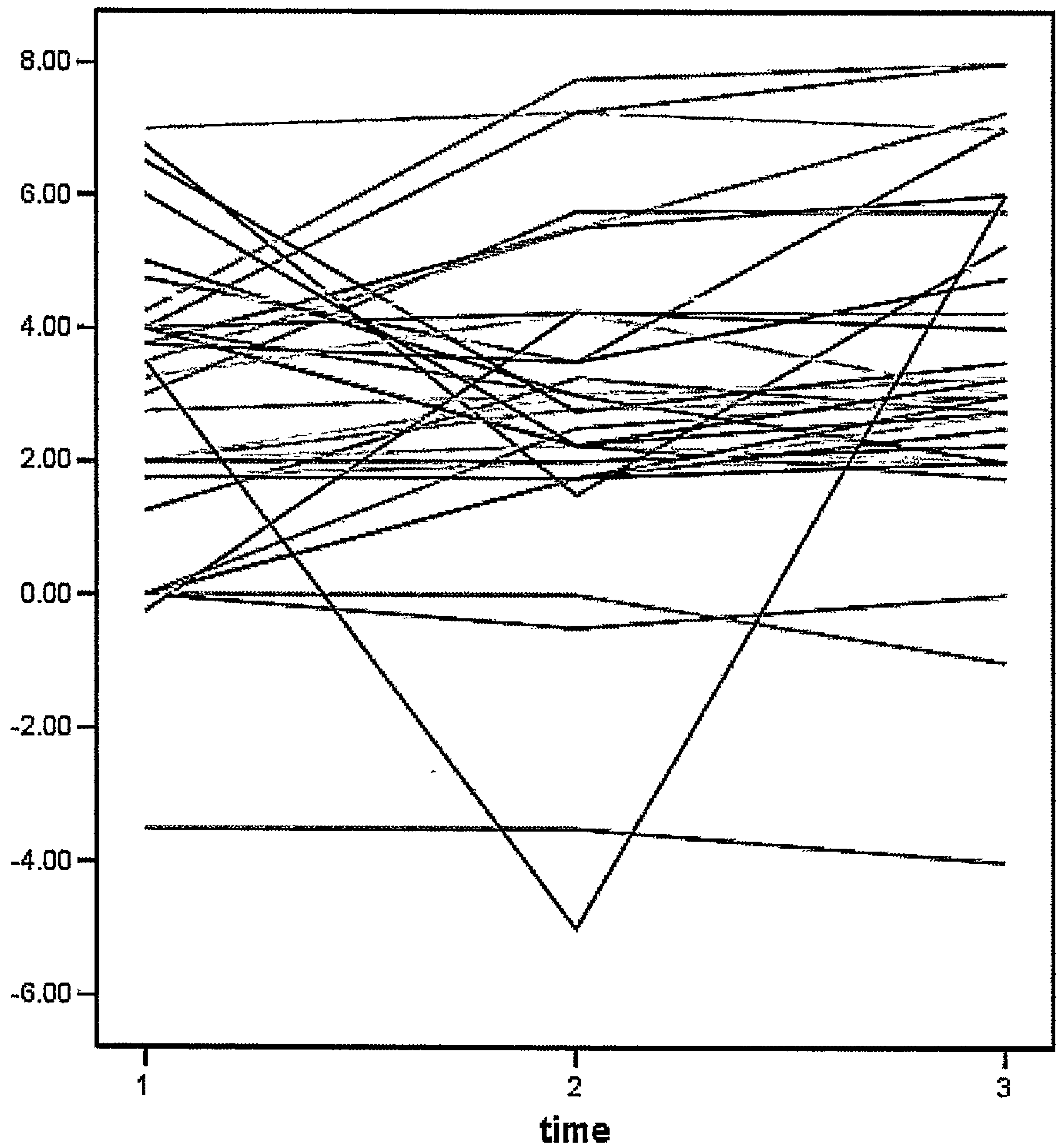
5. L1- OP



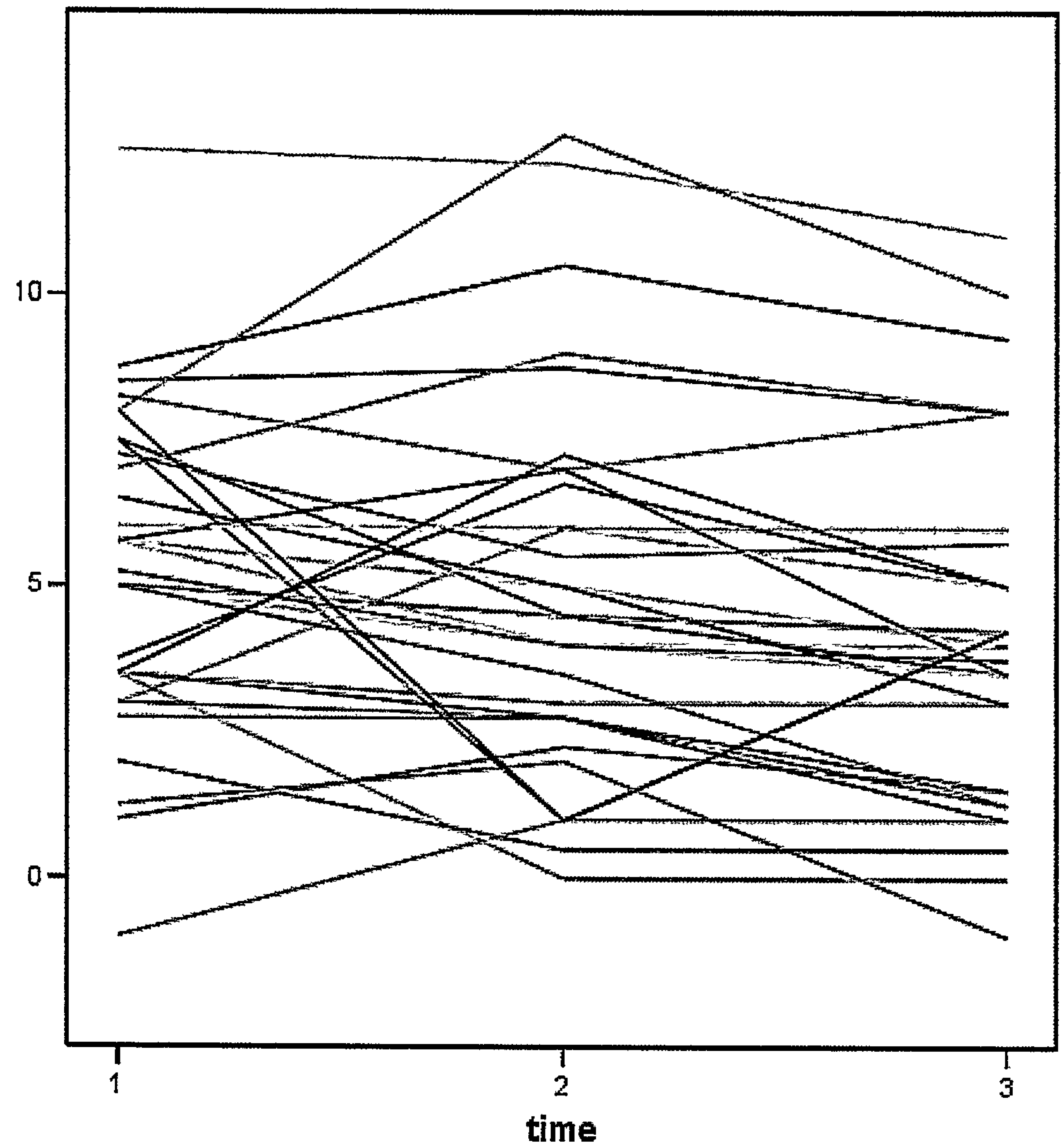
10.Appendix2:



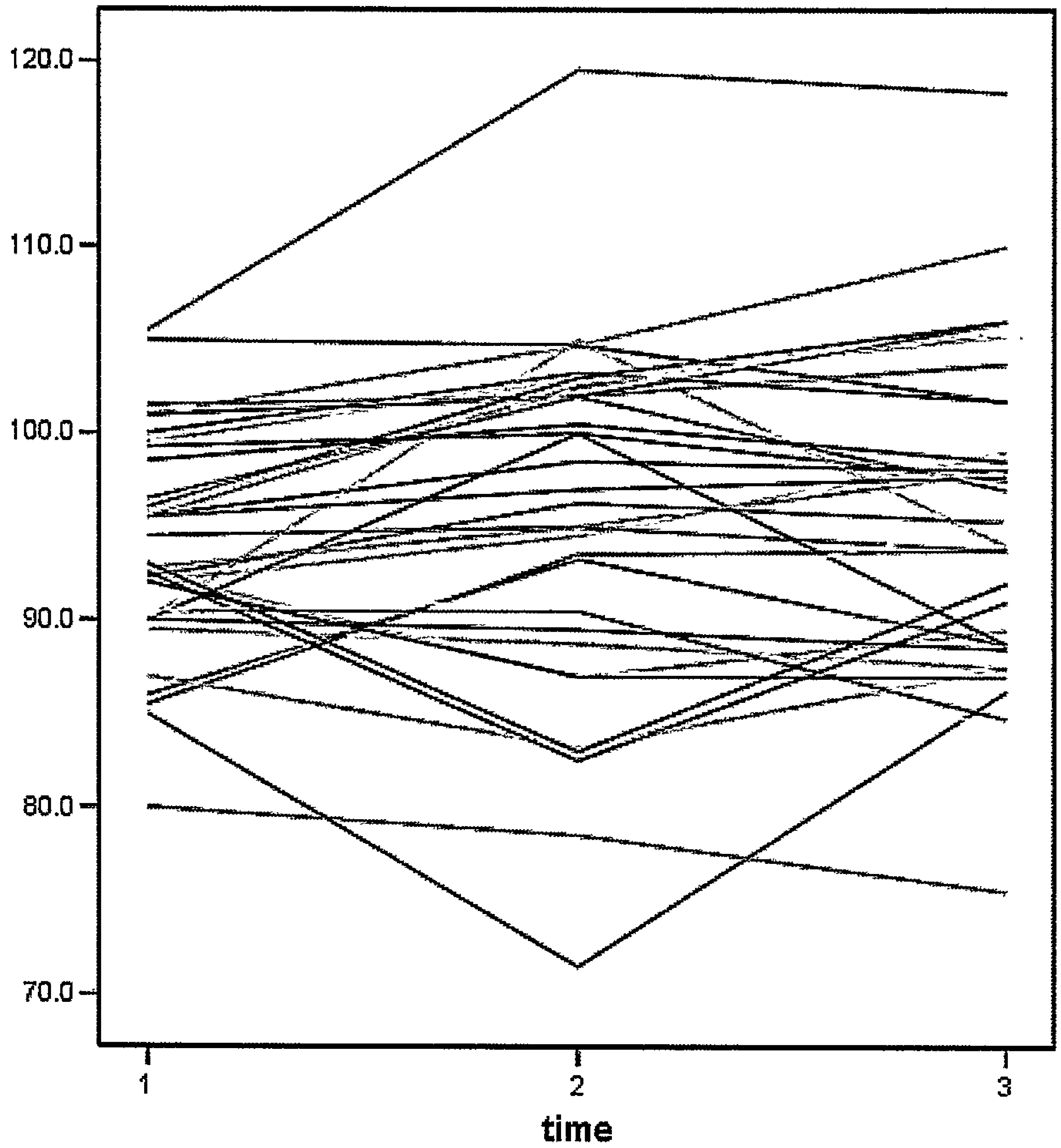
"p distance" individual registrations from before treatment (T1) to after treatment (T2) to 5 years after treatment (T3)



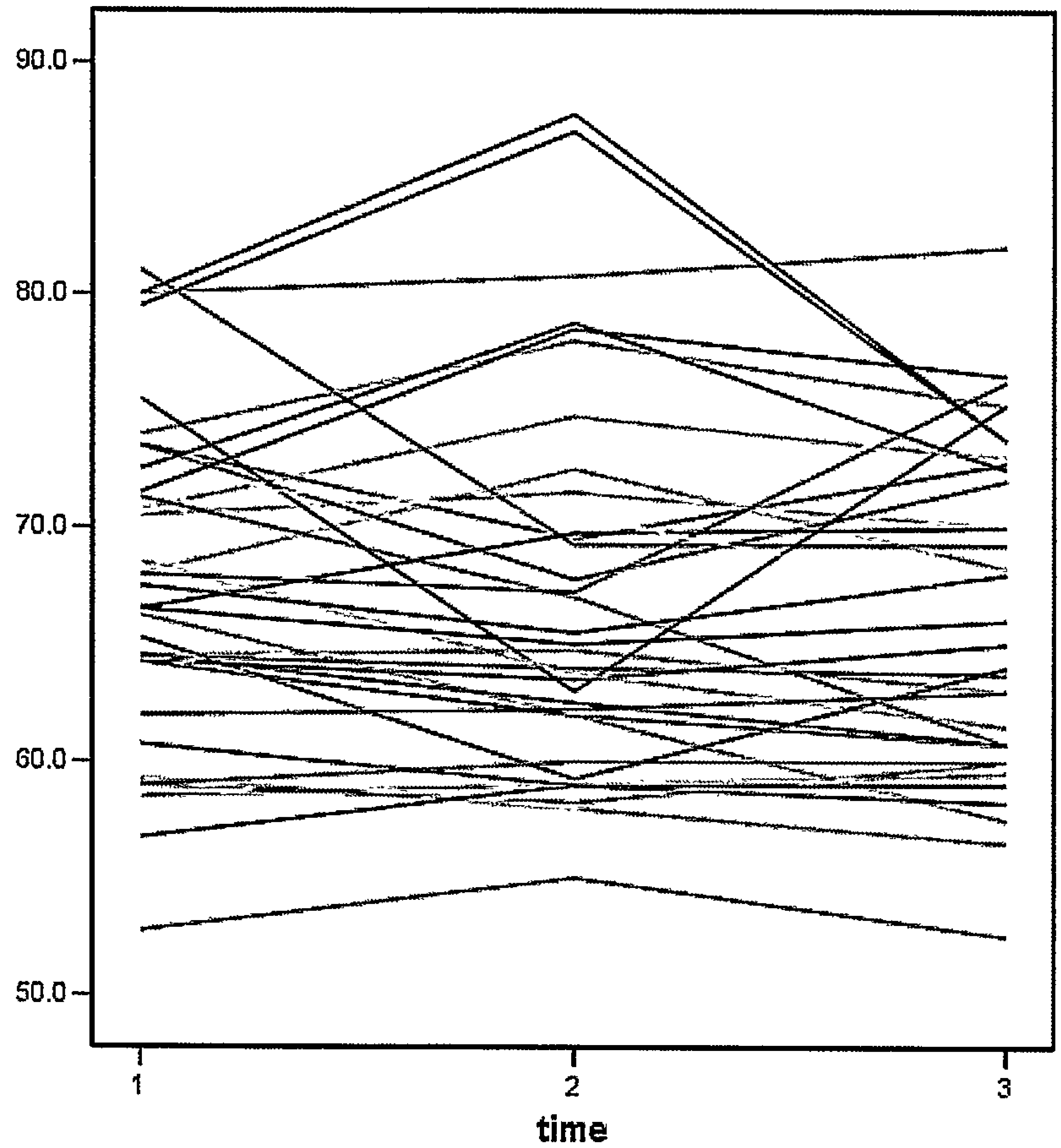
"L1- A Pog" individual registrations from before treatment (T1) to after treatment (T2) to 5 years after treatment (T3)



“L1- N Pog” individual registrations from before treatment (T1) to after treatment (T2) to 5 years after treatment (T3)



"L1 - MP" individual registrations from before treatment (T1) to after treatment (T2) to 5 years after treatment (T3)



"L1- OP" individual registrations from before treatment (T1) to after treatment (T2) to 5 years after treatment (T3)