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Application of graph theory in diagnosis of malocclusion

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ABSTRACT

The objective of this article is to use graph theory as a modality to simplify and explain the properties of complex biological processes in orthodontics so as to aid in diagnosis and treatment planning. Network analysis, an innovative statistical tool, provides a new approach to understand complex problems. It is a graphical model that encodes probabilistic relationship among variables of interest. When used in combination with statistical technique this graphic model which illustrates the causal relationship among different variables and hence can be used to gain understanding about a problem and predict the consequences of intervention. Orthodontics deals with correction of malocclusion and other dentofacial anomalies which usually have a complex multifactorial etiology. Diagnosis and treatment planning may need the correlation of the clinical, radiographic, and the functional data. The use of graph theory to analyse these datas can drastically reduce the complexity of the pertaining problem. The topology of the dentofacial system obtained by network analysis could allow orthodontists to visually evaluate and anticipate the co-occurrence of auxological anomalies during individual craniofacial growth and possibly localize reactive sites for a therapeutic approach to malocclusion. This article discusses the scope of graph theory and its use in dentistry in general and orthodontics in particular.

INTRODUCTION

A major challenge in contemporary orthodontics is to map, understand, and model the architectural and dynamic properties of the various networks that control the behaviour of the craniofacial system. The knowledge basis of orthodontic diagnosis and treatment planning involves an understanding of the huge amount of (possibly interrelated) data obtained from clinical examination and functional and radiographic analyses. In diagnosing malocclusion, the measurements obtained with clinical and radiological methods are likely to be less important than the underlying (and possibly undervalued) correlations among the measurements themselves. The orthodontist is thus exposed to the risk of sub-optimal decisions owing to the complexity of the parameter space. In any case it is essential to understand the action of the principle agent and how its effect can be modified by any others.

GRAPH THEORY

A system of elements that interact or regulate each other can be represented by a mathematical object called a network. Networks provide tools and methodologies to understand systems in which each component can influence the behaviour of many others. At a highly abstract level, the components can be reduced to a series of nodes that are connected to each other by links, with each link representing the interaction between two components. The nodes and links together form a network, or, in more formal mathematical language, a graph. The set of nodes must include all distinct entities that are capable of participating in the relationship under study. Graph theory provides a powerful representation of these functional interactions and highlights their global interdependence. Network structure, and the particular pattern of interactions, can have a major effect on the behaviour of the system; it is the pattern that matters, the architecture of relationships, not the precise identities of the elements themselves. A general way to understand complex biological systems is to represent them using the simplest units of architecture. Such patterns of local and global interconnection are called networks.

A network, or in more formal mathematical language, a graph, is a simplified representation that reduces a system to an abstract structure capturing the basis of connection pattern of the system .The simplest possible network representation reduces the system's elements to nodes (–vertices‖) and their pairwise relationships to links (–edges‖) connecting pairs of nodes. Links represent functional

Interactions or anatomical relationships between the nodes. The network's inference and analysis refers to information on the identity and the state of the elements of a system to their functional relationships and to the extraction of biological insight and predictions.

In this study, we show that graph representation and analysis can be used to gain biological insight through an understanding of orofacial organization and function. We introduce networks as maps summarizing orthodontic connections that promote understanding of how features are connected and how these connections can be informative about the causative mechanisms of malocclusion occurrence and progression. This approach has been proven useful in different various aspects of health research, ranging from the spread of epidemics and the consequences of bad health habits to the network(s) of disorder and disease genes.

MALOCCLUSION

A malocclusion is a misalignment or incorrect relation between the teeth of the two dental arches when they approach each other as the jaws close - Coined by Edward Angle.

CAUSES

Table 1: Graber's classification of malocclusion

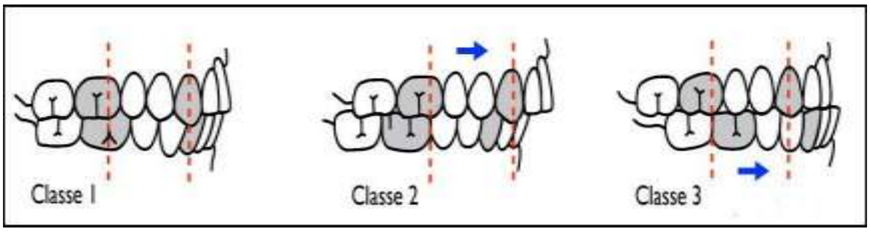
General factors		*Local factors*	
1.	Heredity	1.	Anomalies of number: • Supernumerary teeth • Missing teeth (congenital absence or loss due to accidents, caries, etc.)
2.	Congenital		
3.	Environment a. Prenatal (trauma, maternal diet, German measles, maternal metabolism, etc.). b. Postnatal (birth injury, cerebral palsy, TMJ injury)	2. 3.	Anomalies of tooth size Anomalies of tooth shape
4.	Predisposing metabolic climate and disease a. Endocrine imbalance b. Metabolic disturbances c. Infectious diseases	4. 5. 6.	Abnormal labial frenum: Mucosal barriers Premature loss Prolonged retention
5.	Dietary problems (nutritional deficiency)	7.	Delayed eruption of permanent teeth
6.	Abnormal pressure habits and functional aberrations:	8.	Abnormal eruptive path
	a. Abnormal sucking	9.	Ankylosis
	b. Thumb and finger sucking	10.	Dental caries
	c. Tongue thrust and tongue sucking	11.	Improper dental restorations
	d. Lip and nail biting		
	e. Abnormal swallowing habits (improper deglutition)		
	f. Speech defects		
	g. Respiratory abnormalities (mouth breathing, etc.)		
	h. Tonsils and adenoids		
	i. Psychogenetics and bruxism		
7.	Posture		
8.	Trauma and accidents		

DIAGNOSIS

Clinical -angles classification

ANGLE'S CLASSIFICATION OF MALOCCLUSION

A malocclusion is a misalignment or incorrect relation between the teeth of the two dental arches when they approach each other as the jaws close. Edward Angle, who is considered the father of modern orthodontics, was the first to classify malocclusion. He based his classifications on the relative position of the permanent MAXILLARY FIRST MOLAR. In case where the first molars were missing, CANINE relationship is used.



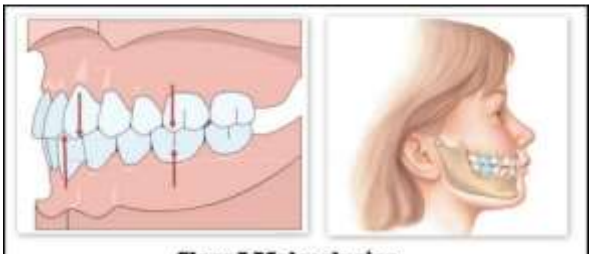
ANGLE Class I: NEUTROOCCLUSION

Molar Relationship: The mesiobuccal cusp of the maxillary first permanent molar occludes with the mesiobuccal groove of the mandibular first permanent molar.

Canine Relationship:- The mesial incline of the maxillary canine occludes with the distal incline of the mandibular canine. The distal incline of the maxillary canine occludes with the mesial incline of the mandibular first premolar.

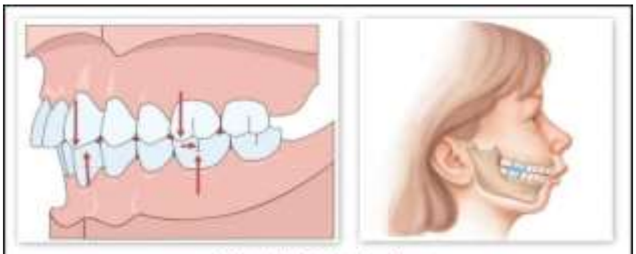
Line of Occlusion: ALTERED in the maxillary and mandibular arches.
– Individual tooth irregularities (crowding/spacing/other localized tooth problems).
–Inter- arch problems(open bite/deep bite/cross bite)

***ANGLE Class II*: DISTOOCCLUSION (overjet)**
Molar relationship: The molar relationship shows the mesiobuccal groove of the mandibular first molar is DISTALLY (posteriorly) positioned when in occlusion with the mesiobuccal cusp of the maxillary



Class I Malocclusion

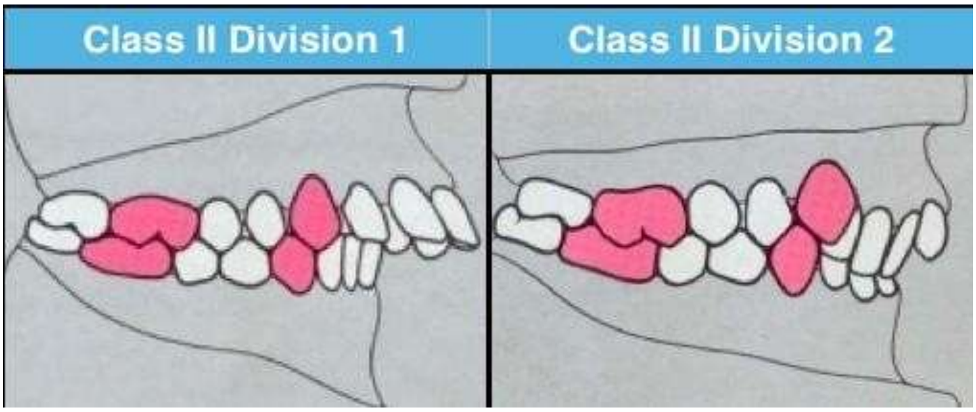
first molar. Usually the mesiobuccal cusp of maxillary first molar rests in between the first mandibular molar and second premolar.
Canine Relationship: The mesial incline of the maxillary canine occludes ANTERIORLY with the distal incline of the mandibular canine. The distal surface of the mandibular canine is POSTERIOR to the mesial surface of the maxillary canine by at least the width of a premolar.



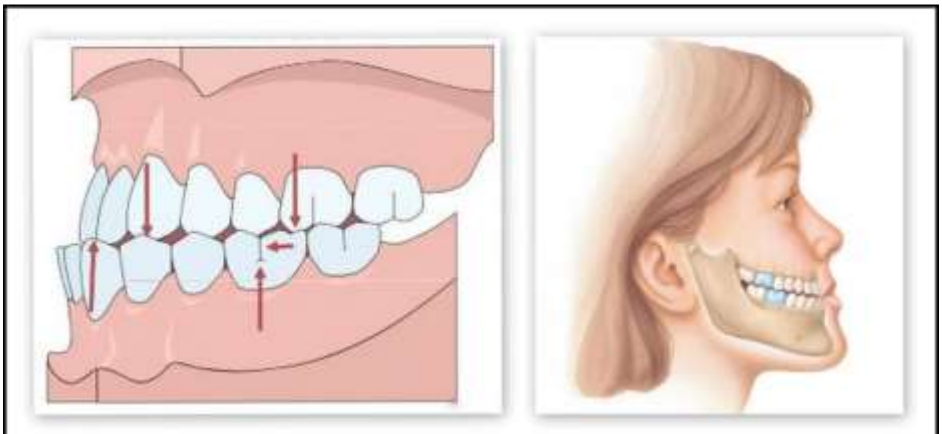
Class II Malocclusion

Class II Malocclusion has 2 subtypes to describe the position of anterior teeth:
• *Class II Division 1*: The molar relationships are like that of Class II and the maxillary anterior teeth are protruded. Teeth are proclaimed and a large overjet is present.

• *Class II Division 2*: The molar relationships are Class II where the maxillary central incisors are retroclined. The maxillary lateral incisor teeth may be proclaimed or normally inclined. Retroclined and a deep overbite exists.



ANGLE Class III: **MESIOOCCLUSION (negative overjet**)
Molar relationship: The mesiobuccal cusp of the maxillary first permanent molar occludes DISTALLY (posteriorly) to the mesiobuccal groove of the mandibular first molar.
Canine Relationship: Distal surface of the mandibular canines are mesial to the mesial surface of the maxillary canines by at least the width of a premolar. Mandibular incisors are in complete crossbite.



Class III Malocclusion

Class III malocclusion has 2 subdivisions:
1. TRUE class III malocclusion (SKELETAL) which is genetic in origin due to excessively large mandible or smaller than normal maxilla.
2. PSEUDO Class III malocclusion (FALSE or postural) which occurs when mandible shifts anteriorly during final stages of closure due to premature contact of incisors or the canines. Forward movement of the mandible during jaw closure can also result from premature loss of deciduous posterior teeth.

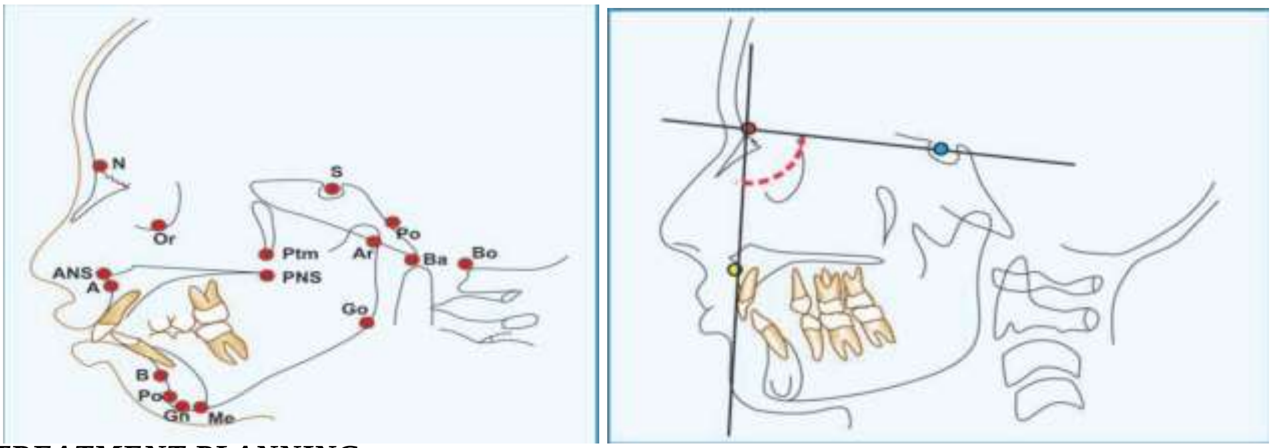
RADIOLOGICAL, LATERAL CEPHALOGRAM- ORTHOPANTAMOGRAM

A number of skeletal, dental, and soft tissue landmarks on the lateral pre-treatment cephalogram are usually traced before treatment to evaluate their changes from the normal occlusion. These landmarks as groups aid in diagnosis and treatment planning rather than as individual units.

For example **:**

The angle SNA is formed by joining the lines S-N and N-A . The mean reading for this angle is 82°. If the angular reading is more than 82°, it would indicate a relative forward positioning or protrusion of the maxilla. Conversely, should the reading be less than 82°, it would indicate a relative backward or recessive location of the maxilla.

S- sella turcica
N- nasion
A- 2 mm anterior to the apices of the maxillary central incisor root.



TREATMENT PLANNING:

The treatment requires correction of one or more of the landmarks . A fixed or removable orthodontic appliance is given for a period of time to regulate growth of the bones and move the teeth to the proper position . The treatment may last from 6 months to upto 3 years.

MATERIALS AND METHODS

Patient population

We randomly selected a group of 44 Angle Class II malocclusion division one subjects and a group of 30 Angle Class III patients Thirty subjects with good facial balance and normal occlusion were recruited as controls. The participants were selected on the basis of normal growth, no history of orthodontic treatment, and completeness of records. The diagnoses were performed separately on the basis of a set of clinical, functional, and radiographic criteria.

Determination of landmarks and cephalometric analysis

Skeletal, dental, and soft tissue landmarks on the lateral pre-treatment cephalogram were traced and digitized.

Table 3. **Cephalometric variables calculated for the entire patient sample (mean and standard deviation)**

	Mean	±SD
Skeletal ap		
SNA	82	2
SNB	80	2
ANB	2	2
WITS	0	2
Skeletal – vertical		
Mandible unit length GoMe (mm)	71 (11 years)	3
SN length (mm)	71 (11 years)	5
Mandible plane angle (SN to GoMe)	33.5	3
Intermaxillary angle (ANS-PNS to GoMe)	26	3
Articular angle (Sar to arGo)	144	6
Gonial angle tot	126	4
Gonial angle sup	53	1.5
Gonial angle inf	73	2.5
Sella angle (NS to Sar)	122	5
Dental		
Interincisal angle	131	4
Overjet	2.5	1.5
Overbite	2.5	1.5
Lower 1 to APog	1	2
Soft tissue		
Lower lip to E (mm)	−3	2

COMPLEX NETWORKS

Networks or graphs are mathematical objects formed by vertices (nodes) and the links (edges) connecting them. They are often used as simple models to extract useful structural information from a variety of mechanical and biological systems. Structural aspects are typically important in problems involving multiple interacting agents. We used the above-defined orthodontic clinical, functional, and radiographic features as vertices (nodes) of the network. The degree corresponds to the number of nodes adjacent (directly connected) to a given node and is a measure of the centrality of a node. In biological terms, the degree allows an immediate evaluation of the regulatory relevance of the node. The clustering coefficient measures whether nodes adjacent to a given node are also mutually adjacent. The shortest path between two nodes measures how far apart (dissimilar) they are in the structure, while the mean shortest path of a biological network.

CORRELATIONS

We constructed our networks from the Pearson product moment correlation coefficients between pairs of orthodontic features (correlation matrix). Each node corresponds to a feature, and each link represents the correlation between two features. The networks were built by fixing a (generally positive) threshold value T: two vertices (features) were connected (linked) if the correlation between them was closer than the fixed threshold value T. A link was discarded if two features co-occurred in fewer than five patients. To prevent false positives, the significance of each correlation was also assessed by calculating the p-value for the null hypothesis; links with $p < 0.05$ were rejected.

Our networks therefore represent the significant correlations among features by discarding false positives and cases of poor statistics.

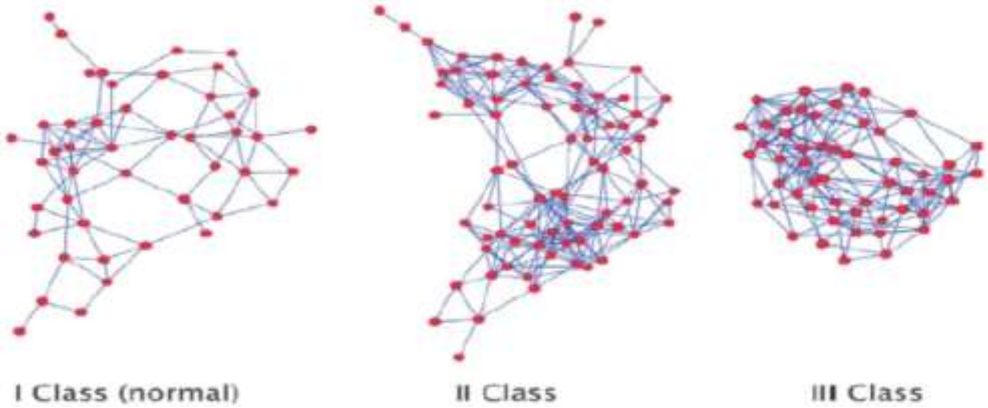
GLOBAL GRAPH METRICS OF CLINICAL, FUNCTIONAL, AND RADIOGRAPHIC DATA

Global graph metrics provide information about the general properties of the orofacial system owing to the structure of the entire graph. Network data are obtained by linking orthodontic features that have medium or high positive Pearson correlation coefficient. All the reported metrics are pure numbers: average degree is the mean of the number of neighbours of a node; clustering coefficient is the average fraction of mutually connected neighbours respect to the maximum possible number of connections; mean shortest path is the average minimum number of links connecting two nodes.

Skeletal class	Average degree	Clustering coefficient	Mean shortest path
I (controls)	4.04	0.28	3.43
II (patients)	6.45	0.36	3.13
III (patients)	7.09	0.31	2.39

RESULTS

We analyzed the network obtained by considering the average degree, clustering coefficient, and mean shortest path of the orofacial data. The average degree was lower in the Class I (normal) network and highest in the Class III network, indicating that malocclusions are characterized by more highly connected clinical, radiographic, and functional features. This observation is reinforced by the larger clustering coefficients of Classes II and III compared with control subjects. Class II and III networks also have very distinct structures; this characteristic is captured by the lower value of the



mean shortest path for Class III patients, indicating that the network is globally more compact – all features are likely to influence each other reciprocally. Networks allow the immediate visualization of complex system properties. The Class III network is characterized by a compact and uniform structure without critical hubs and is compact on both the local and the global scales. The global compactness of this network indicates that all the nodes (features) are equally relevant to the coherence of the system. Conversely, the Class II network contains a few highly connected nodes (hubs), a typical characteristic of scale-free, small-world structures.

CONCLUSIONS

Orthodontic networks are able to represent the orofacial system in a visually intuitive way, making it possible to focus on the most closely connected features. These networks are presumably able to influence the treatment plan, perhaps even shortening it. Here, we present evidence that Class II and III malocclusions have different network structures. In the treatment of a new case, the value of every sign (feature) could be considered in the context of the network specific to that malocclusion. An important issue raised by calls for orthodontic network information is the potential integration of clinical data with radiographic and functional data to better elucidate the etiology, occurrence, and progression of malocclusion. The structures of the correlation networks provide indications of the strength of interactions among orthodontic variables; the correction of interacting additive orthodontic problems could help shorten the treatment and perhaps increase its effectiveness.

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