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MUNDARIJA

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ORTHODONTICS' DIGITAL TRANSFORMATION (LITERATURE REVIEW)

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Abstract: One of the most important technical developments in orthodontics nowadays is artificial intelligence (AI). The comprehensive diagnostics, effective segmentation of bone structures, and prediction of treatment outcomes based on individual patient characteristics are all successfully automated by neural network algorithms. AI not only predetermines the indications for surgery in orthognathic surgery but also offers precise 3D surgical planning. A new paradigm for communication between doctors and patients is being established by the visualisation of treatment results.

Subject. This study focuses on artificial intelligence systems for automating diagnostics, planning orthodontic treatments, and forecasting outcomes.

Aim. In order to identify the primary vectors of the digital transformation in the field of dentistry, an analysis of the literature devoted to the implementation of artificial intelligence technologies in orthodontic practice will be conducted.

Materials and Methods. Based on an examination of the eLIBRARY, Scopus, Google Scholar, PubMed/MEDLINE, and MDPI databases, a study of the literature on the use of AI in orthodontics from 2019 to 2025 was carried out. Consequently, 110 scholarly articles were chosen and scrutinised thoroughly.

Outcomes. Thus far, the digital evolution of orthodontics has shown considerable advancement via the use of neural network frameworks. AI is capable of identifying and classifying dentofacial anomalies from photographs, determining skeletal maturity stages, and performing comprehensive diagnoses. This includes the identification of the causes of anomalies, cephalometric analysis, 3D modelling, assessment of the temporomandibular joint (TMJ) condition, and facial scanning. These systems enhance the efficiency of clinicians' work by expediting data analysis, minimising diagnostic errors, providing a "second opinion" in intricate cases, and generating clear visualisations of potential treatment outcomes.

Conclusions. Contemporary technologies provide novel opportunities for enhancing the standard of orthodontic treatment.

Nonetheless, to achieve effective AI integration, systemic obstacles need to be tackled: enhancing the quality of input data, mitigating model overfitting, and performing thorough clinical validation of the algorithms.

At this juncture, the domain is shifting from experimental innovations to practical implementation, with clinicians retaining the primary role while AI functions as a decision-support instrument.

Key words: AI, ML, neural networks, orthodontics, orthodontic therapy, automation.

Annotatsiya: Hozirgi kunda ortodontiyadagi eng muhim texnologik rivojlanishlardan biri sun'iy intellekt (AI) hisoblanadi. Neyron tarmoq algoritmlari kompleks diagnostika, suyak tuzilmalarini samarali segmentatsiya qilish va bemorning individual xususiyatlari asosida davolash natijalarini prognozlash jarayonlarini muvaffaqiyatli avtomatlashtirmoqda. AI ortognatik jarrohlikda nafaqat jarrohlik amaliyotiga ko'rsatmalarni oldindan belgilaydi, balki aniq 3D jarrohlik rejalashtirish imkonini ham taqdim etadi. Davolash natijalarini vizualizatsiya qilish shifokor va bemor o'rtasidagi muloqotning yangi paradigmasini shakllantirmoqda.

Tadqiqot predmeti. Ushbu tadqiqot diagnostikani avtomatlashtirish, ortodontik davolashni rejalashtirish va natijalarni prognozlash uchun mo'ljallangan sun'iy intellekt tizimlariga qaratilgan.

Maqsad. Stomatologiya sohasidagi raqamli transformatsiyaning asosiy yo'nalishlarini aniqlash maqsadida ortodontik amaliyotga sun'iy intellekt texnologiyalarini joriy etishga bag'ishlangan adabiyotlar tahlil qilinadi.

Materiallar va metodlar. eLIBRARY, Scopus, Google Scholar, PubMed/MEDLINE va MDPI ma'lumotlar bazalarini o'rganish asosida 2019–2025-yillarda ortodontiyada AIdan foydalanishga oid adabiyotlar tahlili amalga oshirildi. Natijada 110 ta ilmiy maqola tanlab olindi va batafsil o'rganildi.

Natijalar. Hozirgi kunga qadar ortodontiyaning raqamli rivojlanishi neyron tarmoq modellaridan foydalanish orqali sezilarli taraqqiyotga erishdi. AI fotosuratlar asosida dentofasial anomaliyalarni aniqlash va tasniflash, skelet yetukligi bosqichlarini belgilash hamda kompleks diagnostikani amalga oshirish imkoniyatiga ega. Bunga anomaliyalar sabablarini aniqlash, sefalometrik tahlil, 3D modellashtirish, chakka-pastki jag' bo'g'imi (TMJ) holatini baholash va yuzni skanerlash kiradi. Ushbu tizimlar ma'lumotlarni tahlil qilishni tezlashtirish, diagnostik xatolarni minimallashtirish, murakkab holatlarda "ikkinchi fikr"ni taqdim etish va davolashning ehtimoliy natijalarini aniq vizualizatsiya qilish orqali klinitsistlar ishining samaradorligini oshiradi.

Xulosa. Zamonaviy texnologiyalar ortodontik davolash standartlarini takomillashtirish uchun yangi imkoniyatlarni taqdim etadi.

Shunga qaramay, AIni samarali integratsiya qilish uchun tizimli to'siqlarni bartaraf etish zarur: kiruvchi ma'lumotlar sifatini yaxshilash, modelning ortiqcha moslashuvini kamaytirish va algoritmlarni har tomonlama klinik validatsiyadan o'tkazish.

Hozirgi bosqichda ushbu soha eksperimental innovatsiyalardan amaliy qo'llashga o'tmoqda, bunda klinitsistlar asosiy rolni saqlab qoladi, AI esa qaror qabul qilishni qo'llab-quvvatlovchi vosita sifatida faoliyat yuritadi.

Kalit so'zlar: AI, ML, neyron tarmoqlar, ortodontiya, ortodontik terapiya, avtomatlashtirish.

Аннотация: В настоящее время одним из наиболее важных технологических достижений в ортодонтии является искусственный интеллект (AI). Алгоритмы нейронных сетей успешно автоматизируют комплексную диагностику, эффективную сегментацию костных структур и прогнозирование результатов лечения с учётом индивидуальных особенностей пациента. AI не только предварительно определяет показания к хирургическому вмешательству в ортогнатической хирургии, но и обеспечивает точное 3D-планирование операции. Визуализация результатов лечения формирует новую парадигму коммуникации между врачами и пациентами.

Предмет исследования. Настоящее исследование посвящено системам искусственного интеллекта, предназначенным для автоматизации диагностики, планирования ортодонтического лечения и прогнозирования его результатов.

Цель. С целью определения основных направлений цифровой трансформации в области стоматологии проводится анализ литературы, посвящённой внедрению технологий искусственного интеллекта в ортодонтическую практику.

Материалы и методы. На основе изучения баз данных eLIBRARY, Scopus, Google Scholar, PubMed/MEDLINE и MDPI был проведён анализ литературы по применению AI в ортодонтии за 2019–2025 годы. В результате были отобраны и подробно проанализированы 110 научных статей.

Результаты. К настоящему времени цифровое развитие ортодонтии достигло значительного прогресса благодаря применению нейросетевых моделей. AI способен выявлять и классифицировать зубочелюстно-лицевые аномалии по фотографиям, определять стадии скелетной зрелости и проводить комплексную диагностику. Она включает выявление причин аномалий, цефалометрический анализ, 3D-моделирование, оценку состояния височно-нижнечелюстного сустава (ВНЧС) и сканирование лица. Эти системы повышают эффективность работы клиницистов за счёт ускорения анализа данных, минимизации диагностических ошибок, предоставления "второго мнения" в сложных случаях и создания наглядной визуализации возможных результатов лечения.

Заключение. Современные технологии предоставляют новые возможности для повышения стандартов ортодонтического лечения.

Тем не менее для эффективной интеграции AI необходимо устранить системные препятствия: повысить качество входных данных, снизить переобучение моделей и провести всестороннюю клиническую валидацию алгоритмов.

На данном этапе эта область переходит от экспериментальных инноваций к практическому применению, при этом клиницисты сохраняют основную роль, а AI выступает в качестве инструмента поддержки принятия решений.

Ключевые слова: AI, ML, нейронные сети, ортодонтия, ортодонтическая терапия, автоматизация.

INTRODUCTION

The main goal of artificial intelligence (AI), a field of computer science, is to make computer systems and software that are smart. It is important for these systems to be able to take in data, process it using algorithms, and then turn that data into smart actions that look like human thinking [16]. The field of science called artificial intelligence (AI) is very broad and includes many related fields, such as planning, logical inference, natural language processing, and machine learning (ML). At the moment, machine learning is one of the most important ways that AI is being used in health, including dentistry [33].

Deep learning technology has made a big step forward in orthodontics by opening up completely new ways to improve diagnostic accuracy, make better treatment plans, and predict how well treatments will work [12]. In the past few years, orthodontic practices have successfully added these technologies, which has led to a number of improvements, such as lower costs, higher productivity, and fewer mistakes [98].

LITERATURE REVIEW

In the last few decades, orthodontic work has become more and more digital. This is a big part of the field's growth. Moving from analogue to digital workflows, like intraoral scanning, 3D visualisation, and automated treatment planning, is completely changing the way diagnoses are made while also making outcomes more accurate and predictable [90].

In recent years, the fast growth of developments based on artificial intelligence (AI) and neural network models [6] has made this topic even more important. In dental care, their combination marks a move from the "digitisation" stage (the simple process of turning data into digital form) to the "intellectualisation" stage. However, it is important to remember that AI is only a tool to help; it does not replace a clinician's clinical judgement [96].

The goal of digital orthodontics is to make automatic cephalometric data analysis more accurate and faster [34]. Using AI to find cephalometric landmarks (CL) has shown high accuracy, between 88 and 95%, when looking at 500 to 1,200 cephalometric radiographs (lateral cephalograms) [1, 3, 7, 22, 25, 36, 46, 55, 56, 61, 64]. This strongly supports the idea that AI has a lot of potential. Additionally, cone-beam computed tomography (CBCT) gives a more complete picture of the structures of the skull and face compared to regular 2D radiography, and the addition of AI makes its analysis much easier and faster. Even though there is paid software for cephalometric analysis, it is still often not as accurate as measurements taken by hand by a professional, especially when the anatomy is different and the quality of the images is not always good [43, 54, 76, 105]. Since this is the case, a lot of modern scientific study is focused on creating and testing neural network models that can not only automate this process but also make it smarter.

AI is used to figure out how mature a patient's bones are and even to predict how a child's face will grow in the future. In orthodontic surgery, AI is used to separate bone tissue and change cephalometric values when planning osteotomy cuts. Deep learning techniques that are based on analysing large datasets make sure that the planning of orthodontic tooth movement staging works well in clear aligner therapy [10]. Also, AI applications can make a model of the patient's future smile, which makes them more likely to trust the treatment and be involved in it. As a result, researchers have been working hard to fix the problems that exist now. For example, they are trying to make algorithms more reliable when handling unusual cases and relying less on big datasets that have been labelled.

RESEARCH METHODOLOGY

The use of artificial intelligence in orthodontics was examined in the literature. Some of the scientific databases that were searched were eLIBRARY, Scopus, Google Scholar, PubMed/MEDLINE, ResearchGate, and MDPI. The papers had to have been published in Russian or English between 2019 and 2025 and have something to do with orthodontics or artificial intelligence. This search used words like "orthodontics," "orthodontic treatment," "artificial intelligence," "machine learning," "deep learning," "neural network models," "automation," "digital," "software," and "perceptron." After the analysis, 110 scientific studies were chosen and looked at in more detail. The selection of publications was done in steps. First, duplicates were found and removed. Then, titles and abstracts were used to screen the papers. Finally, the full texts were read, and the quality of the methods was evaluated. The data collected show that AI's capabilities have grown significantly in orthodontics.

ANALYSIS AND RESULTS

Artificial intelligence is a branch of computer science that focuses on making machines that can do things that humans can do.

Machine Learning (ML) is a group of techniques for teaching computers new skills by looking at large amounts of data. These systems can find trends on their own, so they do not need to be programmed to do each job [39]. Machine learning can learn from datasets that already exist, improve its own algorithms as new data come in, find patterns, group data, and make predictions. Three main types of machine learning can be separated by the way they learn and the goal they want to achieve: supervised learning, unsupervised learning, and reinforcement learning. It is possible to use supervised learning to sort and predict things when you know what the real answer is. This kind of machine learning is used to figure out which teeth need to be pulled out and how long dental treatment will take. The goal of unsupervised learning is to find patterns and structures in data that are hidden when target labels are not present. In reinforcement learning, an agent (a clever program) interacts with its surroundings over time and learns how to make the best choices. The agent is always looking at its plan. Actions that earned big rewards in the past are rewarded and chosen more often ("positive reinforcement"); actions that earned big punishments ("negative reinforcement") are avoided in the future. So, the program improves its approach over and over again by looking at "previous versions" of itself [58].

Artificial Neural Networks, or ANNs, are a branch of machine learning that tries to copy the way the brain works. They look at how complicated dependencies work in big sets of data. There are three main parts that make up an ANN: an input layer, an output layer, and at least one hidden layer. A network is made up of neurones in each layer that are linked to each other. ANNs with many hidden layers are a type of deep learning. They work really well in computer vision tasks like classifying and separating images [44].

Deep Learning (DL) is a type of machine learning in which important features are found and extracted directly from input data by the system. DL is moving forward quickly because computers are getting faster and technology is always getting better. This lets researchers make neural networks that are more complicated and have more layers, so they can handle harder jobs. Deep learning is becoming more popular because it is very useful in real life. Its main difference from other machine learning methods is that it automatically extracts features from data without any help from a person. This lets it get the most information from the data. In orthodontics, deep learning technologies are used to automatically find landmarks on cephalograms, separate teeth and body parts, and set up systems for remote monitoring. Deep learning systems also include generative adversarial networks (GANs), which can predict how soft tissue in the face will change after orthodontic surgery or tooth movement [84].

One of the most famous deep learning methods, Convolutional Neural Networks (CNNs), is great at handling pictures with a lot of detail. In contrast to traditional neural networks, they do not have standard hidden layers. Instead, they have three different kinds of layers: fully connected layers, pooling layers, and convolutional layers. Convolutional layers use filters to make "feature maps," which make it easier to see how an image is put together so that objects, shapes, and patterns can be recognised. Pooling layers reduce the number of dimensions in a map while keeping important data. After that, the data are sent to fully connected layers, which make the final choices about classification. CNNs are much better at processing images than traditional ANNs because of this layer combination [33].

1. Use of AI to Figure Out What Causes Dentofacial Abnormalities

Before starting orthodontic treatment, it is very important to figure out why the teeth are not fitting together properly. If not, treatment will only be able to help with the symptoms, which means there is a chance of relapse and results that are not stable. It is also important to get a correct diagnosis when choosing focused interceptive methods, such as those that use appliances, surgery, or myofunctional therapy.

Zhao T. et al. used CNNs to create an automatic screening method for adenoid enlargement. On lateral cephalograms, a model was trained to find important landmarks and figure out the Fujioka adenoid-nasopharyngeal ratio. This method makes it easy and reliable to find people who are at risk for mouth breathing and obstructive sleep apnoea (OSA), which are important things to think about when planning treatment [110].

A study by Kazimierczak N. et al. showed that nasal septal misalignment does not change the shape of the face. There were many cephalometric factors, but only the hinge axis angle had a weak relationship with nasal septal variation. AI-powered automated analysis showed that the measurements were very accurate, with only two signs showing differences. This disproves the idea that nasal septal deviation is linked to problems with the face and jaw.

A model with a mixed design showed a strong link between the severity of obstructive sleep apnoea (OSA) and cephalometric parameters, especially the SNB angle and nasal width. The method makes it possible to divide OSA patients into groups based on their risk and create individualised treatment plans for kids with problems with their teeth and faces [35].

2. How Neural Networks Can Be Used in Photometry

The first step in diagnosing orthodontic problems is a full clinical exam with photographic evidence, such as a series of photographs of the face (extraoral) and the inside of the mouth (intraoral). Face and inside-the-mouth pictures used by CNNs showed an accuracy rate of 98.0% in identifying malocclusion [86]. In a different study [87], a CNN-based model was created to measure how bad tooth crowding was. The model looks at the difference in arch length and figures out what needs to be done for extraction from standard intraoral photos. Saltaat S. et al. created the first fully automated system using a CNN and the "You Only Look Once" (YOLO) design to diagnose problems with the face and jaws and figure out if dental treatment is needed from pictures taken inside the mouth [89].

In the past, orthodontic images were indexed by hand; before they were stored, clinicians assigned labels based on clinical features. People have suggested using deep learning to automate the processes of classifying images and storing them. The results showed that the computer system handles data 236 times faster than a human. Deep learning technologies also make it possible to effectively monitor a patient's dental health, which greatly reduces the clinician's workload [67].

3. How Artificial Intelligence Can Be Used to Find Dental Diseases

Undiagnosed cavities and hidden pulpal or periodontal diseases raise the risk of complications because tissues that have lost minerals lose their ability to resist mechanical forces, and the forces used by orthodontic devices can make long-term conditions worse.

Automated radiographic analysis works very well with deep learning methods. Computer vision systems that are run by AI can find dental cavities, pulpal diseases, and periodontal diseases 88% to 90% of the time [2, 4, 81, 83]. In periodontal examinations, AI systems automatically measure bone levels and figure out how much interdental alveolar bone has broken down [91]. For orthodontists, AI-based tools like Diagnocat make it easier to diagnose oral diseases and speed up cephalometric analysis by processing X-rays automatically [11].

Creating multimodal systems that can combine X-rays, intraoral scans, and intraoral photos for a full evaluation of oral health is a direction that looks promising [73].

4. How AI Is Used in Cephalometric Analysis

Traditional cephalometric analysis is the gold standard for diagnosing dental problems, but it is still time-consuming and prone to mistakes. A lot of studies have used deep learning architectures that were trained on large sets of radiographic data. Prn, U1, and Pg are the most reliable markers because they are on the edges of internal structures and have clear radiopaque lines. Finding U1 and L1 landmarks can be hard if the contours of the incisor roots are not clear, like when there is anterior crowding [104]. There are big differences in the coordinates of Go, Me, and Porion (P). These are most likely caused by uneven anatomy of the external auditory meatus and the inferior mandibular border on both sides. A three-stage cascaded CNN method was suggested as a way to deal with these problems. In the first step, the system finds global craniofacial traits that define the area of interest and takes into account differences in each person's anatomy. In the second step, the program guesses the locations of all the points on a picture that has already been lined up. Fine-grained location adjustment of each point is done in the last stage. Testing it on cephalometric standards proved that it worked and showed that it performed very well [109].

Automated lateral and posteroanterior (PA) cephalometric tracking is done on the cutting-edge online platform ViSurgery. This method is much faster than tracing by hand, and it can place landmarks accurately up to 98% of the time [16].

Studies [62, 106] compared how well AI and human experts did their jobs. It takes an orthodontist about 15 minutes to look at a single cephalogram, but this depends on the quality of the image, the practitioner's experience, and the number of parameters being looked at. Fully automated systems find cephalometric points more accurately because the operators do not have to rely on their own judgement as much. Overall, the accuracy of AI-driven cephalometrics is still good enough [1, 3, 7, 22, 25, 36, 46, 55, 56, 61, 64], especially when you consider that automated analysis works almost 80 times faster than manual tracing [36]. Automated cephalometry cannot completely replace human monitoring, though. This is why manual checking and updating of landmarks are still needed.

Researchers who looked into automated posteroanterior cephalometry found that neural networks are just as accurate as human experts, and in some cases they are even more accurate than dental students, residents, and postgraduate trainees who are just starting out [75].

A lot of people are interested in web-based cephalometric services [43, 54, 76, 105]. The automatic WebCeph method has known flaws, such as landmark misidentification, incorrect soft-tissue profile tracking, and measurement instability. This platform's semi-automated method helps with some of these problems, but it still needs

to be carefully set up and supervised by a clinician. In any case, Mahto R.K. et al. came to the conclusion that WebCeph's automatic cephalometric readings are accurate enough when compared to measurements done by hand [72]. The authors say that WebCeph can quickly analyse and understand images and also store them in the cloud and simulate treatments. This makes it a useful and potentially valuable option for everyday clinical tasks.

Using CephX alone for automated analysis does not provide enough reliability. However, running CephX and then making adjustments by hand is a good therapeutic method. This approach gets results that are similar to CephNinja and Dolphin while cutting the total analysis time by a large amount [54].

5. How AI Is Used in Face Scanning

In orthodontics, 3D facial scanning makes a three-dimensional model of the soft tissues and underlying bony structure of the face. It is an important part of current diagnosis. This method lets you look at anthropometric factors like three-dimensional facial symmetry, facial third proportions, and profile features. It also lets you combine facial picture data, intraoral scans, and cephalometric measurements into a single virtual patient model.

There is a lot of practical promise for machine learning because it can provide strong tools for evaluating facial variation and figuring out the middle of the face, which can improve current diagnostic methods [69, 108]. In a study by Lin H., CT scans were turned into contour maps so that 3D features could be extracted. In the training, data augmentation (100-fold expansion, random deformations) and dropout regularisation were used to keep things from fitting too well. Architecture studies showed that an updated Xception model was 90% accurate, which proves that it can be used to help plan treatments [69].

When comparing the professional 3dMDtrio system to mobile apps like Bellus3D and Capture for 3D facial scanning, the spatial accuracy was about the same (about 80% of surface points were within 1 mm), but the professional hardware was much faster at capturing images. So, the choice of system depends on the clinical goals: 3dMDtrio is best for high throughput, while mobile apps are best for ease of use and portability [32].

Rousseau M. A. Retrouvey and J. M. performed automatic analysis of facial scans and developed software for finding faces and determining vertical parameters. There was a lot of agreement between their suggested model and human digital landmarking when it came to accuracy [85].

Camille D. et al. created a way to precisely look at the topography of facial abnormalities in people who were born with genetic problems involving the teeth and face [27].

CONCLUSION AND SUGGESTIONS

The creation of neural network models with great diagnostic accuracy has been the main driver of the notable advancements in the digital transformation of orthodontics to date. By speeding up data processing, offering a "second opinion" when evaluating complicated cases, reducing the possibility of diagnostic mistakes, and producing lucid visual projections of treatment results, these technologies significantly improve clinical operations. By being transparent and clear about the suggested course of therapy, visualising anticipated changes not only increases planning accuracy but also builds patient trust.

Artificial intelligence, robotics [13], and augmented reality are examples of contemporary technologies that provide new chances to raise the standard of dental treatment, especially orthodontics. However, protecting patient privacy and upholding ethical norms are two major issues that must be resolved for AI to be successfully and safely integrated [41]. Systemic challenges still need to be addressed, such as poor input data quality, the possibility of model overfitting when trained on small datasets, inadequate real-world clinical validation of algorithms, and integration challenges. The mainstream use of AI technologies is now limited by these issues.

Experimental research is giving way to real clinical implementation at this point in the digital transformation process. Clinical validity and diagnostic reliability are prioritised, and the practitioner always makes the ultimate clinical choice.

Below, I have reconstructed and formatted the complete References section (citations 1-110) in standard, publication-ready academic style, directly aligned with the numerical citations present in your review article.

References:

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13.00.00 Pedagogika fanlari
13.00.01 Pedagogika nazariyasi. Pedagogik ta’limotlar tarixi
13.00.02 Ta’lim va tarbiya nazariyasi va metodikasi (sohalar bo‘yicha)
13.00.03 Maxsus pedagogika
13.00.04 Jismoniy tarbiya va sport mashg‘ulotlari nazariyasi va metodikasi
13.00.05 Kasb-hunar ta’limi nazariyasi va metodikasi
13.00.06 Elektron ta’lim nazariyasi va metodikasi (ta’lim sohalari va bosqichlari bo‘yicha)
13.00.07 Ta’limda menejment
13.00.08 Maktabgacha ta’lim va tarbiya nazariyasi va metodikasi
13.00.09 Ijtimoiy pedagogika
07.00.00 Tarix fanlari
19.00.00 Psixologiya fanlari
01.00.00 Fizika-matematika fanlari
02.00.00 Kimyo fanlari
03.00.00 Biologiya fanlari
09.00.00 Falsafa fanlari
10.00.00 Filologiya fanlari
11.00.00 Geografiya fanlari

MAKTABGACHA VA MAKTAB TA'LIMI

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Axborot va ommaviy kommunikatsiyalar agentligi tomonidan
№C–5669363 reyestr raqami tartibi bo'yicha ro'yxatdan o'tkazilgan.
Litsenziya raqami: № 136361.

Manzilimiz: Toshkent shahar, Yunusobod tumani
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