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Orthodontic-surgical treatment: electromyographic and kinesiographic evaluation in follow up period. Experimental study

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SUMMARY

Introduction. The aim of this study was to investigate muscular function and mandibular kinesiology of patients undergoing orthodontic-surgical treatment by electromyography and kinesiography. Electromyographic evaluation is essential to estimate masticatory forces in patients undergoing combined surgical-orthodontic treatment.

Materials and methods. 60 patients referred for orthodontic surgical treatment were included in the study, 43 patients presented a class III while 17 presented a class II. The patients underwent electromyographic and kinesiographic examinations during all the therapeutic orthodontic-surgical phases.

Results. The relationship between fundamental electromyographic values and age, weight, asymmetry and activation was weak. A strong and positive relationship was observed between the relaxation percentage after TENS (transcutaneous electrical neuromuscular stimulation), the steepness of the post-surgery rehabilitation curve, the initial POC (percentage overlapping coefficient), and for the values in microvolts of the right and left temporal and masseters at the beginning of treatment.

Conclusions. Patients with dentofacial deformities corrected by surgical treatment, have a significant positive treatment outcome in respect of masticatory activity and performance electromyographic evaluation on, before, during and follow up period of the analized patients permit to underline that this examination can predict long term stability.

Key words: orthodontic surgical treatment, electromyography, kinesiography, masticatory muscles.

INTRODUCTION

Electromyographic and kinesiographic examinations permit to evaluate the homeostatic response of the oral cavity to the physiological and pathological changements of the masticatory system (1-3).

Such measurements can be statistically evaluated and are considered important not only during the diagnostic and therapeutic phases of the treatment but also during the follow up (4, 5).

These data improve the overall diagnostic process and this is particulary important in orthodontic surgical treatment.

Stability after surgery seems to be correlated by a functional occlusion in harmony with of oral cavity functions and the activity of the masticatory muscles (6, 7).

Many authors believe that an unappropriated function of the neuromuscular system has significant negative correlations with occlusion and oral functions. Hence, it is essential to make a correct diagnosis and treatment plan taking into consideration the functional aspect of the oral cavity (8-12).

Electromyographic and kinesiographic examinations permit to verify the benefits of the terapy and they are important markers for a possible relapse (13-23).

When the muscles are fatigued or are in a condition of spasm, they must recruit more motor units to maintain the same function; so a higher electromyographyc activity can be recorded (24-37).

The aim of this study was to investigate, from an electromyographic and kinesiographic point of view, muscular functionality and the mandibular kinesiology of

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patients undergoing orthodontic-surgical treatment from the diagnostic phase to the end of treatment and follow up. The aim was to identify whether there was a predictive model of correlation between such measurements.

The research focused on determining whether there was a correlation model between electromyographic values recorded after 4 years from the end of the orthodontic-surgical therapy and the measurements recorded at the beginning, during and at the end of the treatment.

MATERIALS AND METHODS

The sample included 60 consecutive patients with dentofacial deformities (31 males and 29 females mean age 33.45±7.41), referred to the department of Oral Maxillofacial Surgery of Milan University for orthodontic treatment in conjunction with surgical treatment. 43 patients presented -a class III due to mandibular protrusion (between 4 and 8 mm), in particular 20 patients presented an open skeletal bite, while 23 patients presented a deep skeletal bite. 17 patients presented a class II due a mandibular retrusion (higher than 4 mm), in particular 10 patients presented a deep skeletal bite, while 7 presented an open skeletal bite.

In class III open bite patients, the surgical movements were the following: mandibular setback and antero clockwise rotation; maxillary Le Fort I advancement. In class III deep bite patients the surgical movements were: mandibular setback and clockwise rotation; maxillary Le Fort I advancement.

In class II open bite patients the surgical movements were: mandibular and antero clockwise rotation. In class II deep bite patients the surgical movements were: mandibular advancement and clockwise rotation.

All the patients received an electromyographic an kinesiographic examination before treatment, before bonding, every two months during pre surgical orthodontic treatment, the day before surgery and before and after intermaxillary fixation, during the post surgical orthodontic treatment, at the removal of the surgical bite, at the debonding and in follow up controls (follow up average= 6,1±0.1 years after the end of the therapy). The electromyographic and kinesiographic examinations were registered by the Gotzen electromyography and K6-I kinesiography.

Each patient received a questionaire including informations about age, weight, job, sex, previous orthodontic treatment, temporomandibular disorders, ability to masticate different kind of food.

All the examinations were performed by a single operator in order to eliminate variability.

Patient of which all electromyographic and kinesiographic exams were not available and/or did not attend the follow up controls were excluded.

The statistical analysis was carried out mahalanobis methods using the statistical discovery software (2010).

This program allows calculating correlation predictive models through multiple linear regression methods in which a series of data known as dependent variable is related to a series of independent variables.

The aim was to highlight a significant correlation between the electromyographic values obtained at 4 years after the orthodontic-surgical treatment and the values obtained at the beginning and during treatment.

The following parameters have been assessed:

- The TORS (torsion index) at the beginning of treatment.
- The value expressed in microvolts of the right masseter muscle activity in MVC (maximal voluntary contraction) at the beginning of treatment.
- The value expressed in microvolts of the left masseter muscle activity in MVC at the beginning of treatment.
- The value expressed in microvolts of the anterior left temporal muscle activity in MVC at the beginning of treatment.
- The value expressed in microvolts of the anterior right temporal muscle activity in MVC at the beginning of treatment.
- The POC (percentage overlapping coefficient) value at the beginning of treatment.
- The asymmetry value at the beginning of treatment.
- The activation value at the beginning of treatment.
- The relaxing percentage of the muscle pairs after TENS (transcutaneous electrical neuromuscular stimulation) at the beginning of treatment.
- The value expressed in microvolts of the right masseter muscle activity at rest during the intermaxillary block.
- The value expressed in microvolts of the left masseter muscle activity at rest during the intermaxillary block.
- The value expressed in microvolts of the anterior left temporal muscle activity at rest during the intermaxillary block.
- The value expressed in microvolts of the anterior right temporal muscle activity at rest during the intermaxillary block.
- The steepness of the recovery curve after surgery.
- The age.
- The sex.
- The weight.

In addition, the following information was included:

- Previous orthodontic treatment.
- Temporo-mandibular disorders.
- Skeletal class.
- The type of surgery (maxillary, mandibular, maxillary and mandibular ones).

Through the distance method of Mahalanobis we have identified and excluded the outlier values which must be excluded in the evaluation of the linear regression model.

Once eliminated the outlier values, it was necessary to identify which of the independent variables taken as reference in the sample was to be included in the model. To do this, the linear correlation coefficient between the selected couple of dependent and independent variables was assessed.

In case of two variables, the linear correlation coefficient is given by the ratio between the co-variance and the product of the corresponding deviations. This coefficient ranges between –1 and +1.

Where the coefficient is equal to +1, there is a directly proportional positive linear correlation.

Where the coefficient is equal to –1, there is a directly proportional negative linear correlation.

If the coefficient is equal to 0 there is no correlation.

The software allows to evaluate the linear correlation coefficient between the couple of variables identified.

In cases where the coefficient was equal to 0 between an independent variable and a dependent one, the assumption was that for the dependent value there was no correlation and hence it was to be excluded from the model.

If the linear correlation coefficient between two dependent variables was equal to +1 we assumed that there was binding col-linearity between the two dependent variables. In such cases, only one of the two was included in the model.

The regression analysis is a technique of multivariate statistical analysis which aims at identifying the relationship between a variable (dependent variable) and the ensemble of explanatory variables (independent variables) through a correlation model obtained by a linear regression procedure. A t test for each independent variable is performed to verify if the parameter b is different from 0 (i.e. if there is a statistically significant correlation).

Thereby, if the test was significant, there was a linear dependence between the dependent variable and the independent ones selected. Therefore, all independent variables, for which the test was not significant were removed. The Fisher test was then applied to verify if the number of independent variables is sufficient to describe the dependent variable.

The variables in which the test was less significant were removed.

If one or more variables were not significant, the less significant variable was eliminated. The model was then simplified and the procedure was repeated until all variables were maintained.

RESULTS

Muscular activities were higher in class II patients than in class III patients (Figures 1, 2).

Nevertheless this difference was reserved at the end of the treatment. A similar difference was found in the mandibular kinesiology. The maximum mandibular opening and protrusive in movements were greater in skeletal class II patients than in skeletal class III at the beginning of the treatment but these values showed similar amount at the end of the treatment (Figures 3, 4).

Muscular activity is higher in deep skeletal bite patients at the beginning of the treatment than in open bite ones but during the following phases of the treatment, the two values become similar (Figures 5-7).

So it can be summarized that in class II deep bite patients muscular activity and mandibular movements are higher at the beginning of the treatment than in class III patients but at the end of the treatment this difference was reduced and became similar.

The analysis of the data considered, 16 independent variables were selected to correlate with the electromyographic data. For each of the variables, the distribution has been displayed both graphically and statistically through the evaluation of the quantiles, average and standard deviation.

The distribution analysis allows to exclude the presence of an anomalous value. According to Mahalanobis distances method, the results of which are shown in Figure 1, it was highlighted that all the data was below the critical value.

None of the data included in the study reach the critical value established by Mahalanobis technique, hence all patient data was acceptable.

Analyzing graphically the distribution of the electromyographic data and the independent variables it was observed that:

- The fundamental measure ranges from a minimum of 70.12 to a maximum of 99.91 with an average value of 85.11. Such value is considered optimal.
- The data concerning the fundamental measure was distributed randomly with a high number of patients with a fundamental measure between 85 and 90.
- In relation to the age, the variable was between 19 and 54 years with an average age of 29.91.
- Only one case over the age of 50 was registered.
- The mean age was between 25 and 30 years old.

After isolating the patients that had a fundamental measure between 85% and 90%, we noted that:

- They were not represented by a precise age.
- They were not represented by a specific body weight.
- They showed an initial TORS value lower than 10%, therefore considered standard.
- They had an initial POC value higher than 75%.
- They had the masseter muscle values in microvolts at the beginning of treatment higher than 400 microvolts.
- They had the temporal muscle values in microvolts at the beginning of treatment higher than 200 microvolts.
- They had an asymmetrical value betwe en -10% and 10%, considered physiological.
- They had an activation value between -10% and 10%, considered physiological.
- Relaxing after TENS was lower than 40%, reaching the 99% value.
- The steepness curve is higher than 50%.

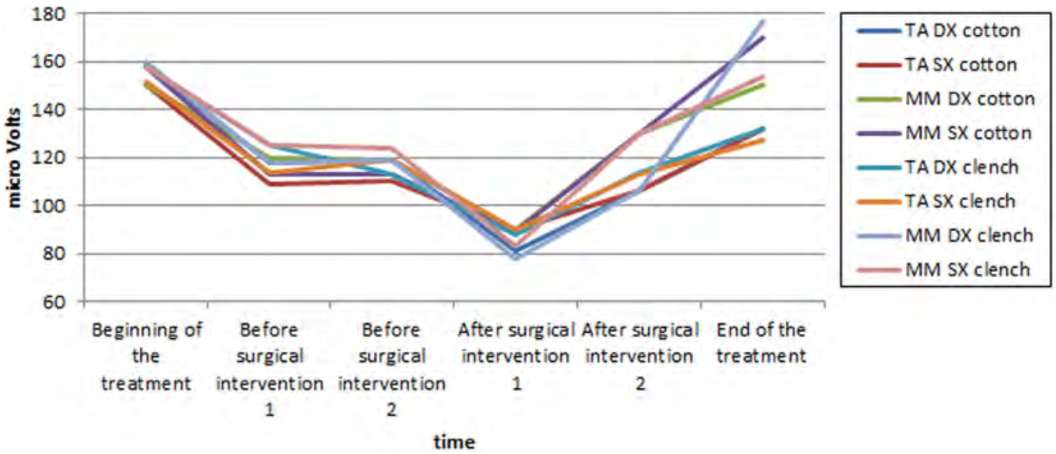

Fig. 1. The muscular activity in the Class II patients (TA, anterior temporal muscle; MM, masseter muscle; SX, left; DX, right; cotton, with cotton rolls; clench, without cotton rolls)

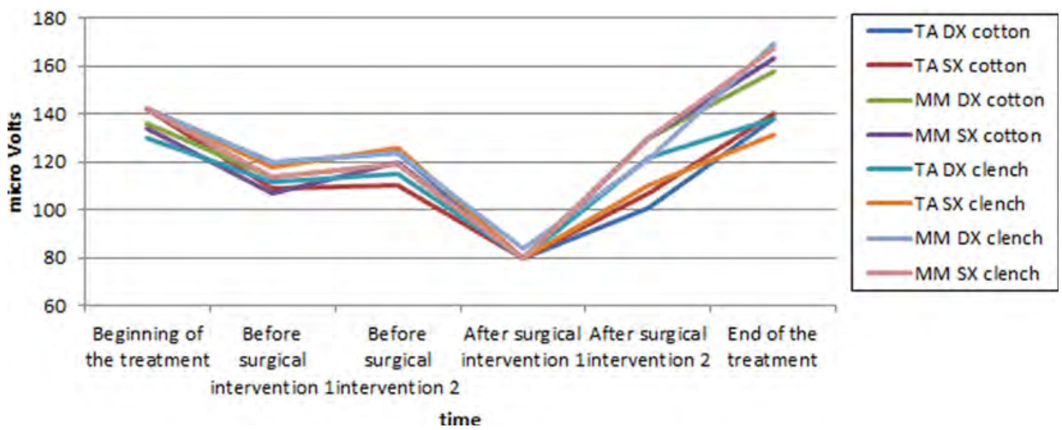

Fig. 2. The muscular activity in the Class III patients (TA, anterior temporal muscle; MM, masseter muscle; SX, left; DX, right; cotton, with cotton rolls; clench, without cotton rolls)

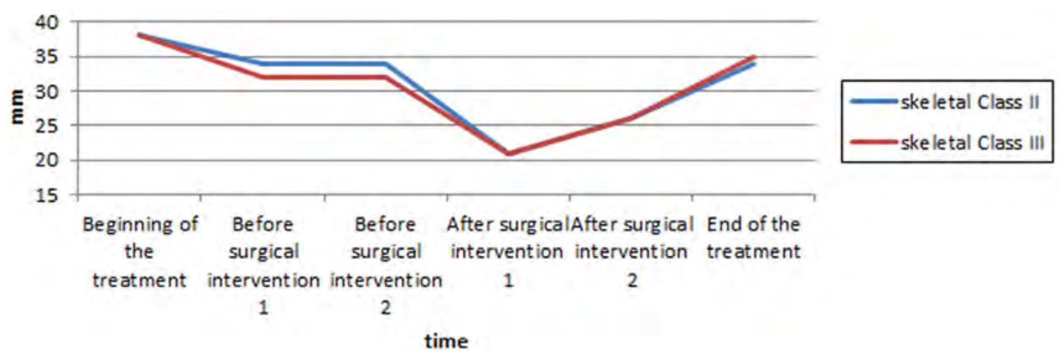

Fig. 3. The maximum mandibular opening, skeletal Class (blue line indicates skeletal Class II patients and the red one indicates skeletal Class III patients)

By Isolating the patients who had a fundamental measure higher than 95% it was noted that:

- There was no specific age.
- There was no specific body weight.
- The initial TORS value was lower than 10%, hence considered standard.
- The initial POC value was between 75% and 85%.
- The masseter muscle value in microvolts obtained at the beginning of treatment was higher than 400 microvolts.
- The temporal muscle value in microvolts obtained at the beginning of treatment was higher than 200 microvolts.
- The asymmetrical value obtained was between -10% and 15%, which is considered physiological.
- The activation value obtained was between -10% and 10%, which is considered physiological.
- The relaxation value after TENS was lower than 40%.
- The steepness curve was higher than 50%.

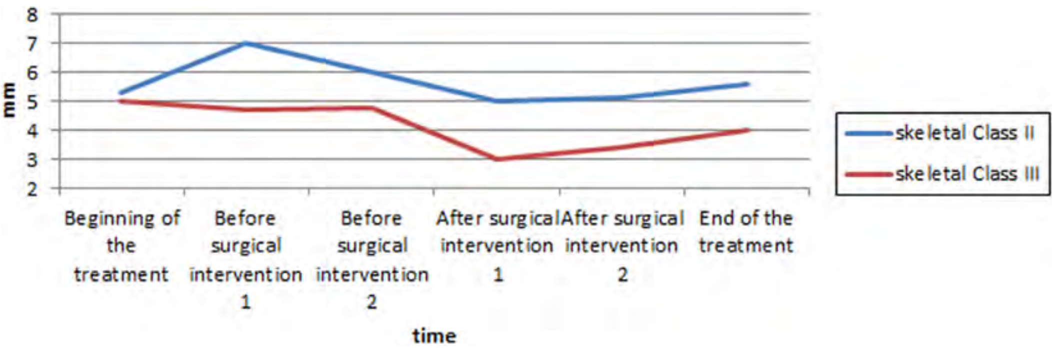

Fig. 4. The maximum mandibular anterior movement, skeletal Class (blue line indicates skeletal Class II patients and the red one indicates skeletal Class III patients)

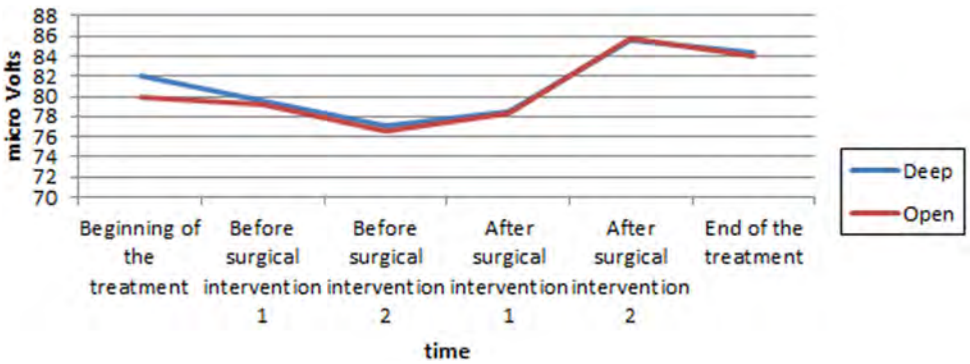

Fig. 5. Mean POC in deep and open skeletal bite (blue line indicates deep skeletal bite patients and the red one indicates open skeletal bite patients)

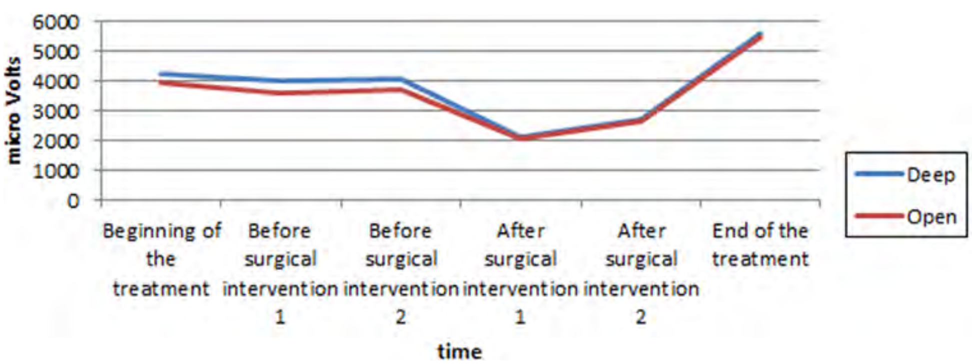

Fig. 6. The effect of the impact with the inclusion of the cotton rolls in deep and open skeletal bite (blue line indicates deep skeletal bite patients and the red one indicates open skeletal bite patients)

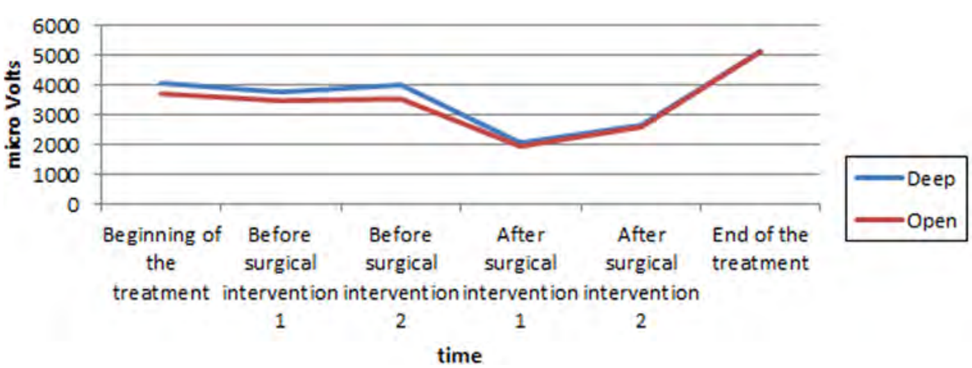

Fig. 7. The effect of the impact on the clench situation in deep and open skeletal bite (blue line indicates deep skeletal bite patients and the red one indicates open skeletal bite patients)

Such findings were also highlighted by the scatter graph and from the matrix of the scatter graph. Particularly, high values of the fundamental measure corresponded to:

- A low value of the initial TORS, compared to the total.
- A high value of the temporal and masseter muscle contraction at the beginning of treatment, compared to the total.
- A high value of the masseter muscle contraction at the beginning of treatment, compared to the total.
- A lower and higher valued compared to the standard values for what concerned the asymmetrical and activation index.
- A high value of the initial POC.
- A Low value of the masseter and temporal muscles during the intermaxillary block.
- A high value of the steepness curve and of the relaxing value after TENS.
- There was no correlations with weight, age and skeletal class.

To the low values of the fundamental measure, instead, corresponded:

- A high value of the initial TORS, compared to the total.
- A low value of the temporal and masseter muscles contraction at the beginning of treatment, compared to the total.
- A low value of the masseter muscle contraction at the beginning of treatment, compared to the total.
- Within the standard values for what concerns the

asymmetrical and activation index.
- A low value of the initial POC.
- A high value of the masseter and temporal muscles during the intermaxillary block.
- A low value of the steepness curve and muscle relaxation after TENS.
- There was no correlations with weight, age and skeletal class.

From the analysis of the correlation chart in which are listed the linear correlation coefficients, it was noted that the relationship between fundamental measure and age, weight, asymmetry and activation was weak. A strong and positive relationship between the relaxation percentage after TENS, the steepness of the post-surgery rehabilitation curve, the initial POC, for the values in microvolts of the right and left temporal at the beginning of treatment and the right and left masseter at the beginning of treatment.

The relationship between the fundamental measure and initial TORS, the right and left masseter at rest during the intermaxillary block and the right and left temporal during the intermaxillary block was strong and negative.

The same type of relationship is shown in the chart in which we have reported the data through a dispersion contained in the correlation ellipses. If the ellipses are flattened and facing downwards, the correlation is strong and negative, whilst if they are flattened and facing upwards, the correlation is strong and positive. In cases where the ellipses are close to the circle shape, there is no correlation.

A correlation between the initial POC and TORS and the fundamental measure is observed. In addition, from the chart it is highlighted that as the initial TORS index increases, the value of the fundamental measure decreases and as the initial POC index increases, the fundamental value increases.

Therefore, for the POC index there is a positive type of correlation whilst for the TORS index the correlation is negative.

Regarding the correlation between the value in micronVolts of the right and left masseter in MVC at the beginning of treatment, it is noticeable that there is a positive correlation. In fact, with the increasing of the masseter muscle activity, the value of the fundamental measure increases.

Therefore, patients who have a high masseter muscles activity at the beginning of treatment, will probably have a high fundamental measure after a long period of time.

Concerning the correlation between the value in micronVolts of the right and left temporal in MVC at the beginning of treatment and the fundamental measure, a positive correlation is noticeable. In fact, as the activity of the temporal muscle increases, the fundamental value increases. Hence, patients who have a high activity of the temporal muscles at the beginning of treatment will have a high fundamental measure after a long period of time.

Analyzing the correlation model between the value in micronVolts of the right and left masseter muscle at rest during the intermaxillary block and the fundamental measure, a negative correlation is noticeable (when this value increases, the fundamental measure decreases). In fact, patients who have a high masseter muscle activity at rest during the intermaxillary block have a low fundamental measure at the long term follow up.

Analyzing the correlation model between the value in micronVolts of the right and left temporal muscle at rest during the intermaxillary block and the fundamental measure, a negative correlation is noticeable hence when this value increases the fundamental measure decreases.

The relationship between the fundamental measure and the percentage of muscle relaxation post-TENS proved a positive correlation, i.e. higher is the muscular relaxation post-TENS, higher is the level of the fundamental measure at the long term follow up.

There also is a positive correlation between the steepness curve and the fundamental measure hence, steeper is the post-surgery rehabilitation curve, higher is the fundamental measure. This implies that patients who have a fast neuro-muscular post-surgery recovery, will have the best electromyographyc values at the long term follow up (Tables 1-2).

Once the correlations were identified, we proceeded to the evaluation of the multivariate linear correlation model using the 16 independent variables. The variables for which the evaluation of the estimation parameter was not equal to the student test, were eliminated.

It was assumed that in the fundamental hypothesis of the test (H), the correlation parameter was zero i.e. there was no correlation. If the t value was higher than the limit value evaluated with a significance threshold of 5%, we rejected the H hypothesis and hence we considered it as a significant correlation. Once the variables were removed, the model remained with 9 variables which all passed the student test.

Once the p-value concerning the Fisher's F test was lower than 0.0001, the Fisher's test was passed. Consequently, the variables were sufficient to describe the relationship between the fundamental measure and the independent variables selected. The graph VII.113 shows the comparison between the values of the fundamental measure expected and the ones observed. It is highlighted that all values are found on a 45° straight line.

This data proves that the values expected by the model are close to the actual observed values.

In particular, the value of the R-chart is high and equal to 0.871 which is considered excellent as it is close to 1.

From the variance analysis, there is a Fisher distribution p-value lower than 0.0001.

The p-value of the *t* Student test distribution was lower than 5%.

From the residual analysis it is noticeable that they are uniformly distributed around 0 which shows how the linear correlation hypothesis is acceptable.

Statistically significant correlations have been proved between the fundamental measure and:

- The TORS at the beginning of treatment.
- The values in micronVolts of the temporal and masseter muscles in MVC at the beginning of treatment.
- The relaxing percentage after TENS.
- The temporal muscle values at rest during the intermaxillary block.
- The steepness value of the rehabilitation curve in the post-surgical phase.

Therefore the values of the masseter muscles in micronVolts during the intermaxillary block and the POC initial value, are not correlated to the fundamental measure in a statistically significant way.

To give more authenticity to the correlations obtained, we assumed to have no data of the fundamental measure and tried to deduce them from the previous electromyographies. Hence, we tried to predict the electromyography values at the follow up on the basis of the previous data obtained.

From the graph of the observed values (actually registered) and the expected ones, it is highlighted how the model is able to foresee the data at both high values and low value of the fundamental measure.

This allows to deduce that the model is predictive.

DISCUSSION

The data collected and analyzed in this study allowed to reach the following conclusions :

- Patients receiving surgical-orthodontic treatment had indices that allowed to formulate a prognosis i.e. to estimate the neuromuscular function and measure at the follow up (38, 39).
- The values that were not statistically significantly correlated between themselves have been rejected. In particular, the kinesiographic values have been rejected both because they were not significantly correlated and because it is known from the studies of Tate et coll and Throckmorton et coll that the long term kinesiographic rehabilitation is not so quick and satisfying as the electromyographic one (24, 25, 34).

By selecting the data, we have obtained 16 indexes, or independent variables obtained from the electromyographies made before and during treatment. Among these, some data was specific to the patient (weight and age), some referred to the electromyographies at the beginning of treatment (initial POC and TORS, values in micronVolts of the 4 muscles at the beginning of treatment, asymmetry and activation values), other data referred to the pre-surgical phase (relaxing % after TENS) and others referred to the intermaxillary block phase (values at rest of the 4 muscles) and the post-surgical phase (steepness of the rehabilitation curve in the post-surgical period).

From the distribution's analysis, it is possible to underline that patients with high, medium or low fundamental measure values had specific characteristics both at the beginning and during treatment. The statistical model utilized allowed the elimination of values which did not correlate (backward elimination). Therefore, the values less correlated were the first ones to be excluded until only highly correlated values were obtained.

Lots of difference between open and deep skeletal bite patients and class II and III patients have been underlined by the analysis of the electromyographic data obtained at the beginning of the treatment. The impact value and muscular activity in microvolt analysis shows a major activity in deep bite patients than in open bite ones and that mandibular movement are higher in class II than in class III patients.

The difference existing between the two groups at the beginning of the treatment, which is statically significative, tend to diseapper at the removal of the fixed orthodontic appliance, confirming the orthodontic-

Table 1. Estimated summary of the values involved in this study. Values shown in the table are the mean values used for the statistic analysis

R-squared	**0.87181**
Correct R-squared	0.846751
Mean Squared Deviation	4.713993
Average of Results	83.13636
Weighted Addition	31

Table 2. MBL changes of presented clinical cases

Origin	**DF**	**Addition of Squares**	**Quadratic Means**	**F Ratio**
Model	8	6953.095	772.567	34.7662
Error	47	1022.1993	22.221	Prob>F
C. total	55	7975.2943		<.0001*

surgical treatment's corrective role in accordance with Santoro and Mairona's study (40). Furthermore, before the start of the fixed orthodontic therapy, patients present a compensatory equilibrium to malocclusion.

During successive phases, electromyographic and electrognatographic values continue to worsen according to Thomas et al. (41), Brown and Moerenhout (42), Santoro and Maiorana (40), and Oliver and Knapman (43). They improve in post the postsurgical orthodontic phase only, during which is useful to performe radiography to verify bone segment stability.

At the end of the orthodontic-surgical treatment, electromyographic values improve and reach optimal values similar to those of the control group. Mandibular movement rehabilitation needs more time than the muscular one even if it is satisfactory and costant too. At the end of the treatment, maximum mandibular opening is still less than the preoperative one. No statistically significative differences between the two groups have been highlighted about mandibular kinesiology.

These last values obtained are then subjected to further statistical analysis which allow to find the values which correlate to the fundamental measure.

This correlation model allows, at the end of treatment, to obtain indices statistically correlated to the fundamental measure. In this study these indices were the initial TORS, the values expressed in micronVolts of the 4 muscles at the beginning of treatment, the temporal muscle values during the intermaxillary block, the relaxing percentage after TENS and the steepness of the curve during post-surgery (44).

One study in 2011 had shown that high values of the temporal' activity at rest during the intermaxillary block were a negative prognostic index (45).

This model can be useful to estimate, during the treatment phase, the post-surgical rehabilitation level of the patient (46-50).

In literature there are no studies that show the same correlation.

CONCLUSIONS

This study highlights:

- The importance of long treatment follow-up.
- Combined surgical-orthodontic treatment must take into consideration the functional functional evaluation.
- Each patient responds to treatment differently and therefore there is a big individual variability in terms of neuromuscular and functional response to the orthodontic-surgical therapy.
- A linear correlation between the electromyographic values obtained before and during therapy and those registered at the follow up allow to make predictive evaluations of the neuromuscular stability in the long term.
- Class II deep bite patients have higher muscular activities and jaw movements than class III open bite patients at the beginning of the treatment.
- These differences are similar at the end of the treatment.

STATEMENT OF CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

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