Assessment of Decision Support System Software in Extraction and Anchorage Planning among Adult Patients using Computer Algorithm

Protocol submitted to
Faculty of Dentistry, Cairo University
for partial fulfillment of the requirements for the Master Degree in 2021

By

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Date: 4-22-2022

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I. Administrative information:

1. Title:

Assessment of Decision Support System Software in Extraction and Anchorage Planning among Adult Patients using Computer Algorithm

2. Protocol Registration:

3. Protocol version:

4. Funding:

No Sources of Funding to be declared

5. Roles and responsibilities:

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II. Introduction:

6. Background and rationale:

It was introduced in dentistry to be used in innovative research and development in addition to facilitating the decision in complicated cases and ensure high patient care quality. In the field of Orthodontics in specific, many studies previously mentioned the idea of artificial intelligence showing very promising results and high degree of reliability. It was used in different domains in orthodontics like diagnosis, treatment planning, evaluation of treatment outcome. In this study, the aim is to access the efficiency of the new decision support system in determining whether the decision is extraction or non-extraction and the anchorage plan required for each case. This was performed in the past in many countries and those studies are published (Will be discussed later in the literature review section)

Research question: Will the computer Algorithm be efficient in producing decisions related to extraction, non-extraction and anchorage planning?

Rationale:
This study will help the orthodontists in making the correct decisions regarding the extraction and anchorage based on clinical data acquired from the patient. Different papers were published to illustrate the previously mentioned concept but with different accuracies. So, this study is testing how efficient this system will be in an attempt to reach high level of efficiency.

Intended use of the index test:
This Index test is intended to be used in extraction/ non-extraction decision and anchorage planning.

Clinical role of the index test:
This index test will be under evaluation aiming to assess the efficiency of newly formed decision support system concerning extraction and anchorage planning in non-growing patients compared to the clinician-based treatment planning of well- finished cases.

Review of literature:

Artificial Intelligence (AI) was defined by (Hamet and Tremblay in 2017) as the usage of the computer to model intelligent behaviour with minimal human intervention. [15] Also, it was given the description as the engineering and science of making intelligent machines that became officially in 1956.[15][14] During the next years, computers started to solve many complicated mathematical problems that soon became of interest to the Department of Defense of the USA. Then, after a period of slowdowns in the 80's, another new golden era started with using logistic data mining and medical diagnosis.[15]

To understand the importance of the artificial intelligence, first some definitions and aims should be mentioned:

Artificial Intelligence	Main objective is to offer a machine the ability to have its own intelligence. Put another way, AI aims for a machine to be able to learn through data, to solve problems by itself.
Machine learning (ML)	o The main backbone of AI. It depends on algorithms to predict outcomes based on data sets and draws influence from many research disciplines. o Its purpose is to facilitate machines to learn from data so they can resolve issues without human input. o The most commonly used techniques of ML include: - Support vector machine (SVM) - logistic regression (LR) - Naïve Bayesian classifier - Decision tree (DT) - Random forest (RF) - Extreme learning machine (ELM) - Fuzzy k-nearest neighbour (FKNN) - Convolution neural network (CNN)

Neural networks	Set of algorithms that calculate signals through artificial neurons that try to imitate the functioning of human neurons.
Deep learning	An integral part of ML. It uses networks with different computer layers in deep neural networks to analyze input

Artificial Intelligence in medicine

AI related to medicine has two main branches: physical and virtual.[15] The virtual one is concerned with informatics approaches from deep learning information management to control of health management systems, including active guidance of physicians in their treatment decisions based on the electronic health records. The second is the physical branch which is best represented by robots used to assist the elderly patient or the surgeon.[15] AI helped in different problems as detection of atrial fibrillation, hypoglycemia, epileptic seizures, and in the diagnosis of diseases based on histopathological examination or medical imaging.[4] The implementation of augmented medicine is long-awaited by patients because it allowed for a greater autonomy and a more personalized treatment plan. Unfortunately, it was met with resistance from physicians who were not prepared for such an evolution in the clinical practice.(Briganti and Le Moine, 2020)[4] This phenomenon also creates the need to validate these modern tools through traditional clinical trials, debate the educational upgrade of the medical curriculum in light of digital medicine as well as ethical consideration of the ongoing connected monitoring.

a- In Cardiology:

The early detection of atrial fibrillation was one of the first applications of AI in medicine. AliveCor received the FDA approval in 2014 for their mobile application Kardia. This application allows for a smartphone-based ECG monitoring and detection of atrial fibrillation. [4] Apple also obtained another FDA approval for their Apple Watch 4 that helps in easily acquiring ECG and detection of atrial fibrillation that can be shared with the practitioner of choice through a smartphone.[4] This was published in American Heart Journal, (Turakhia *et al.*, 2019). The Apple Heart Study is a prospective, single arm pragmatic study that has enrolled 419,093 participants, The primary objective is to measure the proportion of participants with an irregular pulse detected by the Apple Watch (Apple Inc, Cupertino, CA) with AF on subsequent ambulatory ECG patch monitoring. The results of this trial will provide initial evidence for the ability of a smartwatch algorithm to identify pulse irregularity and variability which may reflect previously unknown AF. The Apple Heart

Study will help provide a foundation for how wearable technology can inform the clinical approach to AF identification and screening.[43]

Artificial Intelligence shared with great success during the Covid-19 pandemic (Haleem *et al.*, 2021), it allowed the cardiologists to digitally check a patient's report without even visiting clinics/hospitals to avoid COVID-19 infection. The patient can take consultation through an app, saving time by reducing unnecessary hospital visits during the COVID-19 pandemic. This technology uses complex algorithms for the analysis of complex medical data.[14] AI helps to identify the vital signs regarding heart disease. It is used to identify the disease history and provide proper medication for the treatment. The applications of AI are also for cardiovascular imaging using electronic health records. It has the potential to demonstrate its performance for the medical task to improve diagnosis, prognosis, and efficiency. [14]

Applications of Artificial Intelligence in cardiology during COVID-19 pandemic: [14]

1- Analyzing heart anatomy of COVID-19 patients: Doctors can precisely analyze heart scans to classify the heart's anatomy in addition to the capability for the analysis of echocardiograms in a comprehensive way. Providing different Analyses of cardiac ultrasound (Cheema *et al.*, 2021) from different angles, can help to identify the diagnostic problem. [14][5]

2- Detection of arrhythmias of COVID-19 patients: Researchers have used AI to identify the abnormalities in heart rhythm and design improved procedure for better treatment. It is efficient to predict electrocardiogram and examine the irregular heartbeat and risk of death.[14]

3- Analyzing blood pressure: Detect the amount of blood flowing in and out of the heart, Analyze the symptoms of increasing and decreasing blood pressure, Reduces the risk of heart failure, kidney failure, and risk of heart attack.[14]

4- Oxygen saturation: To identify the asthma disease and increase the potential of doctors to identify the oxygen-related problem.[14]

5- Heart rate detection and analysis: Used to detect the problem occurs during congestive heart failure

6- Predicting heart attack[14][26]: (Mendes *et al.*, 2015) It helps to predict the chances of a heart attack from previous COVID-19 patient data. During blockage in a heart valve, it aware of heart attack chances. Identify the image pattern of heart attack and accurately predict its occurrence. It embraces the personalized and precise care of heart patient by providing proper information on the heartbeat.

7- Analysis of blood flow rate [14]: It helps reduction in the risk of sudden cardiac death. Successfully used for computational fluid dynamics to assess the impact of the blockage on blood flow. Eliminating the various testing of any blockage in the heart. Artificial intelligence model (Goto *et al.*, 2019) provides information to select patients who need urgent revascularization from only 12-leads electrocardiogram in those visiting the emergency room with chest discomfort. [13]

8- Providing proper information and medication for COVID-19 patient [14]: The proper information is quickly provided during an emergency case to make the doctor job easy by Checking day to day improvement of the COVID-19 patient. It automatically prepares for substantial risks and required actions for the clinical recordkeeping of patients.

b- In Pulmonary Medicine [4][42]:

The interpretation of pulmonary function tests (PFTs) to diagnose respiratory diseases is built on expert opinion that relies on the recognition of patterns and the clinical context for detection of specific diseases. A study was conducted (Topalovic *et al.*, 2019) to compare the accuracy and variability of pulmonologists when interpreting PFTs compared with artificial intelligence (AI)-based software that was developed. It was concluded that AI-based software provides more accurate interpretations and may serve as a powerful decision support tool to improve clinical practice.

c- Endocrinology [4]:

It is important for diabetic patients to monitor their glucose levels continuously. Medtronic received FDA approval for their Guardian system for glucose monitoring, which is smart phone paired. In 2018, the company partnered with Watson (AI developed by IBM) for their Sugar.IQ system to help their customers better prevent hypoglycemic episodes based on repeated measurement.

d- Neurology [4][37]:

Intelligent seizure detection devices are promising technologies that have the potential to improve seizure management through permanent ambulatory monitoring (Regalia *et al.*, 2019). Empatica received FDA approval in 2018 for their wearable Embrace, which associated with electrodermal captors can detect generalized epilepsy seizures and report to a mobile application that is able to alert close relatives and trusted physician with complementary information about patient localization. Also, Wearable sensors have proven useful to quantitatively assess gait, posture, and tremor in patients with multiple sclerosis, Parkinson disease, Parkinsonism, and Huntington disease.(Dorsey *et al.*, 2018)[9]

e- Delivering drugs to tumors, organs and tissues [15]:

It is encouraging to learn of the recent development of nanorobots designed to overcome delivery problems that arise when difficulty of diffusion of the therapeutic agent into a site of interest is encountered. This problem occurs when the therapist is attempting to target the core of a tumor which tends to be less vascularized, anoxic, but most proliferatively active. This was done by (Felfoul *et al.*, 2016) using Magneto-aerotactic bacteria delivering drug-containing nanoliposomes to tumour hypoxic regions.[11]

Artificial Intelligence (AI) in Dentistry

It was introduced in dentistry to be used in innovative research and development in addition to facilitating the decision support system and ensure high patient care quality.

It was previously mentioned in systematic review by Chen, Stanley and Att, 2020 [7] where artificial intelligence is used in Oral Medicine in 1995 Speight et al., for the assessment of risk of oral cancer. In 2018, AI was used in periodontics by Lee *et al.*, 2018 for Diagnosis and prediction of periodontally compromised teeth [20]. Also, Feres *et al.*, 2018 [12] used it in differentiation between aggressive and chronic periodontitis.

In the field of Orthodontics, many studies previously mentioned the idea of artificial intelligence showing very promising results and high degree of reliability. Example of those studies will be mentioned in this section.

Artificial Intelligence (AI) in Orthodontics

AI has been used in different domains in orthodontics like diagnosis, treatment planning, Evaluation of treatment outcome-orthognathic surgery on facial appearance/ attractiveness and/or age perception, these points are mentioned clearly in the scoping review published by Bichu *et al.*, in 2021. [3]

The Application regarding Diagnosis and treatment planning:

a- For TMJ Osteoarthritis [9]

The purpose of this study by (Dorsey *et al.*, 2018) is to describe the methodological innovations of a web-based system storage, integration and computation of biomedical data, using a training imaging dataset to remotely compute a deep neural network classifier of temporomandibular joint osteoarthritis (TMJOA). The findings of this study demonstrate a comprehensive characterization of TMJ health and disease at clinical, imaging and biological levels using new flexible tools for a web-based system that provides a neural network-based classification of temporomandibular joint osteoarthritis.

a- For Orthodontic Extractions that will be discussed thoroughly in the next section.

b- For screening of osteoporosis from panoramic radiographs

Bone density changes through a textural and morphological feature analysis on a mandible through panoramic radiographs. So, the study of (Lee *et al.*, 2020) aims to evaluate the discriminating performance of deep convolutional neural networks (CNNs). It was concluded that deep learning-based assessment of panoramic radiographic images could be useful and reliable in the automated screening of osteoporosis patients [21].

Another study by (Hwang *et al.*, 2017) aiming to identify variables that can be used for osteoporosis detection using fractal dimension (FD) , strut analysis and the grey level co-occurrence matrix (GLCM) using multiple regions of interest, to develop an osteoporosis detection model based on panoramic radiography. The conclusion was that analysis of strut features in the endosteal margin area showed potential for the development of an osteoporosis detection model based on panoramic radiography. Dento-maxillofacial Radiology [16].

c- To assess maxillary constriction and/or impacted canines

Nieri *et al.*, 2010 applied Bayesian networks to evaluate the relative role and possible causal relationships among various factors affecting the diagnosis and final treatment outcome of impacted maxillary canines. It was useful to identify possible relationships among the variables considered for diagnosis and treatment of impacted canines [32].

Chen *et al.*, 2020 introduced a novel machine learning method and assessed maxillary structure variation in unilateral canine impaction for advancing clinically viable information through machine learning algorithm utilizing Learning-based multi-source IntegratioN frameworK for Segmentation (LINKS) was used with cone-beam computed tomography (CBCT) images to quantify volumetric skeletal maxilla discrepancies of 30 study groups. It was concluded that palatal expansion could be beneficial for those with unilateral canine impaction, as underdevelopment of the maxilla often accompanies that condition in the early teen years. Efficient and fast CBCT image segmentation will allow large clinical data sets to be analysed effectively [6].

d- Classification of skeletal patterns [33]

Niño-Sandoval *et al.*, 2017 wants to predict the mandibular morphology through craniomaxillary variables on lateral radiographs in patients with skeletal class I, II and III, using automated learning techniques, such as Artificial Neural Networks. The craniomaxillary variables used, showed a high predictability ability of the selected mandibular variables, this may be the key to facial reconstruction from specific cranio-maxillary measures in the three skeletal classifications.

e- Assessment for need for orthodontic treatment and/or prediction of treatment outcome [41]

Thanathornwong, 2018 developed a clinical decision support system to help general practitioners assess the need for orthodontic treatment in patients with permanent dentition by a Bayesian network (BN) as the underlying model for assessment. One thousand permanent dentition patient data sets were chosen from a hospital record system. The study was the first testing phase in which the results that was generated by the proposed system were compared with those suggested by expert orthodontists. The system delivered promising results; it showed a high degree of accuracy in classifying patients into groups needing and not needing orthodontic treatment.

b- For orthognathic surgery and orthodontic extractions [8]

Diagnosis and treatment planning are very important steps in the orthognathic surgery to reach successful treatment. The aim of this study by Choi *et al.*, 2019 was to develop a new artificial intelligent model for surgery/non-surgery decision and extraction determination, and also to evaluate the performance of this model. The success rate of the model showed 96% for the diagnosis of surgery/non-surgery decision, and showed 91% for the detailed diagnosis of surgery type and extraction decision. This study suggests the artificial intelligent model using neural network machine learning could be applied for the diagnosis of orthognathic surgery cases.

c- Prediction of orthodontic treatment outcome—class III M/O [2]

Auconi *et al.*, 2015 conducted a study to determine whether it is possible to predict Class III treatment outcomes on the basis of a model derived from a combination of computational analyses derived from complexity science, such as fuzzy clustering repartition and network analysis. Fuzzy clustering repartition was found to be usefully used to estimate an individualized risk of unsuccessful treatment outcome in Class III patients.

d- To assess airflow dynamics, predict upper airway collapsible sites and obstructive sleep apnea (OSA) [46]

OSA is a common sleep breathing disorder. With the use of computational fluid dynamics (CFD), this study by Yeom *et al.*, 2019 provided a quantitative standard for accurate diagnosis and effective surgery based on the investigation of the relationship between airway geometry and aerodynamic characteristics. Based on the computed tomography data from patients having normal geometry, 4 major geometric parameters were selected. A predictive model was created using Gaussian process regression (GPR)

through a data set obtained through numerical method. The overall Gaussian process regression model's mean accuracy was ~72%, and the accuracy for the classification of OSA was >80%.

e- To predict occurrence of obstructive sleep apnea (OSA) in patients with Down's syndrome [38]

It occurs frequently in Down syndrome patients with reported prevalence ranging between 55% and 97%. Sleep studies are uncomfortable, costly, and poorly tolerated by Down Syndrome patients. The aim of this study by Skotko *et al.*, 2017 was to construct a tool to identify individuals with Down Syndrome unlikely to have moderate or severe sleep OSA and in whom sleep studies might offer little benefit. The main outcome measure was the apnea-hypopnea index. Using Logic Learning Machine. The best model had a cross-validated negative predictive value of 73% for mild obstructive sleep apnea, 90% for moderate or severe obstructive sleep apnea and positive predictive values were 55% and 25%, respectively. The model included many variables from survey questions, patient's age, physical examination findings, medication history, anthropometric measurements and vital signs. With simple procedures that can be collected with minimal cost, the proposed model could predict which patients with Down Syndrome were unlikely to have moderate to severe obstructive sleep apnea and therefore may not need a diagnostic sleep study.

f- Selection of orthodontic appliance type of headgear [34]

A fuzzy model (Okan Akçam and Takada, 2002) that can precisely give choice of headgear type appropriate to the treatment of an orthodontic case was developed. The model was designed to calculate the degree of certainty for choosing whether low, medium or high-pull types of headgear is needed.

The application regarding Automated cephalometric landmarking and/or analysis and/or classification:

a- Lateral Cephalogram [19]

This investigation by Kunz *et al.*, 2020 aim was to create an automated cephalometric X-ray analysis using a specialized artificial intelligence algorithm. Comparing the accuracy of this analysis to the current gold standard (analyses performed by human experts) to evaluate the precision and clinical application of such an approach in orthodontic routine work. Results showed that there was no statistically significant difference between that automated analysis and the gold standard.

b- Frontal Cephalogram

Frontal cephalometric radiography is one of the most important diagnostic methods in orthodontics and maxillofacial surgery. It allows one to determine occlusion anomalies in the vertical and transverse planes and to evaluate the symmetry of the facial skeleton relative to the median plane. Also, the analysis of the position of the jawbone.

The aim of this study by Muraev *et al.*, 2020 was to develop an artificial neural network (ANN) for placing cephalometric points (CPs) on frontal cephalometry and to compare the accuracy of its performance against humans. The results showed that ANNs can achieve accuracy comparable to humans in placing cephalometric points, and in some cases surpass the accuracy of inexperienced doctors. [29]

c- CBCT Images

Manual landmarking is time consuming for some people and highly professional work. Although some algorithm-based landmarking methods was innovated. Some of them lack flexibility and may be susceptible to data diversity. The Automatic 3D landmarking model by Ma *et al.*, 2020 using patch-based deep neural networks for CT image showed that this CNN model could automatically finish landmarking in an average processing time of 37.871 seconds with an average accuracy of 5.785 mm. The study showed a promising potential to relieve the workload of the surgeon. [23]

Another study using Hybrid approach for automatic cephalometric landmark annotation on CBCT volumes by Montúfar, Romero and Scougall-Vilchis, 2018. This algorithm 2.51 mm mean localization error (SD, 1.60 mm) was achieved when comparing automatic annotations with ground truth. [28]

Assessment of growth and development by Cervical vertebra maturation [39]

Skeletal bone age assessment is a common clinical practice to understand growth disorders in children Spampinato *et al.*, 2017 tested several deep learning approaches to assess skeletal bone age automatically; the results showed an average discrepancy between manual and automatic evaluation of about 0.8 years. Moreover, it was the first automated skeletal bone age assessment work tested on a public dataset and for all age ranges, genders and races for which the source code is available, thus representing a baseline for future research in the field.

Evaluation of treatment outcome- orthognathic surgery on facial appearance/ attractiveness and/or age perception [35][36]

R. Patcas *et al.*, 2019) study aimed to use artificial intelligence to describe the impact of orthognathic treatment on facial attractiveness and age appearance.146 consecutive orthognathic patients were collected for this longitudinal retrospective single-center study. Orthognathic treatment had similarly a beneficial

effect on attractiveness in 74.7% especially after lower jaw surgery. This investigation illustrates that artificial intelligence might be considered to score facial attractiveness and apparent age in orthognathic patients.

Another study regarding facial attractiveness by Raphael Patcas *et al.*, 2019 targeting the evaluation of facial attractiveness of treated cleft patients and controls by artificial intelligence (AI) and to compare these results with panel ratings performed by laypeople, orthodontists, and oral surgeons. AI-based results were found to be comparable with the average scores of cleft patients seen in all three rating groups

Detection of activation pattern of tongue musculature

The tongue's deformation during speech can be measured using tagged magnetic resonance imaging, but there is no current method to directly measure the pattern of muscles that activate to produce a given motion.

Evaluation of temperature changes during curing for orthodontic bonding [1]

Aksakalli *et al.*, in 2014 conducted a study for the evaluation of different curing units and light-tip tooth surface distances on the increase of temperature that is generated during orthodontic bonding, using an infrared camera (IR) and artificial neural networks (ANN). The conclusion was that LED unit generate higher temperature changes than did the high intensity halogen (HQTH). The temperature increases during the orthodontic bonding with the increase of the exposure time. A shorter light-tip tooth surface distance leads to higher increase in temperature.

In this section orthodontic extraction/non-extraction and anchorage planning will be illustrated

1) Martina *et al.*, 2006 [25], Introduced the application of an intelligent computation approach to the support of the clinical decision making on orthodontic extractions is illustrated in this work. Artificial neural networks trained using cephalometric and orthodontic cast measurements can provide a valuable support in the extraction therapeutical option in orthodontics.
2) Xie, Wang and Wang, 2010 [45], conducted study aiming to construct a decision-making expert system (ES) for the orthodontic treatment of 200 patients between 11 and 15 years old to determine whether extraction is needed by using artificial neural networks (ANN). Specifically, discussing the factors that affected this decision-making process. It was concluded that ANN was effective and showed 80% accuracy.

3) Jung and Kim, 2016 [17], study was targeting to construct an artificial intelligence expert system for the diagnosis of extractions using neural network machine learning and to evaluate the performance of this model, 156 patients were included in the study. The success rates of the models were 93% for the diagnosis of extraction versus non-extraction and 84% for the detailed diagnosis of the extraction patterns.

4) Thanathornwong, 2018[41] assessed the need for orthodontic treatment using Bayesian-Based Decision Support System. The Bayesian decision support module consisted of relevant variables taken from treatment need indexes (IOTN, ICON, and DAI). These three indexes referred to the same variables focusing on anterior teeth, including overbite, anterior open-bite, diastema, anterior crossbite, anterior displacement, and anterior-posterior molar relationship. The proposed decision support system was evaluated by a comparison of the orthodontic treatment needs assessed by orthodontists with those assessed by the system. It achieved a high degree of accuracy in classifying patients into groups needing and not needing orthodontic treatment.
5) Artificial Neural Networks (ANN) are used by Li *et al.*, 2019 [22] to predict orthodontic treatment plans, including the determination of extraction and non-extraction, extraction patterns, and anchorage patterns. The accuracies of the extraction patterns and anchorage patterns are 84.2% and 92.8%. Since anchorage is important to reach target of extraction and maximum use of the extracted space. This article discussed the highest contributing factors in anchorage planning like curve of spee, Nasolabial angle, UL-EP
6) In 2020, Suhail *et al.*, [40] An expert system was developed that is able to reach suitable treatment decisions that can be valuable to clinicians for verifying treatment plans, minimizing human error, training orthodontists, and improving reliability. A number of machine learning models for this prediction task using data for 287 patients was evaluated independently by five different orthodontists. The benefits of this study that it does not only focus on this binary decision but also which specific tooth/teeth requiring extraction.
7) In 2021, Khanagar *et al.*, [18] published a systematic review aiming to document the scope and performance of the artificial intelligence-based models that have been widely used in orthodontic diagnosis, treatment planning, and predicting the prognosis. Artificial Intelligence (AI) technology has been widely applied for identifying cephalometric landmarks, determining need for orthodontic extractions, determining the degree of maturation of the cervical vertebra, predicting the facial attractiveness after orthognathic surgery, predicting the need for orthodontic treatment, and

orthodontic treatment planning. Most of these artificial intelligence models are based on either artificial neural networks (ANNs) or convolutional neural networks (CNNs). These systems can simplify the tasks and provide results in quick time which can save the dentist time and help the dentist to perform his duties more efficiently. These systems can be of great value in orthodontics.

Anchorage planning is fundamental factor for success of treatment specially when extraction decision was made. Many studies and textbooks discussed in details anchorage.

- In 2019, Li *et al.*[22] Discussed the factors related to decision making of Anchorage which were:

1- Curve of spee

2- Nasolabial Angle

3- UL- EP

- In 2016, Mandava, Ganugapanta and Pradesh [24], published a literature review entitled " Anchorage in Orthodontics" in which anchorage was discussed in details regarding;
  - Different Anchorage definitions according to Nanda and Proffit.
  - Different Anchorage Classifications according to Manner, Number of anchor units, Marcottee's Classification 1990 (*Group A, B, C*), Gianelly and Goldman 1971 (*Maximum, Moderate, Minimum Anchorage*).
  - Sources of Anchorage Intraoral sources as Alveolar Bone, Teeth, Basal Bone, Cortical Bone, Musculature,
  - Anchorage planning depends on the anchorage requirements:

1- Number of teeth to be moved

2- Type of teeth being moved

3- Type of tooth movement

4- Periodontal condition

5- Duration of tooth movement

6- Anchorage value: Anchorage value of any tooth is equal to its root surface area. Molar and 2nd premolar in each arch is approximately equal in surface area to incisors and canine

- In 2019, Nahidh, Am and Sc [30], published Understanding Anchorage in Orthodontics a Review Article in which different anchorage classifications were discussed in full details as:

I. According to the manner of force application:

1. Simple anchorage
2. Stationary anchorage
3. Reciprocal anchorage

II. According to jaws involved:

1. Intra-maxillary anchorage
2. Inter-maxillary anchorage

III. According to the site of anchorage:

1. Intra-oral anchorage
2. Extra-oral anchorage:

• Cervical
• Occipital
• Cranial
• Facial

3. Muscular anchorage

IV. According to the number of anchorage units:

1. Single or primary anchorage
2. Compound anchorage
3. Multiple or reinforced anchorage.

V. According to anchorage demands:

1. Maximum anchorage (Type A anchorage).
2. Moderate anchorage (Type B anchorage).
3. Minimum anchorage (Type C anchorage).
4. Absolute anchorage (direct and indirect anchorage).

Gardiner et al. classified anchorage into six categories as followed:

1. Simple
2. Stationary

3. Reciprocal
4. Reinforced
5. Intermaxillary
6. Extra-oral

- **Mitchell, 2017 [27] Chapter 15 Anchorage Planning**

  Anchorage was defined by the resistance to the unwanted movement, assessment of anchorage requirements was done in three planes of space vertical, horizontal and anteroposterior to reach maximum benefit according to certain points as follows:

1- Space requirements assessment either in crowding or spacing cases by proper space analysis, It was found that maximum anchorage is necessary when all the space of extraction during crowding is needed

* Overcrowding needs increase in the degree of anchorage as mentioned by Eduardo *et al.*, 2013 [15] in 1001 tips for orthodontics and its secrets book

2- Type of tooth movement to be achieved:

- There are six types of tooth movements well known in orthodontic field. Bodily movement is the one that needs more force than tipping movement and therefore more anchorage is needed.

3- Number of teeth to be moved:

- Increase in number of teeth to be moved, increases anchorage demand.

4- The distance of the movement required:

- Increase distance → Increase the anchorage required

5- Aim of treatment:

- If Complex and multiple teeth are to be moved → Increase in the anchorage demand

6- Root surface area:

- The larger the root surface area the greater the demand for anchorage

7- Growth Rotation and skeletal pattern:

- Patients with increased vertical dimension and backward growth rotation of mandible and high angled cases show increased rate of tooth movement and therefore space closure and anchorage loss occur more rapidly.
- Patients with decreased vertical dimension and forward growth rotation of the mandible due to their strong musculature show space loss and anchorage loss at slower rate.

- **Nanda, 2012 [31] in Biomechanics and Esthetics Strategies in Clinical Orthodontics book Chapter 10 (Biomechanic Basis of Extraction Space Closure) classified anchorage into 3 different groups summarized as the following:**

Group A	Group B	Group C
Posterior Segment Maintained in Position (75% of extraction space is needed for anterior retraction)	Symmetric space closure 50% - 50% ↓ Least difficult	Non-critical Anchorage 75% of space closure by movement of the posterior

In which Determinants of Space Closure are:

1- Amount of Crowding

2- Anchorage

3- Axial Inclination of canines and incisors

4- Midline discrepancies, left and right symmetry

5- Vertical dimension

- **(William R. Proffit, 2018) [44] in his book Contemporary Orthodontics Chapter 16**

Maximum Incisor retraction requires maximum anchorage control, the same basic approach is needed with any appliance when maximum anchorage is needed: increased reinforcement of posterior anchorage and decreased strain on that anchorage.

1- Reinforcement by lingual arch

2- Two-Step Frictionless Retraction: Individualized retraction of the canines with auxiliary springs before a second stage of incisor retraction with closing loops is an attractive method for reducing the strain on posterior anchorage

Retraction With Skeletal Anchorage

3- Skeletal anchorage for retraction of protruding incisors is the only way to close extraction spaces totally by retracting the incisor–canine arch segment. The major advantage of skeletal anchorage in retraction of the anterior segment is that if offers vertical as well as anteroposterior control of the teeth to create the desired display of the incisors.

The major disadvantage of skeletal anchorage for maximum incisor retraction in either arch is that it makes over-retraction of the incisor segments possible. The treatment objective is to improve the patient's dentofacial appearance and decrease social problems related to it.

Retracting the anterior teeth too much makes the patient look worse, not better, as lip support is decreased and the nasolabial fold is accentuated. This is more of a problem in Class II or Class III camouflage than correction of bimaxillary protrusion.

Other applications of skeletal anchorage, including distal movement of the entire dental arch to reduce incisor protrusion.

Skeletal anchorage, created by placing bone screws in either arch in the canine region, is the easiest and most effective way to close an extraction space by bringing posterior teeth forward. This is particularly advantageous when more forward movement is needed on one side than the other. In both minimum and maximum retraction, temporary anchorage devices (TADs) now make it much easier to handle what previously were very difficult situations.

7. Study objectives and hypotheses:

The aim of the study includes hypothesis

The program decisions will meet the decisions of the orthodontist in well finished cases in terms of extraction decision and anchorage planning

Objectives:

- To study the efficiency of the program decisions in terms of extraction/non-extraction
- Anchorage planning decisions

III. Methods:

A) Trial design

8. Data and records of previously treated patients at Cairo university and Future University will be collected from the archive before the index test is performed so that the decision support system will be constructed based on the given data

B) Participants:

9. Eligibility criteria:

Inclusion Criteria:

1- Cases with well finished orthodontic treatment.
2- Cases with history of crowding more than 10 mm and requiring extraction.
3- Cases with no severe skeletal discrepancy.
4- Well documented cases with both pre-operative and post-operative records.
5- Patients with a full set of permanent teeth erupted

Exclusion Criteria:

1- Improperly finished orthodontic cases.
2- Cases with mild crowding managed by treatment options other than extraction.
3- Growing patients or showing any residual growth remaining in cephalometric analysis
4- Cases with severe skeletal discrepancy.
5- Poorly documented cases.
6- Patients not sticking to anchorage plan

10. On what basis potentially eligible participants will be identified:

Recruiting well finished cases having history of crowding from Kasr el Ainy with no severe skeletal discrepancy, cases should be well documented. The precise and complete documentation of the patients in terms of the presence of:

(1) Preoperative and postoperative x-rays.

(2) Good quality preoperative and postoperative photographs.

(3) Preoperative and postoperative study models.

(4) Detailed documentation of the treatment sequence and mechanics. If there were incomplete data provided in the patient's file; the patient will then be excluded from the study.

11. Where and when potentially eligible participants will be identified (setting,

location and dates)

Recruiting patients from Kasr El Ainy – Cairo University, future university archive with their specific eligibility criteria once the paper work is approved

12. Whether participants formed a consecutive, random or convenience series:

Any Patient that passes the inclusion criteria in terms of file including patient full records, Mechanics used were well registered and the case was well finished based on that the patient will be enrolled.
No subdivisions will be done

C) Test method:

13. Index test & reference standard in sufficient detail to allow replication

A- The Preanalystical Phase:
Patients should have finished their orthodontic department at Cairo University with full Records available

B- The Analytical Phase:
Experts will analyze the outcome resulting from decision support system regarding extraction or non-extraction and anchorage planning and whether it is comparable to those conventional decisions reached by the orthodontic clinicians during treatment planning

C- Postanalytical Phase: Calculation of the efficiency of the system

14. Rationale for choosing the reference standard

Conventional Decisions (Decisions made by Orthodontic Clinicians) concerning extraction or non-extraction and anchorage planning for well finished cases

15. Definition and rationale for test positivity cut-offs of the index test & reference standard:

The study will test the efficiency of the decision support system according to those by the Orthodontic Clinicians

16 a. Clinical information and reference standard results will be available to the performers of the index test

Index test performers will be blinded

16 b. Clinical information and index test results will be available to the assessors of the reference standard

The assessors will be blinded from the treatment mechanics and results

D) Statistical analysis

17. Methods for estimating or comparing measures of diagnostic accuracy

Co-relation analysis will be used to compare the outcomes of both methods (conventional & computerized) Statistical analyses will be performed using SPSS (version 22.0; IBM Corp, Armonk, NY). More than 1 type of statistical analysis will be used to address the outcomes. Cohen's kappa coefficient will be used to measure the agreement between the 2 methods on the basis of choice of the same options without consideration of the value assigned to each option (qualitative data). If a value were assigned to the option, it would be given 1, and if it were not assigned, it would be given 0. Cohen's kappa coefficient is a more robust method than simple percentage agreement, and its value dictates the strength of agreement (\0.20, poor; 0.21-0.40, fair; 0.41-0.60, moderate; 0.61-0.80, good; and 0.81-1.00, very good.

The concordance correlation coefficient would be used to measure the agreement between the 2 methods on the basis of the values (%) assigned for each treatment option by the 2 methods (quantitative data).

A value of ≥1, corresponds to perfect agreement; ≥ 0.8, very good; ≥0.7, good; ≥0.5, moderate, ≥0.4, fair; ≥0.3, poor; and 0, no agreement.

The sum of absolute difference and the relative sum of absolute difference were used to measure the percent error between the 2 methods on the basis of the values assigned for each treatment option (quantitative data).

18. How indeterminate index test or reference standard results will be handled:

It is not applicable as the outcome will be based on decisions made by the program

19. How missing data on the index test and reference standard will be handled

Any Patient file with incomplete data will not be included from the beginning in the study

20. Sample size calculation and how it was determined

Sample size is being calculated and waiting for approval

IV. Ethics and dissemination

21. Research ethics approval

This protocol will be reviewed by the Ethics Committee of Scientific Research –Faculty of Oral and Dental Medicine Cairo University

22. Protocol amendments

Any modification to the protocol which may have an impact on the conduct of the study, potential benefit of the patient or may affect patient safety will require a formal amendment to the protocol. Such amendment will be agreed upon by the Council of orthodontic Department.

23. Informed consent

Template will be reviewed by the Ethical committee and will be signed by the patients or their legal guardians

24. Confidentiality

All study-related information will be stored securely by the personnel conducting the study

25. Declaration of interest

There is no conflict of interest

26. Access to data

Supervisors, master candidate and programmer will have access to the final trial dataset.

27. Dissemination policy

- The study results will be published as partial fulfilment of the requirements for Master degree in orthodontics
- Topics suggested for presentation or publication will be circulated to the authors.

V. Appendices

28. Informed consent

Not applicable

29. Biological specimens

Not applicable

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