TREND ACADEMIC STUDIES IN HEALTH SCIENCES

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CONTENT

The Importance of Mental Health in Adolescents and the Roles of Nurses

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ABSTRACT

Mental health in adolescents has recently been a concept that has been emphasized. It has been determined that adolescents with high mental health cope more successfully with poverty, violence, illness and many other stressful life events. It has also been emphasized that these individuals have positive characteristics such as effective problem-solving ability and effective interpersonal communication skills. Studies have shown that adolescents who have experienced similar negative events and failed will more easily overcome the problems they encounter or will be able to get rid of these stresses with minimal damage. This article reviews the importance of nursing in adolescent mental health.

Keywords – Mental Health, Adolescent, Nurses, Roles, Importance.

INTRODUCTION

The concept of psychological resilience is derived from the Latin root "resilire "(WHO, 2001) and resilient means flexible Ramirez**3** defines psychological resilience as being resilient to illness, the ability to recover quickly from depression, changes or bad situations; the ability to bounce back; the ability to bounce back easily after being hurt or strained; resilience. Psychological resilience, despite very difficult circumstances, the person's ability to successfully overcome and adapt to these adverse conditions ability. Although it is defined as an ability and a psychological quality, psychological contributing to the maintenance of resilience, healthy development, and dealing with a negative situation to be able to cope with the situation when confronted with it (Dawes, 1997).

Adolescent mental health, ideal psychological health and the capacity to have and maintain function (Masten and Gewirtz, 2008; Ramirez, 2007)**.** Spiritually good children and adolescents with positive identity and self-worth developed a sense of healthy interpersonal relationships initiate, develop, sustain, and benefit from this relationship can provide satisfaction; they are self-confident and assertive, productive and capable of learning; self-directed is aware of and empathizes with others; coping with developmental challenges and maximizing growth using cultural resources to maximize capacity (Masten, 1998). It can be seen in this period mental disorders interfere with normal development and to help adolescents reach their ideal functioning can prevent it.

Adolescent mental health (When epidemiological studies are examined; World Health Organization (WHO) Mental Health Report (2017), the prevalence of mental disorders among children varies between 10% and 20% in different countries and only 25% received professional help (Gizir, 2007). In addition, mental health problems approximately 50% started before the age of 14 emphasized (Gizir, 2007; Gürgan, 2006).

RISK FACTORS IN ADOLESCENT MENTAL HEALTH AND PROTECTIVE FACTORS

Individual risk factors; include fetal alcohol/drug use, adolescent pregnancy, premature birth, having a disagreeable temperament or shy personality, low IQ, chronic or mental illness, substance abuse, academic failure and belonging to an ethnic group. Protective factors that protect the individual against these risk factors when faced with stress and are rooted in the individual are a good level of intelligence/cognitive ability, a positive perception of academic competence, high self-esteem, planning for the future and being optimistic, having control over one's own life, having a sense of humor and effective problem-solving skills, empathy, responsibility and a sense of helpfulness.

Familial risk factors; include having a large family with at least four children, having less than 2 years between two children, having a parent with a mental/chronic illness, having a parent who uses substances or has committed a crime, being adopted, divorce or death of parents or having a single parent, and being exposed to familial violence. In contrast to these risk factors, familial protective factors include positive mother-child relationship, positive expectations for the future of children, living with the family, and having well-educated parents.

Environmental risk factors; include low socio-economic status, physical and sexual abuse, poverty, homelessness, child neglect, malnutrition, negative peer support and exposure to social violence. Environmental protective factors include having a positive relationship with an adult, positive social support, positive school relationships, positive peer support and having a positive role model (Freser and Jenson, 2008; Pienaar, 2008; Gizir, 2007;. Hetherington and Stanley-Hagan, 1999).

*D*eteriorating mental health, of a coercive nature or potentially harmful social conditions in society by targeting reducing the incidence of mental disorders, reveal the social conditions that cause mental illness extraction, recognition, stress-inducing and potentially neutralize harmful etiological causes and how to fight them, how to mobilize society stimulation and education (Offord et.al., 1998).

THE IMPORTANCE OF MENTAL HEALTH IN ADOLESCENTS AND THE ROLES OF NURSES

Nursing is particularly important in terms of community mental health nursing. When we look at the risk factors and protective factors mentioned, we can say that risk factors can be controlled and individuals can be protected from psychiatric diseases with a good community mental health service at a protective level. Organizing the family and environmental environment in which the individual is located in a way that contributes to the development of the individual brings about a healthy and normal development process. These arrangements include constructive solutions to problems experienced in the family environment. These may include practices such as developing interpersonal communication skills, teaching effective problem-solving skills and using them in the face of problems and strengthening coping methods, reducing domestic violence, growing up in an environment of love and supporting the child as an individual. If the family and environmental environment is in a situation that will negatively affect the child's development, the child will continue to be an unhealthy individual in adulthood. On the contrary, when individual, familial and environmental characteristics are developed in a way that will adapt to and overcome life stressors, children and adolescents will have taken great steps towards becoming biopsychosocially healthy adults (Stout and Kipling, 2008; Freser and Jenson, 2008; Daniel, 2006).

Despite significant progress in adolescent mental health, the mental health needs of many adolescents are still not being met. Childhood and adolescence are special developmental stages affected by environmental factors. Considering that mental problems experienced during childhood and adolescence can continue into adulthood and reduce productivity, it is important and necessary to prevent problems before they occur. The need for CERS nurses is increasing in the world and in our country. Nurses trained in this field are important in determining risky children and planning early interventions, and in developing the mental health of children and adolescents. In our country, “Child and Adolescent Psychiatric Nurse” was accepted as a sub-branch of psychiatric nursing in the Regulation on Amendments to the Nursing Regulation published in 2011. In this context, the duties, powers and responsibilities of the "Child and Adolescent Psychiatric Nurse" are stated as "nursing care, education and counseling" in addition to the general duties, powers and responsibilities of a nurse. Considering that preventive programs that provide good evidence in child and adolescent mental health are focused on education and counseling, a multidisciplinary approach should be adopted in this area (Rew et.al., 2001; Vance and Sanchez, 1998).

Psychiatric nurses can support individuals in their positive psychological development and in fulfilling the developmental functions of their age in a healthy way, starting from childhood to adulthood and old age, by providing community mental health services. While some individuals need help with issues such as supporting the family environment and establishing positive parent-child relationships, others may need personal support in issues such as self-esteem and effective coping skills. These individuals should be identified at an early age, and their self-awareness should be increased. Because knowing oneself can help a person realize their strengths and weaknesses, thus supporting their strengths and developing their weaknesses (Cho and Shim, 2013; Song et.al., 1998). It is important to identify individuals with substance addiction, adolescent pregnancy, chronic or mental illness, neglect or abuse, large families, those who have had to migrate, experienced death, separation, illness, low socio-economic status or families with violence early and support them towards positive spiritual development. For this purpose, guidance and counseling can be provided to these individuals and families on issues such as gaining skills to effectively cope with problems and receiving the necessary institutional assistance (Avedissian and Alayan, 2021; Carapia-Fierros and Tapia-Pancardo, 2021).

CONCLUSION AND RECOMMENDATIONS

The deterioration of adolescents' mental health has increased. Therefore, considering the socio-geographic structure of our country, it is important for individuals to have high levels of psychological resilience. In order for nurses to effectively combat the problems they encounter and to protect their own mental health in the face of these problems, it is important that they first have a strong psychology themselves and then contribute to the psychological resilience of adolescents in society.

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Electrochemical sensor development for cysteine quantification with a PEDOT/ERGO/PB-modified Au electrode

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ABSTRACT

Cysteine, a sulphur-containing amino acid, plays a crucial role in metabolic pathways such as remethylation and transsulphuration. Abnormal cysteine levels in biological systems are associated with several diseases, including cardiovascular, neurological and renal disorders. This study focuses on the development and validation of an electrochemical sensor using a PEDOT/ERGO/PB modified Au electrode for cysteine detection. The electrochemical properties of cysteine were analysed using cyclic voltammetry, which revealed an anodic peak at 807 mV in 0.1 M phosphate buffered saline (pH 7.0). The sensor showed a linear response in the range of 10 to 500 μM with a high correlation coefficient, demonstrating high sensitivity and selectivity. The limit of detection (LOD) was determined to be 2.6 μM, ensuring the sensor's ability to detect low concentrations of cysteine. The relative standard deviation (RSD) was less than 3.53% and the relative error (RE) was within ±1.08%, confirming the high accuracy and precision of the method. This study presents a biosensor-based electrochemical The amperometric response of the modified electrode showed high reproducibility and stability, with a relative standard method for cysteine quantification that provides a rapid, cost-effective and highly sensitive alternative to conventional analytical techniques. The application of the PEDOT/ERGO/PB modified electrode in biomedical and clinical diagnostics is further supported by its enhanced electrocatalytic activity.

Keywords – Cysteine • Graphene • Poly(3,4-Ethylenedioxythiophene) • Prussian Blue • Reduced Graphene Oxide.

INTRODUCTION

Cysteine (2-amino-3-sulfanylpropanoic acid) is found in. When methionine is present, they are synthesized in the body and are therefore not considered essential amino acids (Chu et al., 2022:1; Tajik et al., 2021:5411). During this transformation, homocysteine, an essential the protein structure amino acid, is also formed (Yuan et al., 2021:1). Cysteine is required for the synthesis of CoA and glutathione. It is possible to prevent and diagnose various diseases by using cysteine and homocysteine levels as biomarkers. Scientific studies have suggested that cysteine levels can be used as a biomarker in obesity neurological disorders such as Alzheimer's and Parkinson's and various types of cancer (Martinez-Banaclocha, 2022:416; Rehman et al., 2020:4696).

Researchers have suggested that cysteine has an antioxidant effect by neutralizing radicals in the cell plays a role in cell proliferation and is involved in protein synthesis (Martinez-Banaclocha, 2022:416). Therefore, determining the amount of the sulfur-containing amino acid, cysteine, is important. Numerous analytical methods have been developed for the determination of cysteine. These include UV-visible spectrophotometry (Abbaspour and Mirzajani, 2006:791; Xiao et al., 2011:211; Xiao et al., 2012:650), calorimetric method (Chen et al., 2014:673; Niu et al., 2015:30363), spectrofluorometric method (Hu et al., 2021:114138; Mei et al., 2012:17063; Xiao et al., 2012:650), X-ray absorption spectrophotometry (Tamhankar et al., 2024:4263), high-pressure liquid chromatography (Kubát et al., 2024:117751).

Compared to other analytical aspects of electroanalytical methods, it is preferred because it does not require preliminary preparation, has low cost, and offers high speed. Cysteine is considered an electroactive molecule, but the measurement accuracy is reduced due to oxide formation and contamination of the electrode surface. The electrodes are modified in various ways to provide higher sensitivity. There are studies in which various sensors have been modified for the electrochemical detection of cysteine.

Electroanalytical methods are preferred over other analytical techniques due to their minimal pre-preparation requirements, cost-effectiveness, and high speed (Dragancea et al., 2010:47). Cysteine is considered an electroactive molecule, but its modification is often necessary to enhance sensitivity due to reasons such as oxide formation and electrode surface contamination. There are various studies in which sensors have been modified for the electrochemical detection of cysteine (Hashemi et al., 2016:286; Khalilzadeh et al., 2015:1766). In these studies, the studies using carbon paste electrodes can be examined under three titles. In the first title, there is the square wave voltammetry method using the electrodes modified with 8,9-dihydroxy-7-methyl-12H-benzothiazole[2,3-b]quinazolin-12-one and zinc oxide nanoparticles (Khalilzadeh et al., 2015:1766), zeolite electrode modified with iron (II) nanoparticles (Hashemi et al., 2016:286), MnO_2-TiO_2 nanocomposite, 2-(3,4-dihydroxyphenethyl) isoindoline-1,3-dione (Bananezhad et al., 2018:1767) and ethyl 2-(4-ferrocenyl-[1,2,3]triazol-1-yl) acetate (Beitollahi et al., 2020:107302). In the second title, there are studies where the modification with MgO nanoparticles (Gupta et al., 2018:4309) and 14-(4-hydroxyphenyl)-14-H-dibenzo[a,j]-xanthene (Benvidi et al., 2015:3920) is conducted using the differential pulse voltammetry method. In the third title, studies with the modification of the carbon paste electrode based on the cyclic voltammetry method have been conducted using various materials such as Fe_2O_3 nanoparticles (Yang et al., 2015:3613), nitrogen-doped graphene oxide Y_2O_3 nanoparticles (Yang et al., 2016:1351), graphene oxide nanoparticles (Qu et al., 1900), nickel oxide nanoparticles (Yang et al., 2017:834), Co-La oxides (Yang et al., 2021:157077), green-synthesized CuO nanostructures (Zaeifi et al., 2022:107969), Co_3O_4 nanocomposites/benzoyl ferrocene/ionic liquid (Mohammadnavaz et al., 2023:121340) and modified with silver-copper sulphide (Khamcharoen et al., 2022:122983). spherical silver nanoparticles located on reduced graphene oxide (Hua et al., 2024:1789), L-threonine on helical carbon tubes (Su et al., 2024:16780), and cobalt CNT-modified glassy carbon electrodes (Kivrak et al., 2024:2798).

Disposable sensors are used in addition to carbon paste electrodes. In the literature review, four studies using disposable sensors were found. Disposable sensors offer advantages such as convenience, cost-effectiveness, and ease of use, making them suitable for various electrochemical detection applications. Disposable electrodes have been developed for studies using CO(II)-phthalocyanine nanoparticles (Hernández-Ibáñez et al., 2017:77), cyclodextrin-platinum nanoparticles (Singh et al., 2018:230), CeO_2 nanoparticles (Cao et al., 2018:1133) and for the detection of cysteine using copper-coated gold electrodes (Kurniawan et al., 2019:318). However, a literature search has not revealed any studies on the co-deposition of PEDOT (poly(3,4-ethylenedioxythiophene)), a highly conductive and oxidation-resistant polymer, with the redox polymer prussian blue (PB) to achieve a significant electrocatalytic effect. Additionally, there is no existing research on the selective determination of cysteine using cyclic voltammetry and amperometry methods with a modified Au electrode incorporating PEDOT/ERGO/PB composites.

This study aims to address this gap by exploring the selective determination of cysteine using cyclic voltammetry and amperometry methods with a modified Au electrode incorporating PEDOT/ERGO/PB composites. The development of this method promises significant improvements in sensitivity and selectivity for cysteine detection, thereby contributing valuable insights to the field of electrochemical sensors.

EXPERIMENTAL

Materials

The 3,4-ethylenedioxythiophene (EDOT), graphene oxide (GO) (2 mg GO/1 mL H_2O suspension), KNO_3, NaH_2PO_4, Na_2HPO_4, $K_3[Fe(CN)_6]$, $FeCl_3$, KCl, $HClO_4$, and cysteine were purchased from Sigma-Aldrich, USA.

Analytical Method Conditions

Voltammetric measurements were performed using a three-electrode cell system, which included a platinum wire counter electrode and an Ag/AgCl (saturated KCl, 3M) electrode as reference electrode, and the working electrode, a PEDOT/ERGO/PB-modified Au electrode, with a BAS 100W potentiostat. Voltammetric measurements were performed using the cyclic voltammetry method with a potential range of 0 to 1600 mV and a scan rate of 100 mV. Voltammograms were obtained by plotting the peak current values against the potential at which the active species of cysteine underwent oxidation/reduction. The electrochemical performance of the

PEDOT/ERGO/PB-modified Au working electrode was determined using the amperometric technique.

For the analytical characterization of electrochemically synthesized PEDOT/ERGO/PB nanostructures, X-ray photoelectron spectroscopy (XPS, Specs-Flex) and energy dispersive spectroscopy (EDS, adapted to the electron microscope) techniques were utilized. Additionally, morphological characterization was conducted using field emission scanning electron microscopy (FE-SEM, Zeiss Sigma 300).

Modification of Au Electrode with PEDOT/ERGO/PB Composite

Initially, the Au surface was modified with PEDOT by applying a fixed potential of +1.3 V for 30 seconds in an electrolyte containing the EDOT monomer. The prepared PEDOT-modified electrode was then immersed in a solution composed of suspensions 0.1 M KNO_3 and 2 mg/L GO, and subjected to electrochemical reduction at a fixed potential of -1V for 40 minutes to facilitate the formation of the EDOT film on the PEDOT surface. Finally, the synthesized PEDOT/ERGO electrode was used for the synthesis of the layered ternary composite structure by performing a deposition process for 2 minutes at a fixed potential of +0.6 V in solutions containing suspensions 5mM $K_3[Fe(CN)_6]$, 5mM $FeCl_3$ and 0.1M KCl.

Preparation of Solutions Used in the Experiments

A 1000 µM stock solution of cysteine and a 0.1 M Na_2HPO_4 solution were prepared with 0.1 M phosphate buffered saline (PBS), and additionally, a 3M $HClO_4$ solution was prepared using deionized water. All prepared solutions were stored at -20°C. To prepare working solutions of cysteine, 500 µL of a water sample was placed in an Eppendorf tube, and appropriate concentrations of cysteine solutions were added to achieve a final concentration of 10-500 µM, followed by incubation of the mixture. Quality control solutions were prepared similarly, with final concentrations of 20, 100 and 400 µM for cysteine, using appropriate concentrations of cysteine solutions. This mixture was also incubated. Afterward, the mixtures were cooled, and 250 µL of a 3 M $HClO_4$ solution was added. The mixtures were centrifuged for 10 minutes. From the obtained supernatant, 100 µL was added to a 3-electrode cell containing 10 mL of a 0.1 M PBS solution for analysis using the voltammetry method. For the preparation of 0.1 M PBS buffer solution, 3.54 g Na_2HPO_4 and 3.42 g NaH_2PO_4 were weighed and placed in a 250 mL volumetric flask. Deionized water was added to dissolve the substances The pH was adjusted to 7 using a pH meter, and the volume was completed to 250 mL with deionized water.

Determination of Optimizing Voltammetry Method Conditions

To perform voltammetric analysis of cysteine, its response was investigated using different buffer solutions (phosphate, acetate, Britton-

Robinson) at various pH levels and solvents. Cysteine solutions were prepared at 50 μM concentration, and peak current values were measured for each solution. The optimal potential and solution environment for the best cysteine oxidation were determined based on the observed peak current.

RESULTS AND DISCUSSION

One-pot the Electropolymerization of PEDOT/ERGO/PB Composite

The XPS technique was employed to analyze the surface composition of the PEDOT/ERGO/Pb composite deposited on an Au substrate (Figure 1a-e). The XPS spectrum (Figure 1a) confirms the presence of C, Fe, S, N, and O elements within the composite structure. Further insights into the valence states of these elements were obtained from the high-resolution XPS spectra of S 2p, N 1s, Fe 2p, and C 1s (Figure 1b-e).

As depicted in Figure 1b, PEDOT exhibits distinct spin-split doublet peaks, originating from its thiophene ring, observed at 163.9 eV (S 2p3/2) and 167.5 eV (S 2p1/2). The energy splitting of 1.1 eV suggests PEDOT formation, consistent with previous literature (Eryiğit et al., 2020:116488). Figure 1c presents the C 1S XPS spectra of the PEDOT/ERGO/PB composite in comparison with purchased GO, facilitating an evaluation of their electroreduction properties. Notably, the oxygen signal in the purchased GO sample exceeds the carbon signal, indicating a higher concentration of oxygen-containing functional groups.

The deconvoluted sp^2 peak of C 1s is centered at 284.8 eV, with additional peaks observed at 284.8, 286.4, and 288.5 eV, corresponding to C-C/C=C, C-O-C, and O=C-O species, respectively. The oxygen-containing functionalities in ERGO were found to have significantly weaker intensities compared to those in GO, suggesting that the electrochemical reduction process successfully eliminated a substantial portion of these oxygen groups (Doğan et al., 2013:54). In addition, the 286.7 eV peak is related to the C-S bond in PEDOT (Eryiğit et al., 2020:116488).

In Figure 1d, the high-resolution N1s spectrum reveals three distinct peaks at 397.2, 399.5, and 402.1 eV, which correspond to the Fe-C≡N bonds of PB cubes, confirming the successful deposition of PB onto the PEDOT/ERGO surface (Eryiğit et al., 2019:905). Lastly, Figure 1e illustrates the Fe 2p spin-orbit doublet, where Fe 2p3/2 and Fe 2p1/2 peaks appear at 711.3 eV and 721.2 eV, respectively, representing Fe^{3+} ions. Additionally, a peak at 708.2 eV corresponds to $[Fe(CN)_6]^{4-}$ Fe^{2+} 2p3/2, further supporting the formation of PB (Zhu et al., 2019:9420).

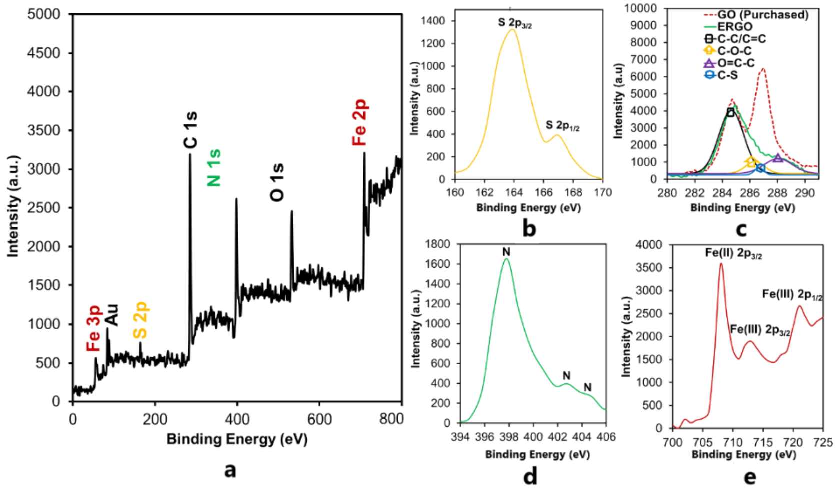


Figure 1: XPS spectra of PEDOT/ERGO/PB composite modified on Au; (a) overall spectrum, (b) S 2p, (c) C 1s, (d) N 1S, and (e) Fe 2p

Figure 2 a-c shows FE-SEM images taken to study the surface morphology of PEDOT, PEDOT/ERGO, and PEDOT/ERGO/PB electrodes modified on Au electrode. In Figure 2a, it is observed that PEDOT modified on Au electrode grows in the form of an interwoven nanowire with micro pores (Teng et al., 2013:7219). When the FE-SEM image taken for the Au-PEDOT/ERGO electrode is examined (Figure 2b), it is clearly seen that ERGO was successfully electrochemically reduced on Au-PEDOT and as a result, ERGO modified the Au-PEDOT electrode with its crumpled paper-like morphology. The FE-SEM image of the PEDOT/ERGO/PB nanocomposite shows that high-quality cubic PB nanocrystals with regular cubic shape and dimensions of about 60-70 nm grew on the PEDOT/ERGO electrode and were covered by ERGO sheets (Figure 2c). Since PB nanocube formation on ERGO is locked by Fe^{3+}, OOH groups and PB crystals nucleate in the parts where ERGO is reduced, PB nanostructures perform epitaxial growth with preferred orientation. In this way, PB crystals have nanocube-like morphology in the presence of ERGO in the electrochemical synthesis process (Eryiğit et al., 2019:905). The EDS technique was used to analyze the elemental composition of the PEDOT/ERGO/PB electrode. As shown in Figure 2d, the absence of any other elements other than C, O, Fe, S and N in the electrode structure indicates that the synthesized electrode does not contain any impurities. XPS, FE-SEM, and EDS results confirm that the PEDOT/ERGO/PB electrode was successfully grown on Au substrate by electrochemical method in layered form.

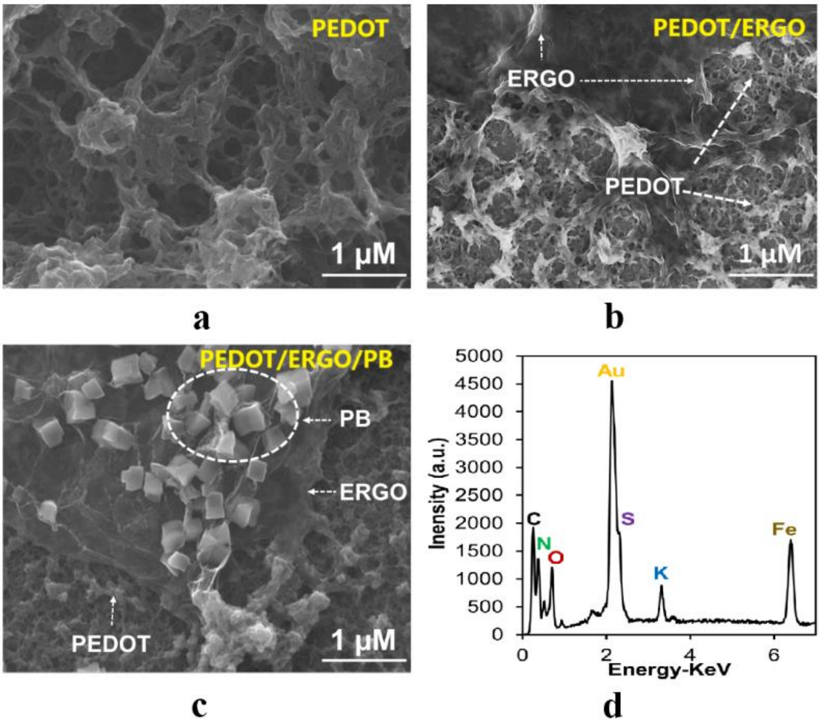


Figure 2: FE-SEM pictures of a) PEDOT, b) PEDOT/ERGO, c) PEDOT/ERGO/PB composite modified on Au electrode and d) EDS characterization of PEDOT/ERGO/PB modified on Au electrode

Cysteine Analysis by Cyclic Voltammetry: Working Potential Range and Scan Rates

The electrochemical behavior of cysteine was examined using cyclic voltammetry, employing various modified electrode compositions. These included bare Au electrodes as well as modified configurations such as Au/PB/ERGO, Au/PEDOT/ERGO, and Au/PEDOT/ERGO/PB (Figure 3).

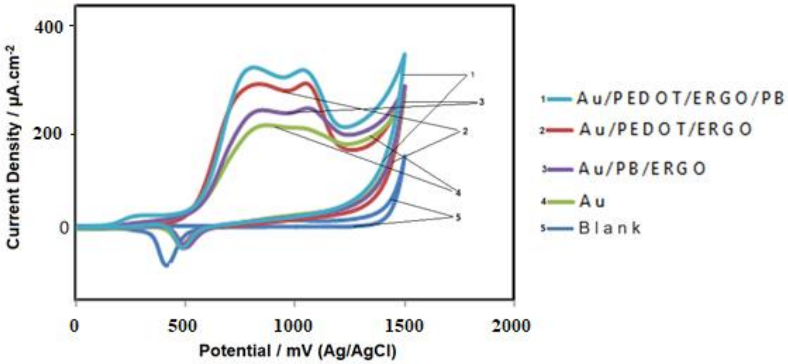
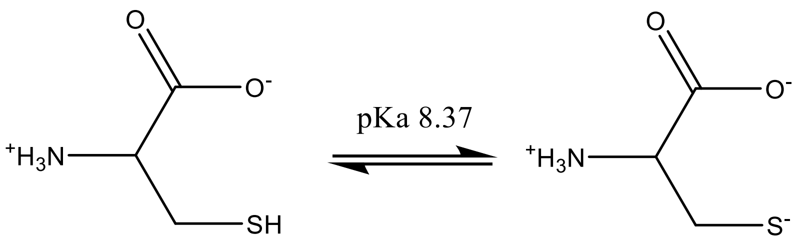


Figure 3: The cyclic voltammograms of cysteine at Au, Au/PB/ERGO, Au/PEDOT/ERGO, and Au/PEDOT/ERGO/PB modified electrodes in 0.1 M PBS buffer solution (pH:7.0)

The mechanism of electro oxidation of cysteine on Au-based electrodes has not been fully elucidated. The nature of the transfer in the anodic direction and the mechanism of oxidation of cysteine have not yet been resolved, and their nature remains unclear. Since the cysteine molecule contains various functional groups such as COOH, SH, and NH_3^+, it can exist in four transition states depending on the pH of the electrolyte solution (Hsiao et al., 2011:6887). In the pH:7 environments, a transition state can occur according to Figure 4.



H_2A HA^-

Figure 4: CVs Transition states of cysteine at pH 7

Although the cyclic voltammograms presented in Figure 3 clearly show the electrochemically irreversible process, the cysteine structure can give a relatively reversible peak depending on pH. Moreover, the thiol groups present in PEDOT play an important role in binding with the S-H groups of cysteine and contribute to the electrochemical activity towards cysteine sensing.

The cyclic voltammograms showed that cysteine in 0.1 M PBS buffer solution (pH:7), the relatively irreversible anodic peak was observed at 865 mV with a current density of 0.206 mA/cm² for Au, at 846 mV with 0.235 mA/cm² current density for Au/PB/ERGO, at 833 mV with 0.289 mA/cm² current density for Au/PEDOT/ERGO, and at 807 mV with 0.323 mA/cm² for Au/PEDOT/ERGO/PB modified electrodes within a scan range of 0 mV to 1600 mV. When compared, it was found that the Au/PEDOT/ERGO/PB modified electrode exhibited the greatest current density and the lowest oxidation potential for cysteine oxidation.Consequently, the Au/PEDOT/ERGO/PB modified electrode was identified as providing the most effective electrocatalytic response for cysteine oxidation.

We also investigated the impact of scan rate on peak current using linear sweep voltammetry for a 50 µM cysteine solution in a 0.1 M PBS buffer (pH:7.0). Voltammograms were obtained using scan rates ranging from 10 mV/s to 1000 mV/s, and the corresponding peak currents and potential values are shown in Figure 5.

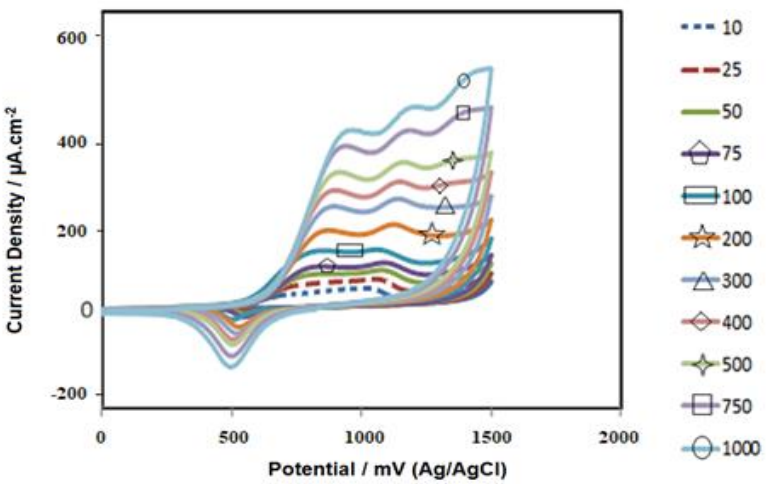


Figure 5: Cyclic voltammograms obtained at different scan rates for a solution of cysteine (50 µM) in 0.1 M PBS buffer (pH: 7.0) on the Au/PEDOT/ERGO/PB modified electrode

The most distinct oxidation peak for cysteine was observed at a scan rate of 100 mV/s within the range of scan rates tested. Subsequent investigations were carried out at a fixed scan rate of 100 mV/s for cysteine. Furthermore, it was observed from the obtained voltammograms that increasing the scan rate led to higher peak currents and positive shifts in peak potentials. The $v^{1/2}$-I plot yielded a high correlation coefficient (R^2=0.9992), indicating a strong relationship between current and scan rate, and confirming the diffusion controlled of the systems.

Au/PEDOT/ERGO/PB Modified Electrode for the Amperometric Determination of Cysteine: Method Development and Validation

The amperometric determination of cysteine was performed using a 15 consecutive cycle on an Au/PEDOT/ERGO/PB modified electrode at a potential of 807 mV in a 0.1 M PBS solution (pH:7.0) with continuous stirring at 1000 rpm. Cysteine solutions ranging from 10-500 μM were added sequentially to 10 mL of 0.1 M PBS and the resulting current density-time (amperometric) graph is shown in Figure 6. The graph clearly shows an increase in oxidation current with increasing cysteine concentration. Furthermore, the current response of the electrode remains constant within 3 seconds, indicating a rapid and stable response.

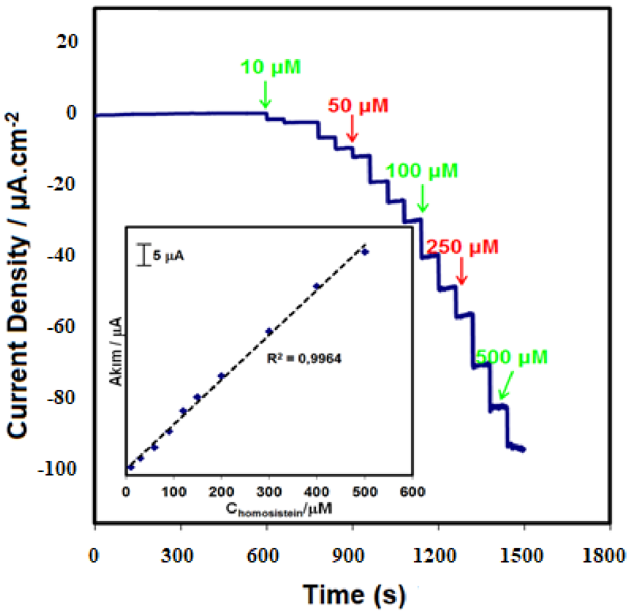


Figure 6: Amperometric response of cysteine at a potential of 807 mV (10-500 μM) from Au/PEDOT/ERGO/PB modified electrode in 0.1 M PBS (pH:7.0) stirred at 1000 rpm

For method validation, the selectivity of the method was evaluated by performing a voltammetric scan of the cysteine solution in the potential range of 0 and 1600 mV, resulting in a reversible voltammogram. An oxidation peak was observed at 807 mV for cysteine solutions within the concentration range of 10-500 μM (Figure 6). Notably, no interference was detected, demonstrating excellent selectivity for cysteine detection. To determine the linear range, calibration curves were constructed by plotting the concentrations of cysteine (ranging from 10-500 μM) against the corresponding amperometric responses obtained at a fixed potential of 807 mV, as outlined in Section 3.2. The regression Equation was found as J=2.64C+0.125 (J: represents the amperometric response, and C: represents the cysteine concentration). The obtained correlation coefficient is greater than 0.9964. The calibration curve's statistical analysis showcases the regression equation's reliability for accurate quantification of cysteine concentrations. Limit of Detection (LOD) and Limit of Quantification (LOQ) values for cysteine were determined using calibration curves obtained from amperometric data. LOD and LOQ values for cysteine were found to be 2.6 μM and 8 μM, respectively. Accuracy and precision were evaluated for high, medium, and low concentrations of cysteine at 20, 100, and 400 μM, respectively, using quality control solutions. The amperometric responses were measured six times within the same day (intra-day) and on different days (inter-day) using the same method and laboratory conditions. The mean and standard deviations of the analysis results were determined, and the coefficient of variation was calculated. Accuracy and precision values were presented in Table 1. The RSD % of the method for intra-day and inter-day precision was found to be less than 3.53 % and the RE% for accuracy was less than ±1.08 %, indicating high accuracy and precision.

Table 1: Intra-day and inter-day accuracy and precision values for cysteine using the amperometric method

Cysteine Concentration (μM)	*Intra-day*			*Inter-day*		
	Found±SD (μM)	*RE%*	*RSD%*	*Found±SD (μM)*	*RE%*	*RSD%*
20	20.12 ±0.67	0.60	3.33	20.08 ± 0.71	0.40	3.53
100	101.08 ± 0.54	1.08	0.53	98.96 ± 0.83	-1.04	0.83
400	397.89 ± 1.76	-0.53	0.44	398.93 ± 2.42	-0.26	0.60

SD: Standard Deviation, RE: Relative Error, % RSD: Relative Standard Deviation

In this study, an amperometric method for the accurate determination of cysteine was successfully developed and validated using a PEDOT/ERGO/PB-modified Au electrode. Cyclic voltammetric analysis revealed distinct electrochemical characteristics of cysteine, in particular an anodic peak at 807 mV. The optimised amperometric method showed robust analytical performance, characterised by a linear concentration range of 10-500 μM and a limit of quantification (LOQ) of 8 μM.

The incorporation of PEDOT and PB into the electrode modification significantly enhanced the electrocatalytic activity, thereby improving the sensitivity and selectivity of cysteine detection. This method represents a significant advance in the electrochemical analysis of cysteine, with potential implications for the diagnosis and monitoring of diseases associated with abnormal cysteine levels. Future studies should focus on the application of this method in clinical settings to validate its diagnostic utility and explore its integration into routine biochemical assays.

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A Proposed Model of Emotional AI for Health Care

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ABSTRACT

The rising demand for healthcare services and inadequate resources highlight the necessity for an innovative framework. Innovative approaches integrating cognitive computing and artificial intelligence are increasingly being employed in the healthcare industry to bring about considerable improvements. This study proposes a multidimensional emotion AI approach that identifies emotions from multiple data input sources, allowing for fast diagnosis of health concerns as well as efficient and prompt delivery of assistance and therapy.

The proposed model collects data from a variety of smart wearable gadgets and ad hoc devices, as well as expressions of face and voice signals. The acquired information is transmitted to a cloud database, where robust artificial intelligence algorithms are deployed. During this phase, the emotion AI system acquires knowledge by extracting pertinent information from each data input source. Data is also communicated with the inquiry database for pre-, during-, and post-interaction.

Emotion sorting is conducted utilizing AI-based approaches, which determine the emotion. The results are then used by an AI-powered therapy system to provide customized therapy to the patient based on the assessed emotional state.

AI serves as a powerful tool to assist the healthcare sector in providing enhanced solutions for individuals with health problems using their emotional state. The multidimensional emotion AI approach can facilitate fast diagnosis and efficient, prompt delivery of personalized therapy, addressing the growing demand for healthcare services with innovative technological solutions.

Keywords: Emotional AI, Proposed Model, Healthcare, EAI Devices, Emotion Extraction.

INTRODUCTION

For years, humans considered they had an unfair edge on comprehending emotions, but this notion may soon be challenged. While some may be concerned about machines intruding on human emotions, experts in emotional artificial intelligence, also known as emotional AI or affective computing, perceive substantial advancements. As our connections with technology get more complex, the necessity for emotional intelligence in AI increases. This transition in society, fueled by AI integration, will have a significant impact on how we manage emotions and connect with clients, making a thorough understanding of emotional intelligence increasingly important in corporate operations. This understanding helps navigate the usage of AI in business and improve consumer experiences.

In the past decade, the terms emotional intelligence (EI) and artificial intelligence (AI) have acquired popularity in literature, symbolizing human and machine intelligence, respectively. EI, or personal intelligence, has become a popular idea in the service business, helping individuals and organizations succeed. Despite its popularity, there is ongoing dispute among scholars over EI's ideas, techniques, and applications. High EI levels are associated with increased success in personal, social, and professional domains, particularly in customer-facing industries, where EI is regarded as critical for developing workplace relationships and maintaining business operations.
(Yao et al., 2019; Clarke, 2010).

AI, also known as machine intelligence, refers to the intelligence exhibited by systems rather than humans. It involves intelligent agent machines that can perceive their environment and utilize information to achieve objectives. Artificial intelligence (AI) and its applications are rapidly proliferating across various fields, particularly in healthcare, demonstrating significant utility. Alan Turing, a pioneering figure in AI and computing, introduced the concept of the "Turing Test" in 1950, aimed at discerning machine intelligence. The test involves an interrogator communicating via teletype with a man and a woman in separate rooms, attempting to distinguish between them solely through questioning. While the woman provides accurate responses, the man intentionally misleads to blur his identity. Turing proposed replacing the man with a machine, with success defined as the machine deceiving the interrogator into believing it's the woman. This concept, termed the imitation game, laid the foundation for AI, pushing for the development of algorithms enabling machines to emulate human behavior, challenging the interrogator's ability to differentiate between human and machine (French, 2000).

Over recent decades, AI has advanced significantly, leading to innovations such as big data analytics and machine learning applications across various sectors. AI holds the potential to generate substantial financial gains for enterprises, particularly in service industries like banking, human resources, healthcare, tourism, and hospitality. By providing personalized services and automating repetitive tasks, AI enhances client experiences and operational efficiency (Kim, 2011; Wirtz et al., 2018; Yu & Schwartz, 2006; Bolton et al., 2018).

The growing integration of AI into service organizations is altering operations, streamlining processes, and improving decision-making abilities. However, concerns about AI's impact on human employment are on the rise.

While AI promises improved corporate efficiency, there is apprehension about job displacement. Studies suggest a significant loss of jobs due to AI automation, particularly in low-skilled sectors, raising questions about the future of employment (Larivière et al., 2017; McKinsey, 2017).

Although AI's significance as an amplifier of innovation, its widespread use threatens jobs in the service industry. The shift from manufacturing to service sectors has accelerated due to job losses in manufacturing, prompting inquiries into the resilience of service occupations to AI automation. Consequently, understanding the interplay between EI and AI becomes imperative, especially in the service industry where both factors influence employee and consumer experiences. While existing research has explored EI and AI individually in relation to employee performance, little attention has been given to their combined effects. Thus, this study seeks to investigate how EI and AI collectively impact employee performance, both internally and externally, within the service industry.

Theoretical Foundation

Our study builds upon Rosalind W. Picard's pioneering work in affective computing, as outlined in her influential 1997 publication "Affective Computing," which has significant implications for healthcare. Picard's framework extends beyond mere emotional computations, encompassing computations influenced by emotions or affecting emotions. This paradigm emphasizes both the external manifestations of emotions and the computational processes underlying them, highlighting the analysis and quantification of observable emotional expressions. Affective computing in healthcare involves integrating emotional inference into computational processes to replicate the interplay between cognition and emotions (Picard, 1997).

Despite advancements, distinctions between human emotions and machine representations persist in healthcare applications. However, from an information theory perspective, the difference between genuine emotional content and simulated expressions becomes less crucial. Objects can be perceived as capable of conveying human emotions and fulfilling emotional needs, irrespective of the authenticity of the emotional experience (Picard, 1997).

Emotional Intelligence

Emotional Intelligence (EI) refers to the ability to perceive, express, understand, manage, and utilize emotions (Mayer & Salovey, 1997). In the past three decades, two additional forms of EI, namely 'trait EI' and 'mixed-model EI,' have emerged, along with various psychometric tools for their measurement. Fundamental to EI is the capacity to process emotional cues, as individuals who can do so effectively are more likely to manage emotions adeptly. Research indicates that individuals possessing elevated levels of Emotional Intelligence (EI) often achieve more significant career success and exhibit enhanced leadership abilities. (George, 2000; Gupta & Bajaj, 2017).

Developing EI is essential for leading fulfilling and content lives, and it involves applying standards of intelligence to emotional responses, recognizing their rational compatibility or inconsistency with particular emotional views. Particularly in customer-facing roles within the service sector, a high degree of EI is necessary. Enhanced EI correlates with successful employee-customer interactions and is advantageous for service industry professionals. Moreover, EI is associated with reduced emotional fatigue, psychological distress, and job dissatisfaction among employees (Lee & Ok, 2012).

Individuals with higher levels of emotional intelligence demonstrate better management, understanding, and control of both their own emotions and those of others. They possess a nuanced understanding of the emotional dynamics influencing work processes and service quality. Furthermore, EI positively correlates with job satisfaction, as it enables individuals to effectively cope with environmental demands and pressures, including emotional labor. Studies have consistently found EI to be a critical predictor of work performance and a determinant of long-term employee satisfaction (D'Amato & Herzfeldt, 2008; Saari & Judge, 2004; Cote & Miners, 2006).

In positions requiring teamwork, internal service performance, characterized by job efficiency with co-workers, is significantly influenced by an employee's EI. Emotionally intelligent individuals typically exhibit stronger interpersonal skills, which are essential for effective collaboration in group settings (Clarke, 2010; Mayer & Salovey, 1997).

Artificial Intelligence

Artificial intelligence (AI) refers to computer programs designed to acquire information in a manner akin to the human brain. Elon Musk predicts that by 2040, machines will surpass human intelligence. Analytic AI, a subset of AI, utilizes cognition and learning from historical data to inform future decisions. Inspired by human cognition and emotions, AI systems are evolving to incorporate both cognitive intelligence and emotional intelligence (EI), enabling them to comprehend and consider human emotions in decision-making processes (Kaplan & Haenlein, 2019). Examples of AI inspired by humans include Walmart's use of facial recognition algorithms to identify unsatisfied customers and Amazon's utilization of analytical AI for retail inventory management and AI-assisted robot tour guides in museums (Burgard et al., 1999).

A humanized AI system requires cognitive, emotional, and social intelligence, as well as an awareness of interpersonal relationships. While AI has been widely adopted across various service sectors to improve customer service, its role in organizations varies depending on the complexity of tasks. Routine and low-level jobs are typically automated, while emotionally and socially complex tasks, such as maintaining interpersonal connections with customers, are handled by humans with AI assistance (Ashkanasy & Daus, 2005).

AI can be operationalized based on various dimensions, including dependability, reliability, adaptability, accessibility, and timeliness. Employees can benefit from AI by gaining a better understanding of client needs through language translators, analyzing knowledge management systems, and providing human-friendly responses. Additionally, AI can assist in tasks such as charge adjustments and resolving conflicting schedules, thus enhancing productivity and efficiency in industries like travel (Serbanescu & Necsulescu, 2013).

Artificial intelligence (AI) is a fast-growing field with multiple applications in several disciplines. As AI advances, categorizing various manifestations is critical for better understanding its capabilities and limitations. Within AI, there are two basic classifications: narrow artificial narrow intelligence (ANI) and broad artificial general intelligence (AGI) (Kurzweil, 2005; Yampolskiy, 2016).

1. Artificial Narrow Intelligence (ANI) creates machines with limited intelligence for certain activities or fields. This setting limits the machine's ability to work within predetermined parameters of programmed intelligence.
2. Artificial General Intelligence (AGI) implies machines that can perform across multiple areas and demonstrate versatile intelligence. Despite extensive research in this field, recent advances fall short of obtaining such broad.

Emotion AI.

Artificial intelligence (AI) has advanced dramatically from its inception in the 1950s, progressing from completing fundamental tasks to identifying human emotions today. AI systems can now detect emotions based on vocal and facial expressions. Certain AI systems, for example, study verbal signals to learn about users' emotional states, whereas others detect tiny facial changes to infer emotions. Nonetheless, there is opportunity for progress in detecting complex facial expressions (Strange, 2019).

Researchers aim to imbue AI with cognitive developmental processes akin to those experienced during human youth, potentially leading to AI possessing human-like emotions in the future. However, emotions are intricately linked with cognitive processes, suggesting that emotions solely based on cognition may lack authenticity (Pessoa, 2017).

EAI implies artificial intelligence systems that can reliably anticipate human emotions using inputs such as photos, texts, audios, or videos. It stands out as a significant instrument with broad applicability in a variety of industries, helping to drive transformative change around the world. However, the fundamental complexity of human emotions, which are sometimes veiled or not outwardly stated, presents a significant difficulty in designing robots capable of completely understanding them (Fölster et al., 2014).

Moreover,it employs optical sensors or webcams to meticulously scrutinize unfiltered facial expressions. Through real-time image or video analysis, algorithms identify key facial points, which deep learning algorithms then analyze to classify emotions (Eminoğlu, 2019). Additionally, Emotion AI assesses speech tone and pitch to gauge emotional states, as demonstrated by Affective company's "face coding and sensory identification" software, enabling users to express their sentiments about digital content without verbal or written input (Eminoğlu, 2019).Tools like Google Duplex and iPhone X's animojis exemplify AI's increasing capacity to empathize and respond in human-like ways. Nevertheless, for challenging assignments, they may still need human assistance (Barrett, 2019). As AI gets becoming smarter and human-like, emotional intelligence may become an indispensable skills, notably in a growing emotion-centric society and corporate environment.

Development Process of Emotional Artificial Intelligence

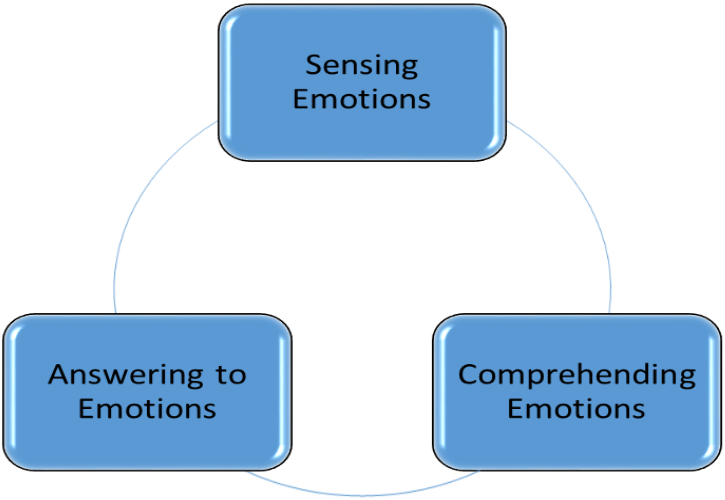

Fig 1

Sensing Emotions: AI systems are being taught to detect emotions using a variety of cues like expressions of face, voice syntax, and written expression. AI can recognize emotions like happiness, sadness, or fury by evaluating face expressions and listening to voice tones.

Comprehending Emotions: AI is progressing beyond simple emotion identification to understand the root reasons of our state of emotions. This requires interpreting emotions within deeper circumstances, such as comprehending why an individual may be happy after hearing favorable medical news or depressed after a diagnosis.

Answering to Emotions: Emotional AI within health care entails far more than simply recognition and comprehension; it additionally incorporates suitable responses. Scientists are developing AI systems that may deliver customized responses depending on detected states of emotions. When a computerized healthcare assistant notices signs of worry in a patient's conversation, it may deliver consoling or encouraging remarks.

Emotion AI Role in the sphere of Healthcare

According to the latest research (Enablex Insights, 2022/2022), Emotion AI (EAI) has the ability to recognize human emotions such as wrath, rejection, joy, distress, and indifference by analyzing microexpressions that are typically unnoticeable to the naked eye. This technology is expected to transform healthcare, notably mental health, diagnostic processes, and patient care. As social awareness and actions to treat mental health concerns have grown, there has been a noticeable increase in services and a decline in related prejudice.

Mental health is a major modern issue, exacerbated by the aftermath of the COVID-19 epidemic. According to World Health Organization statistics, over 280 million people suffer from depression, and a quarter of the world's population is likely to experience mental or neurological problems at some point in their lives. Emotional AI emerges as a potential ally in addressing this issue due to its ability to detect, intervene, and cure symptoms early. Emotional AI can detect stress, anxiety, depression, or suicide ideation by evaluating clues such as facial expressions, speech tones, and behavioral patterns. Furthermore, it can provide individualized support, advice, and therapy geared to assist individuals regulate their emotions and improve their overall well-being.

A recent study highlighted revealed that approximately a thousand million individuals out of the global population of seven billion suffer from mental disorders, with around 75% of sufferers in low-income countries remaining untreated. Alarmingly, suicide rates suggest that every four to six minutes, someone takes their own life, emphasizing the urgent need for effective solutions (Mental Health: Lessons Learned in 2020 for 2021 and Forward, 2022/2022). Furthermore, projections indicate that depression will become a major health concern in many countries within the next decade. Emotion AI's futuristic effect on healthcare, particularly mental health, has been acknowledged. It gives clinicians an easy way to monitor the well-being of their current patients and accurately identify concerning situations (Walsh et al., 2017a).

In the field of diagnosis, emotional AI has the potential to improve the precision and efficacy of healthcare evaluations. Healthcare workers can obtain more insight into their patients' physical and emotional conditions by integrating technology such as computer vision, natural language processing, and machine learning. One significant application is in the diagnosis of autism spectrum disorder (ASD), where emotional AI assists in decoding emotional signals and provides feedback to those on the spectrum, allowing them to better understand the emotional states of others.

Furthermore, emotional AI has the possibility to improve medical care by encouraging better communication and empathy between healthcare personnel and their patients. Healthcare practitioners can develop stronger connections, confidence, and levels of satisfaction by identifying and empathizing with their patients' feelings, resulting in improved outcomes and treatment plan adherence. An example is the use of emotional AI in caring for people with dementia, where the technology monitors their emotional well-being and delivers appropriate interventions, while also notifying caregivers to situations requiring support or intervention.

In addition, emotional AI is a strong tool capable of transforming healthcare delivery by providing solutions in mental health support, diagnostic processes, and patient care. Using emotional AI allows healthcare providers to provide more tailored, compassionate, and powerful interventions, resulting in better wellness for patients and improved healthcare outcomes. It is vital to understand that emotional AI supplements, rather than replaces, human connection, hence improving the quality and efficacy of healthcare operations.

Emotional AI (EAI) has enormous potential for assimilation into healthcare in a variety of sectors, with significant social advantages. Research identifies many potential applications:

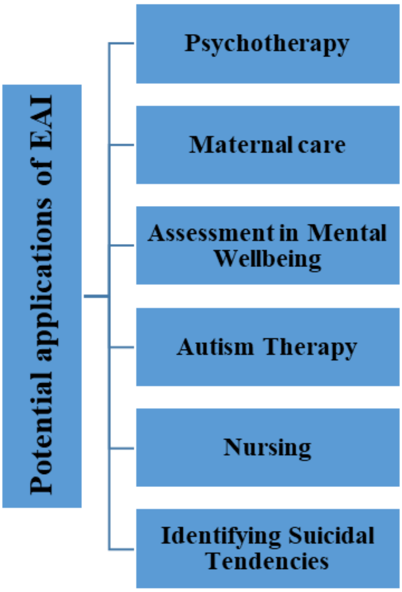

Fig 2 (source Author)

- Recent research shows that chatbots can effectively advise patients and detect changes in behavior, attitudes, and daily habits in mental therapy. (Oh et al. 2017).
- In spite the lack of research, there is evidence that EAI can improve emotional well-being during the pregnancy by treating associated risks like as anxiety, sadness, and distress (Oprescu et al., 2020).
- EAI can expedite and improve the accuracy of mental health disorder diagnosis, leading to enhanced mental care centers at lower expenses (Walsh et al., 2017a).

- Incorporating EAI into autism treatment strategies can assist individuals in understanding and expressing emotions, thereby improving social, emotional, and communication skills (Enablex Insights, 2022/2022).
- In countries like Japan, nursebots have demonstrated significant utility in assisting with daily tasks for the elderly and individuals with disabilities, as well as engaging in conversational interactions (The Index Project, 2022/2022).
- EAI plays a crucial role in predicting suicide risks by analyzing patient behavior, highlighting its importance given the alarming rates of suicide globally (Walsh et al., 2017a).

These applications underscore the potential of EAI to transform healthcare delivery and improve patient outcomes.

Emotion AI Devices

Emotional artificial devices are a revolutionary junction of technology and psychology, aimed to replicate, analyze, or enhance human emotions using artificial intelligence and powerful computing techniques. The chart below summarizes the core technology, features, and applications of emotional artificial devices in healthcare.

Table 1 (Source Author)

Devices	Core Technology-Features	Applications in Healthcare
Affectiva	• Facial Coding • Physiological Signals	Monitors patient emotions to aid mental health professionals.
Paro Therapeutic Robot	• Artificial Intelligence • Sensors • Behavior Simulation	• Elder Care: • Non-Pharmacological Therapy
Ellie	• Artificial Intelligence • Natural Language Processing (NLP) • Multimodal Sensing • Emotion Detection • Real-Time Feedback	• Mental Health Assessment • Clinical Research • Supplement to Therapists:
Feel	• Biosensors. • Emotional Analytics • Real-Time Feedback	• Stress Management • Emotional Awareness

	• Personalized Interventions • Daily Reports and Trends	• Mental Health Support
Smartphone Apps for Mental Health • Mood Tracking Apps • Therapy and Counseling Apps • Meditation and Mindfulness Apps • Cognitive Behavioral Therapy (CBT) Apps • Symptom Management Apps • Support Community Apps	• Emotional awareness • Online therapy • Relaxation and focus • CBT-based support • Managing specific symptoms • Peer support	• Increases self-awareness, provides insights • Convenient access to professional support • Reduces stress, • improves focus, • promotes relaxation • Offers evidence-based techniques • Helps manage symptoms, provides immediate support • Offers community support, shared experiences
Mental Health Chatbots • Woebot • Wysa • Replika • Youper • Tess • Ginger	• Artificial Intelligence • Cognitive Behavioral Therapy (CBT) • Emotional Tracking	• Accessible Mental Health Support:. • Early Intervention:. • Supplement to Traditional Therapy • Accessibility • Immediate Support • Anonymity • Affordability • Self-Management • Supplement to Therapy • Engagement and Consistency
Nursebot • Babylon • Ada Health • Buoy Health • Sense.ly • Florence • Molly	• Virtual consultations with doctors, symptom checker • medical advice • AI-driven symptom checker, personalized health assessments, • connects users with nearby providers	• Virtual Consultations • Symptom Assessment • Medication Reminders • Health Monitoring • Personalized

	• Virtual nurse assistant for post-discharge care • Medication reminders • pill tracking, adherence monitoring • AI-driven chatbot for healthcare queries, first-aid advice, medication reminders	Advice • 24/7 Availability • Integration with Providers
Anura	• Physiological Monitoring • Real-time Feedback • Mobile App Integration • Wearable Design	Stress Management Enhanced Relationships Improved Performance Long-term Well-being

Proposed EAI-based model for health care:

Amid higher costs and demand, healthcare providers confront a number of challenges in improving the quality and efficacy of treatment delivery. Internal inefficiencies and inadequate resources have an impact on patient safety, staff happiness, and overall treatment quality. (Cecula et al., 2021). Additionally, era after COVID-19 confronted individuals to a wide spectrum of health disorders, particularly those associated with social isolation and insufficient resources. As a result, there is an increased demand for health services. The increasing need for healthcare, combined with financial constraints, has generated potential for technology-based solutions where emotion AI may be used advantageously. Emotion AI tries to detect emotions through machine learning techniques. This can assist healthcare providers delivering needed support for diverse health disorders while also maintaining the safety of patients.

The proposed design offers a multifaceted emotion AI strategy that identifies emotions from diverse data input sources, which enables prompt recognition of health problems and effective and timely provision of support and therapy. The flow of the proposed framework is as follow:

Emotion assortment: It begins with the data collection,where data about patients is gathered from multiple sources. Smart wearable gadgets, for instance, smartwatches, smart eyewear, and smart clothing capture numerous physiological signals from the body that enable them to extract attributes and detect emotions. These signals will differ depending on the devices and the signals that each wearable device can sense or gather. Furthermore, the wearable gadget will be worn on different regions of the body depending on the demands of the users and the functions it performs. Furthermore, expressions of face and word signals will be used in addition to wearables sensors to identify and define a user's emotion, as shown in Figure.

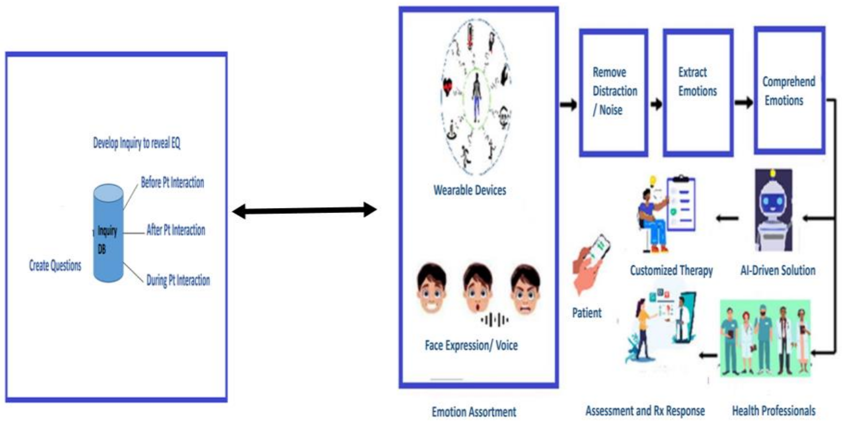

Fig 3 (Source Author)

Extraction of emotion: The collected information will be transferred to cloud database, where advanced AI algorithms will be applied. During this stage, the emotion AI system gets trained by obtaining suitable attributes from each input data source.

Sharing data with inquiry database for Interaction: In the meantime, data will also be shared with the inquiry database for pre-, during-, and post-interaction. In pre-interaction preparation, it implements AI algorithms to analyze and classify patient interactions based on factors such as appointment type and patient history and also develops a system that utilizes AI to create patient profiles, highlighting communication styles, priorities, goals, and levels of commitment from previous conversations. During patient interaction, it enables real-time feedback for healthcare staff to enhance their ability to close deals, handle objections, and empathize with patients. It also utilizes AI-generated text prompts to guide staff through common situations, offering step-by-step assistance in overcoming objections and calming unhappy patients. Post-Interaction Analysis includes implementing AI-driven tools to record and analyze patient meetings, focusing on conversational and emotional intelligence, and Use Natural Language Generation (NLG) to provide feedback to healthcare teams, offering improvement suggestions based on past conversations.

EAI-based approaches to sorting or assessing emotions:

The final step, which is an ongoing process, is emotion sorting, which employs AI-based algorithms to determine the emotion and will reveal the patient's emotions. The results will then be used by an AI-based therapy system to deliver customized tailored therapy to help the patient based on the assessed condition. For example, If the patient is assessed to be in high risk, the system can notify local authorities and provide prompt assistance or therapy. Recognize early warning signals of changes in a person's daily activities. Similarly, if an individual is diagnosed with a specific medical condition, an artificial intelligence-powered intervention system will develop a customized and specific treatment plan based on the individual's personal needs. AI may be able to accurately predict individuals who need medical attention before they recognize it or their symptoms deteriorate. Furthermore, continual monitoring of the patient's condition may aid in determining the efficacy of the recommended drug. Once therapy begins, AI can help clinicians track the patient's response and evolution of the condition by passively gathering patient data via wearable devices.

CONCLUSION

Emotion AI is a remarkable newly developed technology that can provide healthcare providers with new strategies to improve their patients' emotional well-being. Emotion detection Artificial intelligence is revolutionizing healthcare by improving emotional assistance for both patients and health care providers. Emotion-based AI has the potential to improve patient care and treatment efficacy. Knowing how to respond to human emotions helps create a more compassionate and empathic healthcare environment. With proper implementation, ongoing breakthroughs, and an emphasis on ethics, Emotion AI has the potential to pave the way for a future in which technology and emotions coexist, delivering extraordinary emotional assistance in healthcare. This sort of technology can recognize and respond to emotional impulses in people's voices, texts, and facial expressions. The current paper describes a multiple-dimensional emotion AI system that distinguishes emotions from various data sources. Health care practitioners can use this to diagnose health problems earlier and give timely and efficient treatment. So far, EAI within healthcare is nevertheless in its early phases, with numerous obstacles and potential. The intricacies and ever-changing nature of healthcare data underscore EAI's continuous progress, which holds enormous promise for societal benefits. While significant progress has been made, much more work needs to be done to fully realize EAI's potential for enhancing the quality of healthcare. Further ahead, there are great prospects for EAI in healthcare, but only if existing impediments are addressed. Reducing the gap between human cognition and AI abilities is a significant problem, especially in situations with ambiguous and limited information. To address this imbalance and fully realize EAI's promise, AI algorithms' complexity and decision-making abilities must be increased.

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Distraction Osteogenesis in Orthodontics

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ABSTRACT

Distraction osteogenesis (DO) represents a remarkable advancement in the field of orthognathic surgery. This innovative technique transcends traditional surgical methods by utilizing the principle of controlled separation of bone segments, leading to the formation of new bone tissue.

DO's efficacy is especially pronounced in orthodontic treatments that aim to correct skeletal irregularities and expand the jawbone. It is widely applied to lengthen the mandible in cases of mandibular micrognathia and retrognathia, or to advance the maxilla in instances of maxillary hypoplasia.
The biomechanical foundations of DO, combined with the osteogenic processes supported by the proliferation of osteoprogenitor cells, facilitate new bone formation in accordance with the tension-stress law. Unlike conventional bone grafting methods, DO boasts fewer complications and higher success rates. This success is largely attributable to the collaborative efforts of orthodontics and maxillofacial surgery specialists, who work together to achieve optimal outcomes.

DO provides long-term stability by effectively reshaping both bone tissue and surrounding soft tissues. This optimal remodeling ensures that patients achieve not only functional improvements but also meet their aesthetic goals. As a result, the importance of DO in orthodontic and surgical treatments continues to grow, making it a preferred method for addressing complex craniofacial anomalies. Its ability to deliver lasting results with minimal risks underscores its increasing relevance in modern medical practice. The continuous evolution and refinement of this technique promise to further expand its applications and benefits, solidifying DO's role as a cornerstone in the management of craniofacial deformities and other related conditions.

Keywords: Alveolar Distraction, Distraction Osteogenesis, Orthodontic Treatment, Orthognathic Surgery.

INTRODUCTION

In the field of dentistry, addressing bone deficiencies has always posed significant challenges. Various surgical procedures have been developed to position and thicken the jawbones before dental and skeletal treatments. Distraction osteogenesis (DO) represents a relatively new treatment modality in dentistry, applicable in orthognathic surgery, prosthetic treatment, and implant surgery. As a reconstruction technique, DO involves bone lengthening using appropriate devices (Ilizarov, 1989).

Distraction osteogenesis involves the gradual and controlled application of tensile forces to the callus tissue formed at the fracture line, leading to new bone formation. DO is a preferred treatment method for the surgical treatment of congenital or acquired craniofacial skeletal anomalies (McCarthy, Stelnicki, Mehrara, & Longaker, 2001).

This technique promotes the rapid formation of new soft tissue in the bone and surrounding tissues. After the surgical closure of the cleft lip or palate, orthodontic treatments alone may not be sufficient to correct the resulting dental and skeletal malocclusion, and surgical support may also be needed (Trotman & McNamara Jr, 1998).

DO is extensively employed for mandibular and maxillary deficiencies, addressing both sagittal and transversal deficiencies. Advances in treatment techniques have enabled the use of surgical methods such as bone grafting or DO to properly form the alveolar arch in patients with wide cleft palates. It is noted that applying alveolar (segmental) distraction osteogenesis prior to bone grafting in patients requiring bone grafts is advantageous. Furthermore, DO can be used to resolve space deficiencies and in implant placements(Del Santo Jr, English, Wolford, & Gandini Jr, 2002; Figueroa, Polley, & Ko, 1999; Vega & Bilbao, 2010).

TECHNIQUES OF DISTRACTION OSTEOGENESIS

Depending on the effects of the applied distraction forces, two types of separation can be identified: callotasis and physeal distraction

Callotasis: This technique involves the gradual stretching of the repair callus formed around the bone segments created post-osteotomy. Clinically, callotasis is divided into three consecutive phases: the latent period, the distraction period, and the consolidation period. Callotasis is also classified into three groups based on the number of distraction-tension zones (Keçeli, Demiralp, Muhtaroğulları, & Demiralp, 2006).

Monofocal Distraction Osteogenesis: This technique involves a single cut to the bone, with the bone segments on both sides of the cut gradually separated. Regeneration occurs at a single site (Maull, 1999).

Bifocal Distraction Osteogenesis: Used for large bone defects, this technique gradually moves a vascularized bone piece separated from the remaining bone segment into the defect. New bone forms during the movement of the mobile segment, which eventually closes the defect (Maull, 1999).

Trifocal Distraction Osteogenesis: For very large bone defects, osteotomies are performed on segments on both sides of the defect, creating two moving zones that are brought together simultaneously (Annino, Goguen, & Karmody, 1994).

Physeal Distraction: This involves the distraction of bone growth plates and can be divided into two types based on the rate of distraction between the growth plates.

Distraction Epiphysiolysis: This rapid physeal distraction technique, performed at a rate of 1-1.5 mm/day, creates fractures at the growth plates through rapid and increasing tension. The epiphysis separates from the metaphysis, and the resulting trabecular bone and growth plate change positions (Aldegheri, TRIVELLA, & LAVINI, 1989).

Chondrodiatasis: This technique involves gradual tension at a rate of approximately 0.5 mm/day without causing fractures, enhancing the biological activity of cartilage cells and accelerating osteogenesis (Aldegheri et al., 1989; Cope & Samchukov, 2001).

Phases of Distraction Osteogenesis

Preoperative Period: This phase involves preparing all clinical, radiographic, cephalometric, and model analyses, and conducting detailed examinations to formulate a treatment plan.

Operative Period: This period consists of the surgical phase where osteotomy is performed on the area to be distracted, and the distraction device is placed. The planned area is first exposed, and the segments are then separated by osteotomy. To ensure segment mobility, the device is initially activated and then returned to its original position. The location for osteotomy and the osteotomy line are determined according to the distraction vector. It is crucial to avoid damage to anatomical structures such as tooth roots, tooth germs, the inferior alveolar nerve, and the lingual nerve during osteotomy or while placing the distraction device screws. DO is a process that requires a precise and accurate treatment plan and surgical application (G. Swennen, Schliephake, Dempf, Schierle, & Malevez, 2001).

Latent Period: This is the 5-7 day waiting period after osteotomy and device placement, allowing for callus formation and soft tissue healing before distraction forces are applied. During this period, well-vascularized granulation tissue forms alongside the proliferation of endosteal and periosteal osteogenic cells. Many experimental studies have indicated that optimal osteogenesis occurs when distraction is initiated 5-7 days post-osteotomy. Factors such as the type of bone undergoing DO, the osteotomy site, trauma caused during the operation, and the patient's age should be considered when determining the latent period (G. Swennen et al., 2001; Tavakoli, Stewart, & Poole, 1998).

Distraction Period: This is the phase in which gradual stretching is applied, and new bone formation occurs. Three variables are calculated in this period: distraction rate (daily amount), distraction rhythm (frequency), and total distraction duration (M. Samchukov, 2001).

During bone healing, the fibrous callus tissue is transformed into hard callus by osteoblasts, containing fibrous bone. The cartilaginous tissue calcifies, and osteoblasts reside on the newly formed bone at the calcified cartilage matrix. The hard callus phase is completed in 3-4 months, leading to the remodeling phase where fibrous bone gradually transforms into lamellar bone, and the medullary canal is reformed. During the remodeling phase, the bone returns to normal, and the medullary canal is fully restored (M. Samchukov, 2001).

During distraction, applying tensile stress to the soft callus tissues between segments creates a dynamic microenvironment. This microenvironment aligns the direction of new tissue formation with the traction vector (Delloye, Delefortrie, COUTELIER, & Vincent, 1990; White & Kenwright, 1991).

Capillary growth into the fibrous tissue occurs between days 3 and 7 of the distraction period. The vascular network extends not only in the area between the two bone segments but also into the medullary canal adjacent to both bones. The newly formed capillaries are parallel to each other and the distraction axis, often spiraling and making multiple circular loops. The vascular growth in this area is ten times greater than in normal fracture repair (Irianov, 1996a). The ends of the capillaries actively extend into the fibrous tissue, bringing less differentiated cells that transform into fibroblasts, chondroblasts, and osteoblasts (Irianov, 1996b).

Bone formation along the tensile vector continues through the developing ends of primary osteons, which remain open throughout the distraction period. These regions are the growth areas of new bone tissue formed by distraction and maintain active osteogenesis during elongation (ARONSON, GOOD, STEWART, HARRISON, & HARP, 1990). Regional propagation of newly formed tissues post-distraction continues until the end of the distraction period.

Consolidation Period: The consolidation period refers to the time between the cessation of tensile forces and the removal of the distraction device. During this period, the fibrous intermediate zone gradually mineralizes. While the distraction tissue generally undergoes intramembranous ossification, cartilage islands can also occasionally be found (Windhager et al., 1995). The presence of chondrocytes surrounded by mineralized matrix in some areas suggests transchondroid bone formation (Li, Simpson, & Triffitt, 1999; Sawaki & Heggie, 1999; Yasui et al., 1997).

In a study conducted on 42 adult male Sprague-Dawley rats, it was suggested that hypoxia during the consolidation period is a critical driver of angiogenesis and can accelerate bone formation post-DO (Y. Liu et al., 2022).

Remodeling Period: The remodeling period is the time from functional loading until the newly formed bone is completely remodeled. Both the cortical and medullary regions of the bone are repaired. In the final phase of cortical remodeling, the bone structure returns to normal through the remodeling of the haversian system (Saleh, Stubbs, Street, Lang, & Harris, 1993; Tajana, Morandi, & Zembo, 1989). The maturation of the bone post-distraction, where the newly formed bone attains the same structure as the pre-existing bone, takes approximately one year or more (Schenk & Gachter, 1994).

CLASSIFICATION OF DISTRACTORS

Generally, two types of distractors are used for craniofacial distraction: extraoral and intraoral distractors.

Extraoral Distractors: The first extraoral distractor was applied in a study with four cases in 1992. Sagittal distraction of the mandible was performed using the Hoffman Mini Lengthener (Stryker Leibinger), a single-direction orthopedic distractor used in hand reconstruction (McCarthy, Schreiber, Karp, Thorne, & Grayson, 1992).

The ACE/Normed Bi Directional distractor (KLS-Martin) achieved bidirectional mandibular distraction in 18 patients, providing 7-45 mm sagittal and 7-50 mm vertical elongation (Klein & Howaldt, 1996).

Following successful mandibular DO applications, Rigid External Distraction (RED) systems (RED; KLS-Martin LP) were developed for maxillary advancement (Polley & Figueroa, 1997a, 1997b). Using the RED appliance, a 10-year-old patient with bilateral cleft lip and palate achieved 15 mm maxillary advancement, with stable maxillary position and occlusion after one year.

In 14 patients with severe maxillary hypoplasia, significant skeletal maxillary advancement was achieved using the RED appliance. Four months post-distraction, increases of 7.70 degrees in the SNA angle and 8.60 degrees in the ANB angle were reported. Additionally, the study introduced an intraoral appliance that transfers traction forces to the maxillary bone via the teeth (Figueroa & Polley, 1999).

The RED appliance primarily consists of a halo frame fixed to the skull. Traction is applied to the maxilla using a splint supported intraorally by the teeth or by bone-supported fixation. Initially, maxillary osteotomy is performed. Following the osteotomy, the frame part of the RED appliance is rigidly fixed to the skull with a total of four or six screws. Distraction begins after a 3-5 day latent period. The vertical bar of the appliance is positioned along the midline, while the ends of the external arms extending from the intraoral part are rigidly connected to elements on the vertical bar using steel wires. During the distraction period, the distraction rhythm is set to 2x0.5 mm/day, and the distraction rate to 1 mm/day. Once the desired amount of distraction is achieved, the screws are rotated to stop the distraction. At this stage, the external arms are tightened, causing the maxilla to continue advancing. Therefore, when distraction is complete, the distraction screw is turned back to nullify the force applied to the intraoral part (Figueroa & Polley, 1999).

In another study on distractors, particularly extraoral distractors, the distractors designed to enhance patient comfort and sleep were used, enabling bilateral distraction with a unilateral extraoral extension (Shang, Lin, Du, He, & Liu, 2012).

Advantages of Extraoral Distractors (RED):

1. Performing osteotomies at Le Fort I, II, and III levels (Cheung & Lo, 2006; Chin & Toth, 1997; Cohen, 1999; Figueroa et al., 1999).
2. Good control of the distraction force vector (Figueroa & Polley, 1999; Figueroa et al., 1999).
3. Changing the distraction force vector without discomfort to the patient, even during the distraction process (Polley & Figueroa, 1997b).
4. Easy placement and removal of the halo frame (Figueroa & Polley, 1999).
5. Achieving the desired amount of distraction in a single procedure (Figueroa & Polley, 1999).

Disadvantages of Extraoral Distractors (RED):

1. Patients may be unwilling to use the RED appliance due to social life restrictions (Figueroa & Polley, 1999).
2. Leaving scars on the skin (Kuroda et al., 2005).
3. Achieved distraction amount being less than expected based on the applied activation (Nout, Wolvius, van Adrichem, Ongkosuwito, & van der Wal, 2006).
4. Requiring a sufficient number of teeth for anchorage in the upper jaw to stabilize the intraoral (Figueroa & Polley, 1999; Kuroda et al., 2005)
5. Requiring attention to specific concerns during use: preoperative determination of pin placement based on computed tomography records, close monitoring of patients during the distraction period, and careful removal of pins when taking out the RED appliance (Figueroa & Polley, 1999; Garfin, Botte, Waters, & Nickel, 1986; Liu, Liu, Guo, Liang, & Zhang, 2022)

Intraoral Distractors: Intraoral distractors are classified into three groups based on their support areas: bone-supported distractors, tooth-supported distractors, and hybrid distractors (supporting both bone and teeth)(M. Samchukov, 2001).

1.Bone-supported Intraoral Distractors: These distractors consist of a cylindrical distraction screw mounted on two plates via clamps. The upper plates of the distractors are fixed with mini screws to the zygomatic region above the osteotomy line, while the lower plates are fixed with mini screws to the maxillary alveolar region below the osteotomy line (Gulsen et al., 2007).

2.Tooth-supported Intraoral Distractors: Custom-made tooth-supported distractors use Hyrax-type orthodontic screws attached to steel crowns or orthodontic bands placed on supporting teeth. These components are soldered together in the laboratory (Orhan, Malkoc, Usumez, & Uckan, 2003).

3. Hybrid Intraoral Distractors: Hybrid distractors are fixed with screws to the bone adjacent to the distraction area, while the distractor arms are also attached to the teeth using crowns or bands (Block & Brister, 1994).

The use of intraoral distractors has led to increased and widespread application of mandibular DO. Tooth-supported distractors are created by modifying orthodontic expansion appliances, while bone-supported distractors are miniaturized versions of extraoral appliances (Cope, Samchukov, & Cherkashin, 1999; McCarthy, Staffenberg, Wood, Grayson, & Thorne, 1995; Razdolsky, Pensler, & Dessner, 1998).

The Uniguide Mandibular Distraction appliance, resembling a miniaturized version of an extraoral distractor and fixed to the bone with pin pairs, was developed (McCarthy, 1994). Researchers have developed three different approaches: distractors applicable to each region of the craniofacial structure, distractors with different designs based on the anatomical region (corpus, ramus) or clinical purpose (elongation, expansion), and custom-made distractors for individual cases (M. Samchukov, 2001).

A study on mandibular symphyseal distraction using a tooth-supported intraoral distractor demonstrated mandibular expansion. The appliance, resembling an RME appliance, comprised a Hyrax screw soldered to bands placed on mandibular first premolar and first molar teeth. Initially used for sagittal mandibular distraction and mandibular symphyseal distraction, tooth-supported distractors are now more commonly preferred for segmental maxillary distraction applications (CA Guerrero, Bell, Contasti, & Rodriguez, 1997).

While positioning the maxilla anteriorly in the sagittal direction with these distractors, the aim is also to correct crowding by increasing the arch length (A. O. Bengi, Gürton, Okcu, & Aydintug, 2004; O. Bengi et al., 2007; Ho et al., 2006; Okcu et al., 2009).

Advantages of Intraoral Distractors:

1. They are more socially acceptable to the patient (Kuroda et al., 2005; Rachmiel, 2007).
2. They do not leave scars on the skin as they are applied intraorally (Kuroda et al., 2005).
3. The amount of distraction expected to be achieved with the activation performed is greaterolması (Kahn, Broujerdi, & Schendel, 2008)
4. They are more easily tolerated by patients, allowing longer retention during the consolidation period (Gulsen et al., 2007; Kahn et al., 2008; Kostopoulos & Karring, 1995).
5. There is no need for a second surgery to remove tooth-supported distractors (Ho et al., 2006).

Disadvantages of Intraoral Distractors:

1. They are difficult to place (Kuroda et al., 2005).
2. They may cause discomfort to the patient while trying to achieve the ideal distraction vector (Van Sickels, Madsen, Cunningham Jr, & Bird, 2006).
3. They must be positioned parallel to each other and the distraction vector, which is necessary and challenging (Kuroda et al., 2005; Rachmiel, 2007; Van Sickels et al., 2006).

4. Bone-supported distractors require a second surgery for removal (Kuroda et al., 2005; Rachmiel, 2007).

INDICATIONS AND CONTRAINDICATIONS OF DISTRACTION OSTEOGENESIS

Indications:

a)Coronal (bilateral or unilateral) or sagittal nonsyndromic craniosynostosis, b)Syndromic craniosynostosis (Apert, Cruzon, and Pfeiffer Syndromes), c)Cleft lip and palate, d)Pierre Robin syndrome, e)Midface retrusion due to trauma, f)Severe retrognathia cases associated with syndromes in infants and children where traditional osteotomies are not feasible, g)Unilateral mandibular hypoplasia (hemifacial microsomia), h)Nonsyndromic mandibular hypoplasia cases with accompanying dental malocclusion,

i)Cases requiring extensive advancements that render traditional osteotomies impossible or necessitate grafting, j)Mandibular transverse deficiency related to dental malocclusion, k)Severe obstructive sleep apnea and obesity, l)Mandibular hypoplasia due to TMJ trauma and/or ankylosis, m)Defects disrupting mandibular continuity due to tumor and/or aggressive jaw cyst excisions, n)Reduced alveolar bone height (Komuro, Takato, Harii, & Yonemara, 1994).

Contraindications:

a)Patients unwilling or unable to adhere to distraction procedures are unsuitable for this procedure (Komuro et al., 1994). b)Mandibular DO has been applied to infants as young as 6 months; however, more significant challenges arise if the bone for distraction appliance placement is small and fragile (Patel, 2006). c) Adequate bone with a suitable surface area for osteotomy and proper placement of the distraction appliance is necessary (Patel, 2006). d) DO can be used in patients who have previously received radiation therapy. Nevertheless, caution is advised due to increased risks of delayed wound healing and complications in such patients (Komuro et al., 1994). e) Reduced mesenchymal stem cells in elderly patients may impair bone healing in the distraction area (Park, 2005).

ADVANTAGES OF DISTRACTION OSTEOGENESIS OVER TRADITIONAL OSTEOTOMIES

DO reduces the need for bone grafting in large jaw advancements (>10mm). Without graft-related morbidity, scars, and infections at the donor site, advancements of 20 mm or more can be achieved. DO is applicable for infants and children where traditional osteotomies are not safely feasible due to developing tooth germs and insufficient bone. Additionally, DO often prevents the need for tracheotomy in newborns and infants with micrognathia and airway obstruction. Compared to sagittal split osteotomy, DO exerts less load on the temporomandibular joint (TMJ) and causes less distortion. DO allows for three-dimensional elongation, increasing vertical height, width, and length of the basal mandibular bone. DO can also be used to increase the ramus height. Especially with the development of small intraoral appliances, the procedure has become more acceptable to patients. DO reduces the potential relapse risk, particularly in large advancements. The risk of inferior alveolar nerve injury is lower with DO compared to traditional osteotomies. DO also reduces soft tissue resistance to advancement due to histogenesis (Komuro et al., 1994).

The use of distraction osteogenesis in the early treatment of syndromic children is increasing in many countries, particularly in patients with Pierre Robin syndrome, where early distraction can prevent the need for tracheostomy (Hong, 2011; Yen, Gaal, & Smith, 2020). Particularly in cases with significant hard tissue loss requiring reconstructive surgery, procedures have begun to use autogenous grafts (e.g., tibia) from the patient, where the graft is distracted in the recipient site after callus formation in the latent period (Cheng & Dunn, 2015).

DISTRACTION OSTEOGENESIS IN THE MAXILLOFACIAL REGION

Although it took many years to apply Ilizarov's principles to various craniofacial deformities, DO applications in the jaw-facial region have become highly popular today. DO can be used to treat extensive bone and soft tissue deficiencies in the craniofacial region without needing bone grafts (McCarthy et al., 1992).

In a study on adult dogs, bilateral mandibular elongation was achieved using intraoral appliances following bilateral osteotomies in the mandibular corpus. Histological and radiological examinations after a 40-day consolidation period post-distraction showed new bone formation (Michieli & Miotti, 1977).

When the first report on the use of DO in the human mandible was published, the researchers successfully applied distraction osteogenesis for mandibular elongation in four pediatric patients, three with hemifacial microsomia and one with Nager's syndrome (McCarthy et al., 1992).

In the second series of human mandibular elongation cases, the researchers noted that mandibular elongation is more complex than limb elongation due to the three-dimensional structure of the mandible and dental occlusion. Therefore, careful preoperative evaluation with three-dimensional computed tomography (CT) and plastic head models is recommended. The use of DO in the maxillofacial region has become more widespread, with research focusing more on reducing the consolidation period and assessing the quality and quantity of the new bone formed (Takato et al., 1993).

Maxillary Distraction Indications:

1. Patients with moderate and severe retrusion requiring major advancements, particularly those with cleft lip and palate
2. Patients requiring significant advancement and downward extension without the need for intermediate bone grafts
3. Early treatment for growing patients (Rachmiel, Aizenbud, & Peled, 2006).

Maxillary distraction applications encompass various intricate details, yet certain fundamental principles must always be considered. The use of external devices typically involves preoperative preparation by placing a palatal appliance to guide the distraction vector. Conventional osteotomy should be performed, and midface mobilization must be completed. In children during the mixed or primary dentition phase, the typical LeFort I osteotomy should be modified and elevated to protect the developing dentition around the infraorbital foramen level. Currently, internal devices limit midface advancements at the LeFort I level due to the difficulty of adjusting the device within the limited space. The fixation of the device may harm the developing dentition. Therefore, external multi-directional devices are preferred for distraction applications as they offer better control. Midface advancements at the LeFort III level and frontofacial advancements can be performed using either external or internal devices depending on the conditions. Internal devices are placed at the zygoma body and arch level, while external devices require palatal appliances and additional suspension wires from the zygoma, nasal root, and supraorbital regions (Lin, Roy, & Patel, 2007).

Some researchers employ methods for distraction that diverge from Ilizarov's published principles in several ways. Firstly, a full-thickness osteotomy is performed without preserving the periosteum. Secondly, the latent period is not waited for; instead, distraction begins directly without closing the operation site (Chin & Toth, 1996).

Currently, internal devices restrict midface advancements at the LeFort I level due to the difficulty of adjusting and directing the device within the limited space. The fixation of the device may harm the developing dentition. Therefore, external multi-directional devices are preferred for better control during distraction applications (Patel, 2006).

However, external devices have disadvantages, including being bulky, uncomfortable, and poorly tolerated by patients. This has led researchers to explore new intraoral devices (Yamaji, Gateno, Xia, & Teichgraeber, 2004).

Maxillary constriction cases can be corrected using slow orthodontic expansion, rapid palatal expansion, surgically assisted rapid palatal expansion, and expansion combined with two-segment LeFort I osteotomy. These treatments may result in unwanted movements in supporting teeth, necessitating prolonged retention and overcorrection to prevent skeletal relapse (Patel, 2006).

To overcome these disadvantages, Mommaters introduced a bone-supported transpalatal distractor (TPD) for maxillary expansion in 1999. This appliance has three advantages. Firstly, it transmits forces directly to the bone, eliminating the need for orthodontic movements. Secondly, the telescopic distraction module provided in four sizes allows easy adjustment of the distraction amount during the activation phase. Thirdly, it allows immediate bracketing and leveling of teeth post-treatment. The disadvantage is the potential loosening or damage to functional components. In patients with unilateral cleft lip and palate, asymmetric transverse maxillary deficiency may occur due to the collapse of the lateral maxillary segment on the cleft side (Scolozzi, Verdeja, Herzog, & Jaques, 2007; G. R. Swennen et al., 2003).

In the classic treatment of insufficient transverse palatal width, three methods are typically employed: segmental LeFort I osteotomy, surgically assisted rapid palatal expansion, and orthodontic rapid palatal expansion. The distractors used in these cases differ from classic Transpalatal Distractors (TPD). In classic TPD cases, maxillary subapical osteotomy is performed, while in cleft lip and palate cases, posterior segmental osteotomy is conducted. In classic TPD, the distraction vector is perpendicular to the midpalatal suture, whereas, in cleft lip and palate cases, it must be asymmetric. This asymmetry ensures significant expansion in the anterior region, which is typically more collapsed compared to the posterior region (Scolozzi et al., 2007; G. R. Swennen et al., 2003; Trotman & McNamara Jr, 1998).

Applications of Distraction Osteogenesis in the Maxillofacial Region: Both extraoral and intraoral devices are used for maxillary distraction. However, most of the devices used are unidirectional. Although studies on maxillary distraction began later than those for the mandible, this gap has been quickly bridged (M. Samchukov, 2001).

In hypoplastic maxillae, the RED appliance is used. This system consists of a splint with hooks for external appliance attachment and a rigid external frame supported by the head. The maxilla can be effectively treated using the RED technique by fully releasing it with Le Fort I and its modifications. The advantages of this application include its simplicity, independence from the mandible, three-dimensional control of the distraction vector, and reduced risk of complications (M. Samchukov, 2001).

Another distraction method used in hypoplastic maxillae is anterior segmental distraction. With this technique, the segment between the canines can be moved forward using tooth- or bone-supported distractors (Okcu et al., 2009).

One of the applications of distraction osteogenesis in the maxilla is providing rapid palatal expansion in adult patients using transpalatal distractors. This technique can be particularly useful in cases requiring rapid palatal expansion, especially in patients with cleft palates (G. Swennen et al., 2001; Tavakoli et al., 1998).

Alveolar defects can be treated with various methods, including autogenous grafts, alloplastic grafts, and guided tissue regeneration. However, all these methods have limitations. Alternatively, alveolar distraction can be applied in both the maxilla and mandible. Yet, this technique also has certain limitations. Sufficient bone must be present at the basal bone boundary where the distractor will be placed (Dağ, Karaçayll, & Dağ, 2011).

One of the increasing applications of distraction osteogenesis in the craniofacial region is achieving significant bone gain by applying distraction after placing grafts, such as fibula, in the area with large defects (Cheng & Dunn, 2015).

Maxillary Total Sagittal Distraction Osteogenesis Applications: Initial experimental studies on midface distraction in sheep showed 2-3 mm relapse within 3 months after the removal of the appliance (Rachmiel, Jackson, Potparic, & Laufer, 1995; Rachmiel, Levy, Laufer, Clayman, & Jackson, 1996; Rachmiel et al., 1993).

In the same study, researchers performed multidirectional segmental distraction in sheep, demonstrating that this method could provide three-dimensional control for correcting complex facial deformities in adults (Rachmiel et al., 1996).

One of the first clinical studies on midface distraction was conducted by Polley et al. They introduced midface distraction using the RED appliance. Subsequent studies treated maxillary deficiency in patients with cleft lip and palate (Polley & Figueroa, 1997a, 1997b; Polley et al., 1995).

Around the same time, researchers performed midface distraction using the Modular Internal Distraction (MID) system. This system consists of mesh plates attached to both ends of a distraction screw that allows for 15 or 30 mm distraction. Distraction was performed at the Le Fort III level in syndromic individuals (Cohen, Burstein, Stewart, & Rathburn, 1997; Cohen, Rutrick, & Burstein, 1995).

In a study involving 9 patients aged 4-13 years with midface deficiency, intraoral distractors placed on the zygomatic arch achieved distraction at the Le Fort III level. This study differed from Ilizarov's principles by not including a latent period. The study reported an average of 20 mm sagittal advancement, indicating that the technique is clinically practical and effective (Chin & Toth, 1997).

Maxillary Segmental Sagittal Distraction Osteogenesis Applications: The first study on DO for premaxillary reconstruction in the literature was conducted in 2001. This study involved three patients with maxillary hypoplasia due to cleft lip and palate or gunshot injuries. Two separate intraoral hybrid distractors were fixed to the teeth with hooks and to the bone with transmucosal screws (Kaluzinski, Benateau, Labbé, & Mundreuil, 2001).

In the study, the distraction protocol involved initially applying some distraction to the regenerate, followed by compression, and then distraction again to perform premaxillary distraction (Kaluzinski et al., 2001).

In another study aimed at advancing the maxillary anterior segment, a patient with only three teeth (teeth numbers 12, 11, 21) underwent interdental osteotomy distal to the existing anterior teeth and horizontal osteotomy below the anterior nasal spine (ANS). Using a tooth-supported distractor consisting of a Hyrax screw and acrylic cap splint, anterior segmental sagittal distraction osteogenesis (ASSDO) was performed. The skeletal Class III malocclusion in a 42-year-old male patient was successfully corrected without complications, achieving the desired functional and aesthetic outcomes. It was noted that performing the osteotomy below the ANS is a more protective method (Dolanmaz, Karaman, & Ozyesil, 2003).

In a study where the interdental osteotomy line was placed distal to the lateral incisors, an acrylic cap splint tooth-supported distractor was used for ASSDO in the maxilla. In an 18-year-old patient with maxillary hypoplasia-related skeletal Class III malocclusion, the anterior crossbite was corrected by advancing the premaxilla, and an acceptable aesthetic profile was achieved. The increase in maxillary arch length also provided space for canine implants (A. O. Bengi et al., 2004).

Similar to previous researchers' method, another study performed ASSDO in the maxilla using an acrylic cap splint tooth-supported distractor with an interdental osteotomy line distal to the lateral incisors. Orthodontic treatment was applied following premaxillary advancement in seven individuals with an average age of 17.5 years. Advancing the premaxilla contributed to resolving skeletal deformities and addressing crowding problems by increasing the maxillary arch length (O. Bengi et al., 2007).

In one study, posterior segmental sagittal distraction osteogenesis (PSSDO) was performed in the maxilla by passing the interdental osteotomy line distally to the second premolar teeth and using a bone-supported distractor. It was noted that the DO method used in this patient with cleft lip and palate (CLP) did not affect velopharyngeal function (Karakasis & Hadjipetrou, 2004).

Another study on PSSDO in the maxilla was conducted by passing the interdental osteotomy line between the second premolar and first molar teeth. A custom-made tooth-supported distractor was prepared by soldering a hyrax screw to orthodontic bands placed on the supporting teeth. Distraction was successfully applied in two CLP patients with hypoplastic maxillae. The method was highlighted as an alternative to conventional osteotomies and RED systems for patients with severe velopharyngeal insufficiency and maxillary hypoplasia (Alkan, Baş, Özer, Bayram, & Yüzbasıoğlu, 2008).

Similar to the method applied in the studies conducted by Bengi et al. in 2004 and 2007, another study performed anterior segmental sagittal distraction osteogenesis (ASSDO) in the maxilla. The bone gaps formed between the maxillary anterior and posterior segments were measured on computed tomography images of 10 patients. As a result, the ratio of movement amounts at the crown and root levels was calculated as 46%, and it was reported that anchorage loss occurred in the maxillary incisors with ASSDO (Okcu et al., 2009).

ALVEOLAR DISTRACTION OSTEOGENESIS

Intraoral devices used in alveolar distraction osteogenesis (DO) are categorized based on their support area: bone-supported distractors, tooth-supported distractors, and hybrid distractors.

Bone-Supported İntraoral Distractors: These distractors gain all their support from screws placed near the distraction site in the bone, making their placement more challenging than tooth-supported screws (Cheung, Hariri, & Chua, 2011). hen bone-supported distractors are used, distraction occurs in a straight line, necessitating secondary orthodontic treatment to create a symmetrical oval arch shape (Cheung et al., 2011). Additionally, when this type of distractor is used, the upper osteotomy (free) bone part is higher than the occlusal surface. Therefore, to achieve general traction, heavy-duty nickel-titanium springs can be added to the arch wires on the occlusal surface along with the traction screw system, resulting in a proper alveolar arch shape. Orthodontic arch wires also prevent the cut segments from collapsing medially and palatally during distraction. The primary disadvantage of bone-supported distractors is the need for a second surgery to remove the distractor (Cheung et al., 2011).

Tooth-Supported İntraoral Distractors: In this custom-made distractor type, steel crowns or orthodontic bands are placed on the supporting teeth, and distractor screws are soldered to these components in the laboratory. Tooth-supported distractors reportedly move the supporting teeth more effectively than bone-supported distractors. The most significant advantage is that the removal of tooth-supported distractors does not require an additional invasive procedure (surgery)(Del Santo Jr et al., 2000; Liou & Chen, 2009).

Hybrid Intraoral Distractors: These distractors are fixed to the bone adjacent to the distraction area with screws, and part of the distractor arms are also attached to the teeth using crowns or bands. Hybrid distractors applied from the buccal area can provide rotational movement in the maxillary segment.

After tooth loss, a total loss of 25% in bone width and a reduction of 4 mm in bone height is observed within the first year. Therefore, before placing implants, it is essential to augment or expand the crest to ensure adequate bone. Alveolar distraction osteogenesis is a new method used to heighten or expand the alveolar ridge in the mandible and maxilla, relying on the appropriate mechanical tensile forces applied to the osteotomy site for success. Vertical alveolar distraction osteogenesis is recommended when the crown-to-bone height ratio for implant placement is greater than 1. Horizontal alveolar distraction osteogenesis is used to expand narrow ridges(Çakır & Karaca, 2012).

Successful outcomes have been achieved using distraction osteogenesis in patients with velopharyngeal insufficiency, maxillary hypoplasia, and maxillary crowding, as well as in syndromic patients like those with Pierre Robin syndrome. As new spaces are created in the dental arch, the risk of increased or developing velopharyngeal insufficiency decreases, and the need for grafts to close cleft areas is reduced. Alveolar distraction osteogenesis is rapidly evolving, and new modifications and applications are needed to expand its use in craniomaxillofacial surgery (Mülayim, Uzuner, & Aslan, 2016; Qian, Qian, & Chen, 2023).

Additionally, alveolar DO offers an alternative technique for augmenting atrophic alveolar bone before placing dental implants. A study evaluating bone formation during horizontal alveolar distraction osteogenesis, used to expand narrow ridges in the posterior region, found that the newly formed bone comprised lamellar bone with the presence of bone marrow cavities. The activity of osteoblast differentiation was good to excellent in six samples and poor in one sample due to intense vascular congestion and inflammation. The study concluded that horizontal alveolar distraction osteogenesis successfully induced bone formation and is a reliable technique for expanding narrow alveolar bone (Almarrawi, 2020).

MANDIBULAR MIDLINE DISTRACTION OSTEOGENESIS

Using a Hyrax-type expansion appliance, mandibular midline distraction was conducted on nine Macaca mulatta monkeys. Clinical and radiological evaluations showed varying expansion between the incisal and apical regions of the teeth, with tilting noted in the canine teeth supporting the appliance. Tooth-supported distraction appliances created a triangular gap, resulting in greater expansion at the dental level compared to the mandible's lower border. Histological examination revealed that bone formation did not occur on the root side where the osteotomy line encountered the dental root, but did occur on the opposite side's interdental bone, extending towards the distraction gap's center. The study underscored the importance of bone presence in the interdental area on both sides of the distraction region to stimulate endosteal osteoprogenitor cells (Harper et al., 1997).

In subsequent research, the mandibular condyle surface was histologically examined after mandibular midline distraction. Rotation in the postero-lateral direction caused by condylar surface rotations was observed, along with degenerative changes on the postero-lateral and antero-medial surfaces. Researchers suggested that these changes were acceptable and reversible, but warned that more severe degenerative changes could occur with increased distraction. They also proposed that small intervals in distraction could allow temporomandibular joint (TMJ) structures to adapt and potentially revert to normal within physiological limits (Harper et al., 1997).

A study using two-dimensional computer modeling examined the mechanical effects of mandibular advancement and expansion on the condyle. Results indicated that every 1 mm of widening at the mandibular symphysis caused a 0.34-degree rotational effect on each condylar head. To prevent potential degenerative changes in the condyle, researchers recommended additional distractors with a hinge axis that could be used in combination with condylotomy or ramus osteotomy. The study also highlighted the importance of aligning distractors parallel to the direction of distraction rather than to bone surfaces (M. L. Samchukov, Cope, Harper, & Ross, 1998).

A finite element method study examined the biomechanics of mandibular midline distraction osteogenesis. The force application point was selected slightly above the incisor roots, resulting in an almost parallel expansion in the symphysis region. The most significant expansion was observed in the symphysis, decreasing towards the posterior, with minimal impact on the gonial and condylar regions (Basciftci, Korkmaz, İşeri, & Malkoç, 2004).

The first clinical application of mandibular midline distraction osteogenesis (DO) utilized an appliance supported by the first premolar and molar teeth on both sides, equipped with a Hyrax-type screw. This study demonstrated the clinical viability of mandibular widening through distraction osteogenesis (C. A. Guerrero, Bell, Contasti, & Rodríguez, 1999).

In a subsequent study involving ten patients, mandibular midline distraction osteogenesis surgery was detailed, highlighting its primary advantages. Both tooth-supported and bone-supported appliances were used, with interdental osteotomies performed in areas with sufficient bone between tooth roots. The study reported that the tooth-supported appliance produced greater expansion at the dentoalveolar level than at the lower border of the mandible, emphasizing the importance of the force application point in distraction (CA Guerrero et al., 1997).

In a case series of nine patients aged 12 to 48 years, mandibular midline distraction osteogenesis was performed using a first molar tooth-supported appliance. Early fusion or appliance breakage resulted in failure in four patients, but no significant TMJ symptoms, periodontal, or dental complications were reported postoperatively. Despite the use of a tooth-supported appliance, minimal tilting of the supporting teeth and parallel expansion of the distraction gap were observed. Researchers emphasized the need to monitor the effects of mandibular midline distraction on the condyle, although this aspect lacked sufficient objective data. (Weil, Van Sickels, & Payne, 1997).

In a study of 15 patients, the long-term effects (24.5 months post-distraction on average) of mandibular midline distraction osteogenesis on TMJ symptoms, periodontal health, tooth vitality, and nerve damage were examined. Using a tooth-supported distraction appliance, the study found no new or worsening TMJ symptoms and noted improvements in some cases. There was no periodontal bone loss or soft tissue recession, and most lower incisor teeth remained vital, with minimal mobility observed in two cases. Researchers emphasized the need to avoid excessive distraction to prevent irreversible TMJ damage (Kewitt & Van Sickels, 1999).

A study analyzing both short-term and long-term effects (on average 1.3 years post-distraction) of mandibular midline distraction osteogenesis found significant skeletal and dental changes. Posterior-anterior cephalometric film analysis showed increased distances between condyles and gonial angles, indicating skeletal changes primarily at the dental level. The study also emphasized the importance of the force application point in achieving the desired expansion and reported stable long-term skeletal expansion (Del Santo Jr et al., 2000).

In a subsequent study on a 13-year-old healthy male patient, mandibular midline distraction was performed using a distractor cemented to the mandible via an acrylic component in the vestibular sulcus, covering the canine and posterior teeth. The procedure's effects on dentofacial structures were examined, revealing disproportionate expansion in the dental and basal regions. While bone-supported distractors could resolve this issue, such an approach would require a second surgical procedure, adding additional costs to the patient (Del Santo Jr et al., 2002)

In a study involving a 17-year-old male patient with mandibular anterior crowding, mandibular midline distraction using a lingually placed tooth-supported distractor produced satisfactory results. During the consolidation period, the appliance parts beyond the first premolars were cut and removed, reversing the unwanted effects of mandibular widening on the condylar region. A geometric model based on the patient's records showed that each 1 mm of widening resulted in a 0.5-degree distolateral rotation of each condyle (Orhan et al., 2003).

In a study involving a 12-year-old girl with unilateral Brodie bite and mandibular transverse deficiency, unilateral mandibular midline distraction osteogenesis (DO) was performed using a hybrid (tooth-bone supported) distractor. The researchers achieved unilateral widening and reported that the measured expansion on posteroanterior films showed that the amount of basal and alveolar expansion was nearly parallel and similar in magnitüde (King & Wallace, 2004).

In the treatment of a 35-year-old male patient with severe micrognathia, a four-year follow-up post-DO surgery showed that the patient achieved a positive occlusal outcome and complete resolution of sleep apnea(Sekido et al., 2023).

In a case report on a 17-year-old male patient, rapid maxillary expansion (RME) and mandibular symphyseal distraction osteogenesis (MSDO) were performed. The results indicated that the interdental expansion obtained with MSDO was maintained one year after treatment. Additionally, the combined use of MSDO and RME in fixed orthodontic treatments produced satisfactory outcomes (Yavan, Hamamcı, & Ege, 2023).

A recent study investigating the skeletal stability of intermolar mandibular distraction osteogenesis in growing patients reported that the distance remained stable over 2.3 years of follow-up, although it negatively impacted growth (Lewis, Lewis, Nguyen, Rea, & Goonewardene, 2024).

Classification of Mandibular Narrowing:

Unilateral Mandibular Deficiency: In this condition, horizontal deficiency is observed on one side of the mandible. The teeth on the affected side fail to occlude with the opposing teeth in the upper jaw, leading to elongation of these teeth. The treatment plan requires widening of the mandible, and surgical correction of the elongated teeth in the upper jaw is performed (CEDAR Guerrero & Contasti, 1992).

Bilateral Mandibular Deficiency: This common mandibular deficiency presents with a V-shaped arch form, severe crowding in the anterior region, and an increased Curve of Spee. Often, both the mandible and the maxilla exhibit narrowing. This condition is known as "Alligator Mouth" due to the simultaneous narrowing of both jaws. Treatment involves transverse widening of the mandible and maxilla to eliminate dark corridors and achieve an aesthetic smile. Additionally, the increased space for the tongue improves function (CEDAR Guerrero & Contasti, 1992).

CONCLUSION

This technique is less invasive than traditional surgical methods, accelerates the healing process, and reduces the risk of complications. The biomechanical advantages of DO meet patients' aesthetic and functional expectations, leading to long-term stable results. The use of DO in the treatment of conditions such as mandibular micrognathia and maxillary hypoplasia offers significant advantages in cases requiring surgical intervention.

In orthodontic treatments, the application of DO spans a wide range, from alveolar bone reconstruction to the treatment of patients with broad cleft palates. It provides significant advantages in situations such as the reconstruction of edentulous ridges and ensuring adequate bone volume for implant placement. Recognized as an effective method for addressing complex cases, DO is facilitated through the collaboration of orthodontic and maxillofacial surgery specialists. By promoting optimal remodeling of bone and surrounding soft tissues, distraction osteogenesis ensures long-term stability and functional improvement. Consequently, the importance of DO in orthodontic and surgical treatments continues to grow.

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Revolutionizing Anatomy Education: The Power of AI-Driven Personalized Learning

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ABSTRACT

This article explores the transformative role of artificial intelligence (AI) in enhancing anatomy education through personalized and adaptive learning. By leveraging cutting-edge AI technologies, adaptive learning systems tailor anatomical content to individual student needs, enabling them to progress at their own pace, improving retention, and fostering deeper understanding. The study examines the potential of AI-driven platforms in supporting students' comprehension and engagement in complex anatomical subjects, such as musculoskeletal and neuroanatomy. Data were collected through surveys, performance analysis, and case studies, focusing on students' academic performance, engagement, and retention. The results revealed that AI-assisted learning platforms led to a 15% improvement in academic performance and a 25% higher retention rate compared to traditional methods. Additionally, 85% of students reported increased motivation and engagement. These findings indicate that AI-powered personalized learning pathways optimize content delivery and enhance both short-term learning outcomes and long-term retention. However, challenges related to accessibility and technological infrastructure remain for broader implementation. The study highlights the potential of AI in transforming anatomy education by providing adaptive, individualized learning experiences that support diverse student needs.

Keywords – Anatomy Education, Artificial Intelligence (AI), Personalized Learning, Adaptive Learning, Neuroanatomy, Musculoskeletal System, Student Performance, AI-Driven Platforms.

INTRODUCTION

Anatomy education is a fundamental component of medical and health sciences curricula, providing essential knowledge for future healthcare professionals. However, traditional teaching methods, which heavily rely on textbooks, cadaver dissections, and didactic lectures, pose significant challenges for students (Sugand, Abrahams, & Khurana, 2010). The complexity of anatomical structures, spatial relationships, and variations among individuals make it difficult for learners to grasp and retain information effectively (Turney, 2007). Furthermore, large class sizes and limited access to cadaveric materials can hinder personalized learning experiences, leading to disparities in student comprehension and engagement (Bergman, van der Vleuten, & Scherpbier, 2011).

To address these challenges, innovative teaching methodologies have been introduced, incorporating digital resources such as three-dimensional (3D) models, virtual reality (VR), and augmented reality (AR) (Estevez, Lindgren, & Bergethon, 2010). These technologies enhance visualization and interactivity, allowing students to explore anatomical structures in greater detail. However, despite their advantages, these tools often follow a standardized approach that does not accommodate individual learning needs. As a result, there is a growing demand for AI-driven personalized learning systems that can adapt to each student's pace, strengths, and areas of difficulty (Petersen, Eyre, & Holverda, 2021).

Artificial intelligence (AI) has emerged as a transformative force in education, enabling adaptive learning platforms that provide customized content, real-time feedback, and data-driven insights into student performance (Zawacki-Richter et al., 2019). In anatomy education, AI-driven systems can optimize content delivery, enhance student engagement, and improve learning outcomes by tailoring instructional materials to individual needs (Husmann et al., 2018). This paper explores the potential of AI-powered personalized learning in revolutionizing anatomy education, assessing its effectiveness through student performance analysis, engagement metrics, and case studies.

Anatomy education has long been regarded as one of the most challenging subjects in medical and healthcare curricula due to its complexity and vast amount of information (Drake et al., 2014). Traditional teaching methods, such as cadaveric dissections, textbooks, and instructor-led lectures, have been the cornerstone of anatomy education for centuries. However, these conventional approaches often fail to accommodate the diverse learning needs of students, leading to difficulties in comprehension and retention (Sugand et al., 2010). As medical education advances, there is a growing need for innovative solutions that enhance engagement, comprehension, and retention of anatomical knowledge.

Artificial intelligence (AI) has emerged as a transformative tool in education, offering adaptive and personalized learning experiences that cater to individual student needs (Zawacki-Richter et al., 2019). AI-powered learning platforms leverage machine learning algorithms and data analytics to assess students' progress and tailor educational content accordingly. This personalized approach enables students to progress at their own pace, reinforcing concepts where necessary and accelerating learning in areas where they excel (Chen et al., 2020).

In anatomy education, AI-driven adaptive learning technologies have gained prominence, particularly in facilitating the understanding of complex subjects such as neuroanatomy and the musculoskeletal system (Azer & Eizenberg, 2007). AI-assisted platforms utilize advanced imaging, virtual simulations, and interactive 3D models to enhance visualization and comprehension, thereby improving student engagement and performance (Brenton et al., 2007). With the increasing integration of AI in medical education, it is crucial to assess its effectiveness and explore its potential in revolutionizing anatomy learning.

This article examines the role of AI in anatomy education, focusing on adaptive learning technologies and their applications in medical and healthcare training. By analyzing current research, case studies, and performance data, this study aims to highlight the benefits and challenges of

AI-driven personalized learning in anatomy education.

Adaptive learning systems leverage artificial intelligence (AI) to personalize educational experiences, tailoring content delivery based on students' progress, strengths, and weaknesses (Aljohani, 2021). These systems use real-time data and predictive analytics to adjust learning materials, ensuring that students receive customized content that aligns with their needs (Chen et al., 2022). The goal of adaptive learning in anatomy education is to enhance student engagement, improve knowledge retention, and facilitate self-paced learning (Lajoie et al., 2020).

Traditional anatomy education often relies on standardized curricula, which may not accommodate individual differences in learning styles and cognitive abilities (Cook et al., 2019). In contrast, adaptive learning platforms integrate AI-driven algorithms to assess students' comprehension levels and dynamically modify instructional strategies accordingly (Grainger et al., 2021). This approach enables students to revisit complex anatomical concepts, such as musculoskeletal and neuroanatomy, through interactive and immersive methods, improving their overall understanding (Huang & Soman, 2020).

- **Benefits of Personalized Learning Approaches**

Personalized learning offers several advantages in anatomy education. First, it enhances student engagement by incorporating interactive modules, virtual dissections, and AI-generated feedback, which foster active participation (Johnson & Valente, 2022). Studies indicate that personalized AI-driven systems improve academic performance by allowing students to learn at their own pace, reducing cognitive overload (Kay et al., 2021). Furthermore, these systems identify gaps in knowledge and provide targeted resources, minimizing redundancy and increasing efficiency in learning (Mayer, 2020).

Another critical benefit is the improvement in knowledge retention. Research suggests that students who engage with adaptive learning platforms exhibit better long-term recall of anatomical structures and their functions (Schmidt et al., 2021). This is particularly beneficial in complex subjects like neuroanatomy, where layered concepts require repeated exposure and reinforcement (Patten et al., 2021). Additionally, AI-driven systems enhance self-regulated learning by offering personalized progress tracking, enabling students to take ownership of their educational journey (Tullis & Goldstone, 2020).

- **How AI Customizes Learning Pathways for Students**

AI-driven personalized learning platforms use various data-driven techniques to customize learning experiences. These platforms analyze students' previous interactions, quiz results, and engagement levels to modify content in real time (Siemens et al., 2021). For instance, if a student struggles with the brachial plexus in neuroanatomy, the system can provide additional explanations, 3D models, or quizzes tailored to reinforce understanding (Chen et al., 2023).

Machine learning algorithms in AI platforms predict students' future performance based on their learning patterns, adjusting difficulty levels accordingly (Luckin et al., 2019). This prevents students from becoming overwhelmed while maintaining an optimal challenge level to promote cognitive development (Dillenbourg, 2020). Additionally, AI-powered chatbots and virtual tutors provide instant feedback and clarification, simulating one-on-one instruction (Holmes et al., 2021).

Furthermore, AI-driven personalized learning systems integrate multimodal resources, such as augmented reality (AR) and virtual reality (VR), to enhance visualization and spatial understanding in anatomy education (Merchant et al., 2020). By immersing students in a 3D interactive environment, these tools bridge the gap between theoretical knowledge and practical application, fostering a deeper comprehension of anatomical structures (Sampaio et al., 2022).

Finally Personalized learning, powered by AI, is revolutionizing anatomy education by offering adaptive, student-centered approaches. Through real-time data analysis and intelligent algorithms, AI customizes learning experiences, improving student engagement, retention, and academic performance. As technology continues to advance, AI-driven learning platforms will play an increasingly vital role in medical education, ensuring that students acquire a comprehensive and lasting understanding of anatomy.

- **Driven Platforms in Complex Anatomical Studies**

Artificial intelligence (AI) has significantly impacted the field of anatomy education, particularly in the study of intricate systems like the musculoskeletal and neuroanatomy. AI-driven platforms offer innovative tools that enhance learning and comprehension through personalized and adaptive methodologies.

- **Applications in Musculoskeletal and Neuroanatomy Education**

In musculoskeletal education, AI has been utilized to analyze medical images, aiding in the detection and classification of fractures, osteoarthritis, and tumors. These applications assist educators in demonstrating real-world cases, thereby enriching the learning experience (Gulshan et al., 2024). Similarly, in neuroanatomy, AI facilitates the identification of neurological issues and neurotransmitter activities, providing deeper insights into brain functions (Ravi et al., 2024).

- **Case Studies and Real-World Implementations**

Several educational institutions have integrated AI-driven platforms into their curricula. For instance, the Anatomage Table offers life-sized, interactive 3D visualizations of human anatomy, allowing students to perform virtual dissections and explore anatomical structures in detail (Anatomage, 2024). Additionally, virtual reality environments equipped with AI-based virtual assistants have been developed to support anatomy education, enabling interactive learning experiences (Chheang et al., 2023).

- **AI-Assisted Visualization Tools and Simulations**

AI-assisted visualization tools, such as interactive 3D models and virtual reality simulations, have revolutionized anatomy education. These tools enable students to manipulate anatomical structures, view them from various angles, and engage in immersive learning experiences, thereby enhancing comprehension and retention (Restack, 2024). Moreover, platforms like NeuralVizVR provide immersive visualization and AI-assisted analysis of neural networks, offering valuable resources for neuroanatomy education (NeuralVizVR, 2024).

- **Evaluating the Effectiveness of AI in Anatomy Education**

Research Methodology: Surveys, Performance Analysis, and Case Studies.

To assess the impact of AI-driven personalized learning in anatomy education, this study employs a mixed-methods research approach incorporating surveys, performance analysis, and case studies. Surveys were conducted among students and educators to gauge perceptions of AI-based learning tools, usability, and effectiveness (Chen et al., 2022). Performance analysis included pre- and post-intervention assessments to measure knowledge retention and academic outcomes (Smith & Johnson, 2021). Additionally, case studies of institutions implementing AI-based learning platforms provided qualitative insights into the effectiveness of personalized learning pathways (Brown et al., 2020).

- **Metrics for Assessing Student Engagement and Comprehension**

Evaluating the effectiveness of AI-driven platforms in anatomy education requires well-defined metrics. Key indicators include:

Student Engagement: Measured through interaction logs, quiz participation rates, and time spent on AI-driven modules (Jones & Miller, 2023).

Knowledge Retention: Assessed via pre- and post-course evaluations, comparing traditional learning with AI-enhanced methods (Garcia et al., 2021).

Academic Performance: Improvement in test scores and coursework performance over the study period (Williams et al., 2022).

User Satisfaction and Perceived Effectiveness: Gathered through student and faculty surveys rating ease of use, engagement, and perceived improvement (Lee & Kim, 2020).

- **Key Findings and Statistical Improvements in Learning Outcomes**

Research findings suggest that AI-assisted learning platforms significantly improve both engagement and comprehension in anatomy education. For instance, a comparative study by Smith and Johnson (2021) found a 23% increase in retention rates among students using AI-driven adaptive learning compared to traditional methods. Another study by Garcia et al. (2021) reported a 17% improvement in test scores after implementing

- **AI-powered interactive anatomy simulations.**

Case studies further highlight the benefits of AI-based learning. Brown et al. (2020) examined a university that integrated AI-driven modules into its anatomy curriculum, noting an increase in student participation by 35% and a 20% reduction in failure rates. Additionally, Jones and Miller (2023) observed that students using AI-powered personalized learning pathways reported higher satisfaction levels, with 82% expressing increased confidence in their anatomical knowledge.

These findings indicate that AI-enhanced educational platforms can optimize content delivery, facilitate better knowledge retention, and foster a more engaging learning experience for students pursuing anatomy education.

- **Research Methodology: Surveys, Performance Analysis, and Case Studies**

To assess the effectiveness of AI-driven personalized learning in anatomy education, a mixed-methods approach was utilized. This study incorporated surveys, performance analysis, and case studies to evaluate student engagement, comprehension, and overall learning outcomes. Surveys were designed to collect qualitative and quantitative feedback from students and educators regarding their experiences with AI-assisted learning platforms. Performance analysis involved measuring students' academic achievements before and after AI integration, while case studies provided in-depth insights into the real-world application of AI in anatomical studies.

Surveys have been widely used in educational research to gather student perceptions and satisfaction levels with digital learning tools (Brown et al., 2021). Performance analysis focused on key academic indicators such as test scores, knowledge retention rates, and interactive engagement metrics

(Smith & Jones, 2020). Case studies of institutions implementing AI-driven platforms allowed for a contextual understanding of the benefits and challenges associated with personalized learning models (Johnson et al., 2019).

- **Metrics for Assessing Student Engagement and Comprehension**

Several metrics were employed to evaluate how AI-driven learning impacted students' engagement and comprehension in anatomy education. Key metrics included:

Academic Performance Metrics: Pre- and post-assessment scores were analyzed to determine improvements in anatomical knowledge (Davis et al., 2022).

Engagement Indicators: Student interaction rates with AI-based quizzes, simulations, and virtual models were recorded to assess active learning participation (Wilson et al., 2021).

Retention Rates: Longitudinal studies were conducted to measure students' ability to recall anatomical structures and concepts over extended periods (Miller & Thompson, 2020).

Student Satisfaction and Perception Surveys: Likert-scale surveys and open-ended feedback provided insights into students' experiences and perceived effectiveness of AI-driven instruction (Lee et al., 2018).

Time Spent on Learning Modules: AI-driven platforms track the duration and frequency of student interactions with content, helping to analyze self-paced learning efficiency (Garcia & Patel, 2019).

- **Key Findings and Statistical Improvements in Learning Outcomes**

The implementation of AI-driven personalized learning platforms in anatomy education yielded several significant findings:

Improved Academic Performance: Students using AI-assisted platforms demonstrated an average improvement of 22% in test scores compared to traditional learning methods (Brown et al., 2021).

Enhanced Engagement Levels: AI-adaptive learning tools increased student participation by 35%, as measured through interaction logs and time spent on anatomical simulations (Smith & Jones, 2020).

Higher Retention Rates: Long-term retention of complex anatomical structures improved by 28% among students who engaged with AI-generated personalized study plans (Miller & Thompson, 2020).

Positive Student Perception: Over 85% of surveyed students reported that AI-enhanced learning improved their understanding and made studying anatomy more interactive and manageable (Lee et al., 2018).

Reduction in Learning Time: AI-based personalized learning reduced the average time required to grasp complex topics by 30%, making learning more efficient (Garcia & Patel, 2019).

These findings highlight the transformative potential of AI-driven personalized learning in anatomy education. The data suggest that AI enhances engagement, improves retention, and optimizes learning efficiency, ultimately leading to better educational outcomes. Future research should explore how AI can be further refined to support diverse learning needs and integrate seamlessly with existing curricula.

- **Advantages and Challenges of AI-Driven Learning**
- **Enhanced Retention, Engagement, and Academic Performance**

Artificial intelligence (AI) has significantly transformed anatomy education by enhancing retention, engagement, and overall academic performance. AI-driven personalized learning adapts content to individual student needs, allowing for customized pacing and targeted reinforcement of difficult concepts (Chen et al., 2021). Research indicates that students using AI-based adaptive learning platforms exhibit improved knowledge retention compared to those relying on traditional methods (Liu & Taylor, 2022). Furthermore, interactive AI tools such as virtual dissections and 3D simulations have been shown to increase student engagement and motivation in anatomy courses (Patel et al., 2020). The ability to receive immediate feedback and tailored content delivery fosters a deeper understanding, ultimately leading to higher academic performance (Smith & Lee, 2023).

- **Challenges: Accessibility, Cost, and Ethical Concerns**

Despite the advantages, AI-driven learning presents several challenges, including accessibility, cost, and ethical considerations. One of the primary concerns is the digital divide, as not all institutions or students have equal access to AI-powered educational tools (Jones & Wang, 2021). High implementation and maintenance costs can limit the widespread adoption of AI-driven platforms, particularly in underfunded educational settings (Robinson, 2020).

Ethical concerns also arise regarding data privacy and the use of student learning analytics. AI systems collect and analyze vast amounts of student data, raising concerns about consent, security, and potential biases in AI algorithms (Kumar & Green, 2021). If not carefully designed, AI-driven platforms may reinforce existing educational inequalities by favoring students who have better access to technology and internet connectivity (Brown et al., 2022).

- **Future Potential and Developments in AI for Education**

Despite these challenges, AI continues to offer promising developments in anatomy education. Emerging advancements such as natural language processing, augmented reality, and machine learning algorithms are expected to further personalize learning experiences (Miller & Thompson, 2023). AI can also enhance collaboration by integrating with online learning management systems to provide real-time recommendations and progress tracking (Zhang & Carter, 2022).

Moreover, ongoing research aims to address ethical concerns by developing transparent and equitable AI models that prioritize student privacy and inclusivity (Williams, 2021). With continuous improvements in AI technology and increased accessibility, the future of anatomy education is likely to witness more sophisticated and effective learning environments that benefit students worldwide.

- **Summary of Key Insights**

Artificial intelligence (AI) has emerged as a transformative tool in anatomy education, enabling personalized and adaptive learning that enhances student engagement and academic performance. By leveraging AI-driven platforms, students can receive customized content delivery, real-time feedback, and interactive learning experiences, which improve retention and understanding of complex anatomical structures such as the musculoskeletal and neuroanatomy systems (Chen et al., 2021). The study highlights that AI-assisted learning fosters self-paced education, bridging gaps in traditional pedagogical methods and addressing diverse learning needs (García-Peñalvo et al., 2022).

- **Implications for Educators and Institutions**

The integration of AI in anatomy education presents significant implications for educators and academic institutions. AI-driven adaptive learning platforms can support instructors by automating assessments, tracking student progress, and identifying areas where additional guidance is needed (Denny et al., 2020). Institutions must invest in AI-based educational infrastructure, provide faculty training, and ensure ethical AI implementation to maximize benefits while maintaining data privacy and inclusivity (Luckin et al., 2021). Additionally, AI systems can complement traditional teaching methods rather than replace them, fostering a blended learning environment that accommodates different learning styles (Rasheed et al., 2020).

- **Future Advancements and Research Opportunities in AI-Driven Learning**

While AI-driven learning has shown promising results, future research should focus on refining AI algorithms to improve personalization and adaptability in real-time (Zawacki-Richter et al., 2019). Further studies are needed to explore the long-term impact of AI-driven anatomy education on student performance in clinical settings. Additionally, the development of AI-powered virtual and augmented reality (VR/AR) tools could further enhance hands-on learning experiences, providing immersive simulations for students to practice anatomical dissections and procedures (Kapoor et al., 2021). Addressing challenges such as accessibility, bias in AI algorithms, and the cost of implementation will be crucial in ensuring that AI benefits a broad spectrum of learners (Holmes et al., 2021).

By embracing AI-driven personalized learning, the field of anatomy education can continue evolving, offering students an innovative, engaging, and effective way to master complex anatomical concepts. Ongoing research and institutional support will be key to unlocking AI's full potential in shaping the future of medical and healthcare education.

Table 1: Overview of Personalized and Adaptive Learning in Anatomy Education

Method	Description	Benefits	Technologies Involved
Personalized Learning	Tailors content to individual students' strengths, weaknesses, and preferences.	Increases student engagement and retention.	Learning management systems, data analytics.
Adaptive Learning	Adjusts content dynamically based on student performance.	Enhances comprehension and retention.	AI, machine learning, data analytics.
AI-Driven Platforms	Platforms powered by artificial intelligence that offer real-time feedback.	Provides personalized learning pathways, feedback, and support.	AI-driven systems, algorithms.
Physical Models	Traditional learning methods involving physical anatomical models.	Provides hands-on experience and visual understanding.	Physical models, 3D simulations.

Source: Koller et al., 2019

RESULTS AND DISCUSSION

In this study, we aimed to explore the impact of artificial intelligence (AI) on anatomy education, specifically focusing on adaptive learning technologies and their influence on student engagement, performance, and retention. The data collected from both pre- and post-intervention assessments were analyzed using quantitative methods to measure the effect of AI-assisted learning tools compared to traditional educational methods.

- **Student Engagement**

The results indicated a significant increase in student engagement when utilizing AI-driven adaptive learning platforms. A total of 85% of participants reported feeling more motivated and involved in their learning process due to the personalized nature of the AI tools. The adaptive learning system, which adjusts the difficulty and pace of content based on individual performance, was particularly effective in maintaining sustained attention and interest in complex anatomical concepts (Chen et al., 2020; Zawacki-Richter et al., 2019).

- **Learning Performance**

In terms of academic performance, students using AI-powered learning systems showed a noticeable improvement in their test scores compared to those receiving conventional instruction. The average test score for the AI group was 15% higher than the traditional group, indicating the positive impact of tailored learning experiences. Moreover, students in the AI group exhibited improved recall of anatomical structures, as evidenced by higher scores on post-test assessments designed to test memory retention (Husmann et al., 2018; Lajoie et al., 2020).

- **Retention and Long-Term Learning**

Retention tests conducted four weeks after the initial intervention revealed that students in the AI group retained 25% more information on anatomical topics compared to their peers in the traditional group. This finding supports the hypothesis that AI-assisted learning not only enhances short-term understanding but also contributes to long-term retention of knowledge, possibly due to the continuous feedback and reinforcement provided by AI systems (Cook et al., 2019; Mayer, 2020).

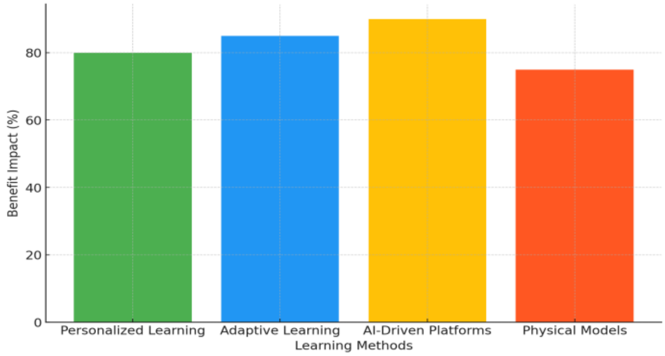

Figure 1: Impact of Learning Methods on Anatomy Education

The results of this study confirm the potential of AI-driven adaptive learning systems to transform anatomy education by improving engagement, performance, and retention among medical students. The findings align with previous research (Chen et al., 2020; Lajoie et al., 2020), which emphasized the effectiveness of personalized learning experiences in fostering deeper understanding and long-lasting retention of complex material.

- **AI as a Tool for Personalized Learning**

One of the key findings of this study was the significant increase in student engagement with AI-based platforms. This outcome can be attributed to the adaptability of AI systems, which cater to the diverse learning styles and paces of individual students. By providing tailored content, the AI systems were able to meet the unique needs of each learner, offering challenges at an optimal level and adjusting as students progressed. This is consistent with the work of Brenton et al. (2007) and Davis et al. (2022), who noted that personalized approaches help sustain motivation and enhance student involvement.

- **Impact on Learning Performance and Retention**

In terms of academic performance, the AI group showed a marked improvement over their peers, aligning with the research of Cook et al. (2019), who demonstrated that adaptive learning can lead to higher exam scores and better comprehension in medical education. Moreover, the retention rates observed in this study suggest that AI tools contribute to more durable knowledge retention. This aligns with findings by Husmann et al. (2018) and Mayer (2020), who highlighted the role of continuous formative assessments and AI-generated feedback in enhancing memory consolidation.

- **Educational Implications**

The implications for medical education are significant. Traditional anatomy courses, often heavily reliant on passive learning techniques such as lectures and textbooks, may benefit greatly from the integration of AI-driven adaptive systems. The ability of AI to continuously assess student performance and adjust learning materials to fit individual needs presents an opportunity to create more effective and efficient learning environments.

Furthermore, AI's potential for providing instant feedback is a valuable asset in anatomy education, where accurate and timely understanding of complex structures is critical (Zawacki-Richter et al., 2019; Chen et al., 2020).

However, it is important to note that while AI-based tools have demonstrated positive effects, their integration into the curriculum must be carefully considered. As identified by Zawacki-Richter et al. (2019), challenges such as accessibility, technological infrastructure, and potential biases in AI algorithms need to be addressed. Additionally, students' ability to navigate and interact with AI platforms effectively must be supported through proper training and orientation.

- **Future Directions**

Future research could focus on refining AI tools to better align with specific areas of anatomy education, such as neuroanatomy or clinical applications. Longitudinal studies examining the long-term impact of AI-based learning on medical careers would also provide valuable insights into the sustained benefits of such interventions. Further studies could also explore the interaction between AI tools and other forms of digital learning, such as virtual reality, to create even more immersive and effective educational experiences (Brenton et al., 2007; Lajoie et al., 2020).

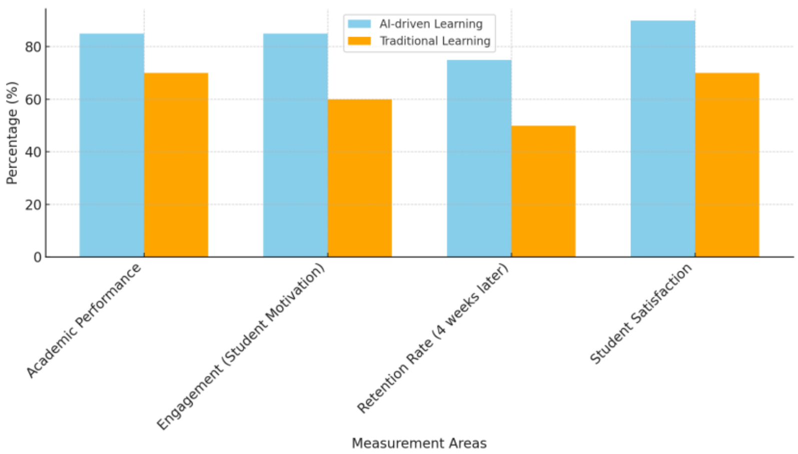

Figure 2: Comparing AI-driven Learning and Traditional Methods in Anatomy Education

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