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Authors' Affiliation:
[1]Institute of Dentistry of the Central Clinical Hospital of the Medical University of Łódź, Pomorska 251, 92-213 Łódź, Poland
[2]Centralna Wojskowa Przychodnia Lekarska CePeLek SPZOZ, 78 Koszykowa Street, 00-911 Warszawa, Poland
[3]Jessenius Faculty of Medicine, Comenius University Bratislava, Malá Hora 10701/4A, 036 01 Martin, Slovakia
[4]Zespół Przychodni Specjalistycznych Sp. z o.o., 1 Skłodowskiej-Curie Street, 33-100 Tarnów, Poland

ORCID List:
Jakub Papierz: 0009-0002-8920-5725
Katarzyna Cybulska: 0009-0001-9004-3447
Julia Banaszczyk: 0009-0007-4957-1153
Erwin Górski: 0009-0004-2668-097X
Stanisław Janczarski: 0009-0002-4794-0246
Gabriela Królczyk: 0009-0008-2839-5020
Aleksandra Pietrzyk: 0009-0000-6855-2117
Mikołaj Cezary Krajewski: 0009-0001-5317-5248

***Corresponding author:**
Jakub Papierz,
Institute of Dentistry of the Central Clinical Hospital of the Medical University of Łódź, Pomorska 251, 92-213 Łódź, Poland

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Complications and Adverse Effects of Clear Aligners versus Fixed Orthodontic Appliances: A Literature Review

Jakub Papierz[1]*, Katarzyna Cybulska[1], Julia Banaszczyk[1], Erwin Górski[1], Stanisław Janczarski[1], Gabriela Królczyk[4], Aleksandra Pietrzyk[2], Mikołaj Cezary Krajewski[3]

ABSTRACT

Introduction and Objectives: Treatment of malocclusion with clear aligners (CAs) and fixed appliances (FAs) differs in biological, physiological, and biomechanical aspects. As a result of an increasing demand for aesthetic orthodontic treatment and patient comfort, this work highlights cases when CA is less likely to cause complications than FA treatment. *Results*: Scientific literature states that CAs do not cause enamel demineralization, have lower risks of WSL development, and maintain periodontal health better than FAs. CAs protect teeth from EARR by applying controlled intermittent force system. Besides, there is a decreased pain experience, decreased use of analgesics, and higher OHRQoL in CAs treatment. On the other hand, CAs cannot manage complex tooth movements, including tooth rotation, bodily movement, and bite correction. This leads to posterior open bite problem. Moreover, the maintenance of occlusal contacts, attachment placement, and patient compliance continue to be problematic. *Conclusions*: CAs present a reliable, predictable, and safe tool for treating patients who are more susceptible to periodontal disease and root resorption. Although advances in CAD/CAM technology and polymer development are promising, further clinical studies should be performed before declaring CAs as a standard treatment for any malocclusion.

Keywords: clear aligners; fixed appliances; orthodontic complications; root resorption; periodontal health; white spot lesions

1. INTRODUCTION

The goal of orthodontic therapy includes the correction of malocclusions, providing an adequate stomatognathic system function, and enhancing facial aesthetics (Proffit et al., 2018). Nevertheless, even though fixed appliances (FAs) equipped with metallic or ceramic brackets and elastic archwires have been traditionally used in orthodontics and considered a gold standard for many years, it still involves the risk of various iatrogenic complications and biological problems (Czarnecki et al., 2020). The complexity of FAs causes a complicated surface topography and biofilm buildup, causing hygiene complications and a greater risk of damaging periodontal

tissues (Rossini et al., 2015; Lu et al., 2018). The constant application of force by means of elastic archwires might cause biochemical injury in the oral cavity. Such treatment can lead to decalcification of the teeth, external apical root resorption (EARR), and changes in the vasculature of the pulp tissue (Galan-Lopez et al., 2019; Jasso-Lara et al., 2023).

It is known that the method of tooth movement with the removable elastomeric appliances started to develop since 1945 with the development of tooth positioner technology by Harold Kesling (Kesling, 1945). The transition toward removable appliances began in the late 1990s as a result of the development of computer-aided design and computer-aided manufacturing techniques, intraoral scanning, stereolithography, and the appearance of the commercial Invisalign appliance (Phan and Ling, 2007; Joffe, 2003). Recently, there has been an evident increase in the interest of adults in discreet and comfortable treatment approaches (Tamer et al., 2019; Jacobs et al., 2014). The modern CA treatment includes highly developed digital planning processes (Tartaglia et al., 2021; Galindo-Riedel et al., 2022) and sophisticated multilayer thermoplastic polymer material with high resistance to stress relaxation that can provide light continuous force action (Lombardo et al., 2015).

Despite the initial clinical experience showing poor predictability of CA in cases of severe tooth movement, involving root torquing, extrusion, and rotational correction of rounded teeth (Kravitz et al., 2009), the rapid development of the science of polymer chemistry and advanced attachments has greatly expanded the potential clinical applications (Weir, 2017). However, despite the popularity of CA among both dentists and patients, the adverse effects, biological safety profile, and biomechanical limitations of CA therapy compared to FAs remain controversial issues. This paper reviews the entire range of complications and adverse effects caused by CA therapy in contrast to FAs. By analyzing the current literature, it tries to determine the practical safety limits for this procedure and the situations where the risks of complications become evident.

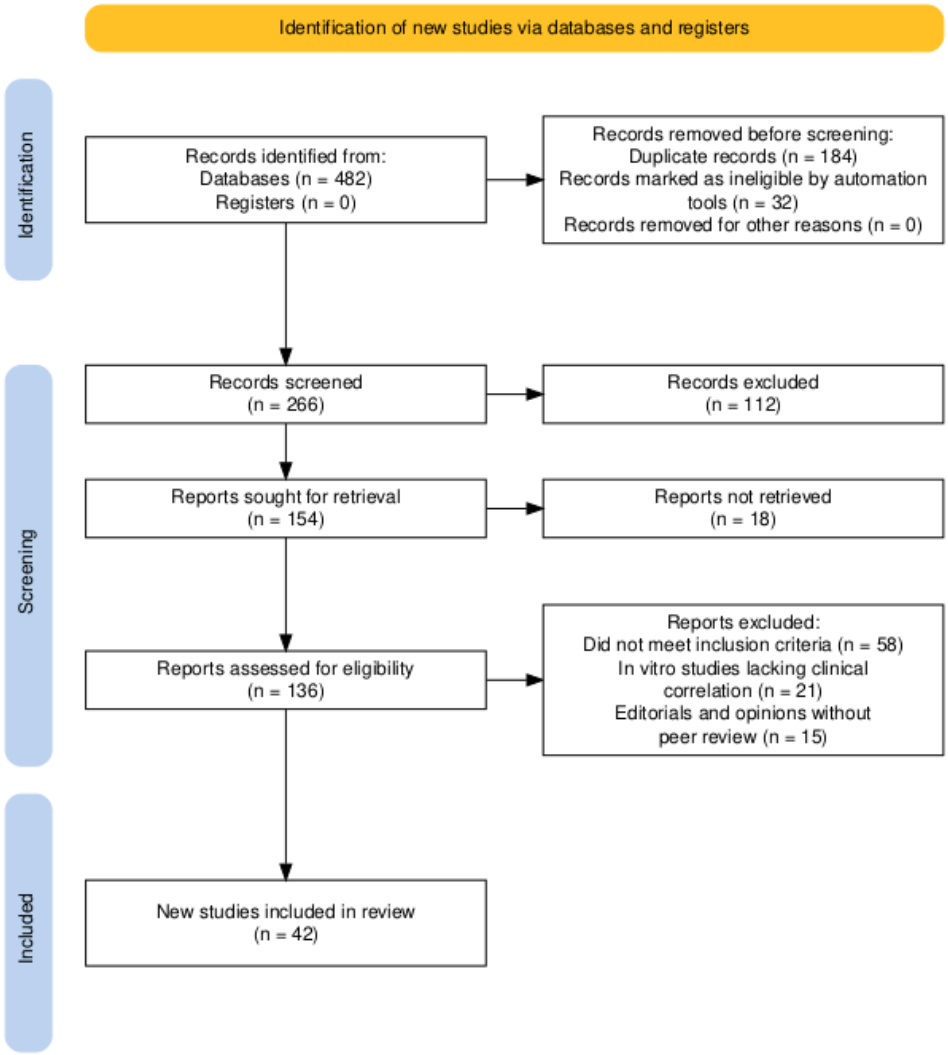

Figure 1. PRISMA 2020 flow diagram of study selection.

2. REVIEW METHODS

A narrative review of the literature approach was used in this study. The scientific literature on the topic was collected using a systematic search in different databases, such as PubMed, MEDLINE, Web of Science, and Google Scholar. The keywords were: "clear aligners," "Invisalign," "fixed appliances," "orthodontic issues," "root resorption," "periodontal condition," and "white spot lesions."

The inclusion criteria included scientific papers that compared negative outcomes or complications from clear aligners and fixed appliances and provided evidence of clinical, radiographic, microbiological, and experimental findings. The exclusion criteria included those articles that concentrated only on non-orthodontic uses of aligners, in vitro studies without any clinical implications, editorials and letters to the editor, and non-peer-reviewed papers. In total, 42 articles were chosen for analysis (Figure 1).

3. RESULTS AND DISCUSSION

Periodontal Health, Microbial Ecology, and Oral Hygiene Performance

Application of fixed orthodontic appliances results in immediate and profound changes of the intraoral environment. Presence of orthodontic brackets, archwires, auxiliary hooks, and elastic or metallic ligatures serves as a barrier for natural cleansing mechanisms provided by saliva, the tongue, and buccal mucosa (Rossini et al., 2015; Al-Moraissi et al., 2024). Additionally, these components prevent effective tooth brushing and flossing, resulting in rapid dental plaque accumulation in both supra- and subgingival locations (Lu et al., 2018). High inflammatory activity of such patients is often seen in terms of high Plaque Index (PI), Gingival Index (GI), and Bleeding on Probing (BOP), together with higher Probing Depth (PD) during the course of the treatment (Lu et al., 2018).

For this reason, the usage of aligners can be considered to be beneficial from a biological point of view because aligners allow for the removal of appliances during meals and treatments that include brushing, flossing, and fluoridation (Rossini et al., 2015). According to the results of systematic reviews and meta-analyses done by Rossini et al., (2015), Lu et al., (2018), and a recent meta-analysis, the indices of PI, GI, and PD of the patients with aligners were found to be lower than those of bracketed patients in the corresponding age groups. As far as the effects on oral microorganisms are concerned, it was found that the use of aligners positively affects oral microflora. At the same time, fixed appliances were found to increase the number of anaerobic periodontopathogens and cariogenic bacteria, such as S. mutans and Lactobacillus.

However, the recent umbrella reviews provide a critical evaluation of the periodontal outcomes and note that aligners are not absolutely safe from periodontal risks. The effectiveness of aligners depends on patient adherence and hygiene behavior. In cases when a patient does not provide proper oral hygiene and puts the aligners onto the teeth covered with dental plaque, the thermoplastic material creates an isolated microenvironment that allows saliva, bacteria, and fermentable food residues to accumulate in it up to 20-22 hours a day. Under such unfavorable hygiene conditions, local gingivitis and periodontal pockets may appear in the absence of brackets (Martin-Carreras et al., 2023).

Enamel Demineralization, Salivary Dynamics, and White Spot Lesions

The process of enamel demineralization and its appearance as White Spot Lesions (WSLs) is the most common problem among the aesthetic problems related to orthodontic therapy (Albhaisi et al., 2020). In general, WSLs are characterized as subsurface enamel porosities that emerge due to the acid-induced dissolution of hydroxyapatite crystals by organic acids such as lactic acid that is produced through fermentation of dietary carbohydrates by bacterial plaque. For the therapy with fixed appliances, the rough interface between the bracket resin and the archwire ligation provides a retentive environment, where plaque is accumulated and protected from the buffering function of the saliva (Buschang et al., 2019). Clinical research shows that the rate of newly emerging WSLs for fixed orthodontic therapy can be as high as 25.6% (Azeem and Sadowsky, 2014).

It is possible to state that therapy with clear aligners provides significant protection of hard tissues from demineralization (Albhaisi et al., 2020; Zhang et al., 2024). It was shown through prospective studies that the rate of new WSLs in the aligner groups can be as low as 1.2% (Azeem and Sadowsky, 2014). The smooth surface of thermoplastic aligners is not able to retain bacterial plaque due to the lack of retention sites, and there is no attachment on the large labial surface of the teeth, which allows the normal salivary flow and remineralization process to take place after removal of the appliance for oral hygiene (Lu et al., 2018; Buschang et al., 2019).

Despite the obvious advantage, the dentist should also discuss a specific problem connected to the removable aligner therapy called the "reservoir effect". If a patient eats acidic beverages, fruit juices, or snacks without conducting proper oral hygiene before inserting the aligners, the liquids can get trapped under the plastic layer. As a result, the aligner prevents natural clearance and buffering

functions of the saliva, and a stagnant low pH fluid layer is formed in contact with the enamel surface, causing rapid demineralization and WSLs development (Jiang et al., 2021).

Biomechanics of External Apical Root Resorption (EARR) and Pulpal Changes

External Apical Root Resorption (EARR) is one of the irreversible complications of biological nature related to orthodontic tooth movement. EARR occurs due to excessive mechanical forces transmitted to the tooth root that overcome the physiological blood pressure of the periodontal ligament (PDL) (about 20-26 g/cm²), leading to ischemia, hyalinization, and then necrosis of the PDL. The necrotic tissue triggers a sterile inflammatory reaction characterized by the activity of multinucleated odontoclasts and osteoclasts and resorption of the external layer of the cementum and apical root dentin (Zheng et al., 2017). Powerful continuous forces caused by continuous nickel-titanium or stainless steel archwires are related to a high risk of considerable apical root shortening (Yi et al., 2018).

Comparative volumetric three-dimensional radiographic evaluation with the use of Cone-Beam Computed Tomography (CBCT) demonstrates that clear aligners have lower incidences and severities of EARR compared to conventional fixed appliances (Gandini et al., 2014; Yi et al., 2018). From the biomechanical perspective, fixed archwires cause continuous forces that keep the PDL compressed in a state of ischemia. At the same time, light viscoelastic forces caused by clear aligners rapidly relax. Regular pauses during which blood flow in the PDL can be restored allow for repair of minor cemental lacunae before the irreversible apical root resorption takes place (Zheng et al., 2017). Serious root resorption (>2 mm) is rare during clear aligners therapy and is observed only in complicated cases with root intrusion or heavy torquing of the incisors (Gay et al., 2017). Current clinical studies also demonstrate that, despite the use of composite attachments to facilitate root movements, aligners remain safer for the root (Aman et al., 2022).

Concerning the effect on the neurovascular pulp, constant pressure exerted by the fixed appliance can impair apical blood supply and lead to hyperemia, sensory deficit, and potentially pulp necrosis in case of any injury (Jasso-Lara et al., 2023). Minimal forces exerted by the clear aligner do not impair the pulpal vascularity and keep the pulp alive and reactive to active movement (Galan-Lopez et al., 2019; Jasso-Lara et al., 2023).

Pain Experience, Soft Tissue Trauma, and Oral Health-Related Quality of Life (OHRQoL)

Orthodontic force exerted in a mechanical fashion causes compression and tension in the periodontal ligament (PDL), and subsequently initiates an inflammatory response due to the release of prostaglandins, substance P, bradykinin, and histamine. The biochemical reaction triggers the sensitization of the nociceptors and leads to pain and masticatory soreness in the patient. It is usually highest in the first 24 to 48 hours following appliance insertion/archwire activation (Antonio-Zancajo et al., 2020). According to VAS measurements, while both techniques elicit pain, patients treated with clear aligners exhibit significantly less pain intensity, pain peak, and duration of the pain experienced compared to those under the fixed appliances (White et al., 2017; Antonio-Zancajo et al., 2020). Several RCTs have proven the results and found that analgesic intake was reduced among the clear aligners (Al-Sammali et al., 2022).

In addition to neurogenic PDL-related pain, conventional fixed appliances cause physical damage to surrounding soft tissues. Metallic brackets' sharp edges, archwire's projecting ends, additional hooks, and elastic ties cause mechanical irritation of the non-keratinized buccal/labial mucosa, leading to ulcers, hyperkeratosis, and angular cheilitis. Clear aligners have smooth, properly adjusted thermoplastic edges and fit tightly in the dental arch, reducing the risk of ulcers and soft-tissue injuries (Cardarelli et al., 2021).

Consequently, OHRQoL evaluation results favor clear aligner treatment. Patients receiving clear aligners complain of little speech disturbance, maintain intact eating abilities because of appliance removal, have improved self-confidence and higher overall treatment satisfaction during orthodontic treatment (Javidi et al., 2017).

Temporomandibular Joint Dynamics, Muscle Function, and Occlusal Relationships

The interaction between the application of orthodontic forces, occlusal contact pattern, and Temporomandibular Disorders (TMD) is one of the crucial areas in clinical research. Clear aligners cover all occlusal surfaces of the dental arches using a thin layer of polymer film (usually about 0.75 mm thick per arch). The complete occlusal coverage is similar to occlusal splints or bite planes that disocclude the natural dentition and eliminate any eccentric occlusal interferences (Ferrara et al., 2022). EMG studies have shown that the use of aligners causes a significant reduction in tonic electrical activity of the masseter and anterior temporalis muscles when performing maximum clenching and in a resting state (Mampieri et al., 2020). It may reduce the already existing myofascial pain, bruxism-induced muscular fatigue, and joint clicking and discomfort in the early stages of orthodontic treatment (Ferrara et al., 2022; D'Antò et al., 2021).

However, this complete occlusal coverage of the dental arches presents another clinical challenge particular to the use of clear aligners: the development of posterior open bite. The fact that the thermoplastic material exists between the upper and lower occlusal surfaces for around 20 to 22 hours daily creates a continuous "bite-block effect". Such constant intrusive force may cause the unwanted micro-intrusion of the posterior molars and premolars. Additionally, aligners prevent the natural vertical eruption and settling of posterior teeth in the process of sagittal or transversal correction (Giancotti et al., 2017).

As a consequence, the fixed orthodontic appliances possess a much greater ability to achieve proper occlusal contact and tight "cusp-to-fossa" occlusion directly after appliance removal. Patients who finish clear aligner treatment often suffer from light, diffuse, or partial posterior occlusal contacts at the end of the active series of aligners. To address this problem, clinicians often apply the post-treatment settling procedure, which involves split aligners, vertical intermaxillary elastics, or selective occlusal equilibration (Pinho et al., 2020; Al-Bitar et al., 2020).

Overall Risk Assessment, Biomechanical Limitations, and Clinical Performance

A synthesis of the existing literature shows that the decision between clear aligners and fixed appliances is a compromise between the biological safety and predictability of mechanical control (Papageorgiou et al., 2020; Robertson et al., 2022). Clear aligners have an especially good biological safety record. There is significantly less destruction of the periodontal tissues in cases of aligner use, a decreased number of enamel demineralizations, apical root resorptions, pulpitis, and mucosal injuries (Galan-Lopez et al., 2019; Jasso-Lara et al., 2023). Operationally, there is a significant decrease in emergency appointments due to loose brackets, archwire displacement, or puncture wounds of the soft tissues (Borda et al., 2020).

On the other hand, the main problem with clear aligners is that they cannot be considered a reliable instrument from a biomechanical standpoint and fully rely on patient compliance (Borda et al., 2020). Aligners produce a reciprocal push force, not a pull one, thus making some complicated movements of the teeth more challenging without any additional help. The movements that cannot be performed easily include bodily translation of roots, premolar rotation correction more than 15 degrees, extrusions of teeth, and root torque in the areas of extractions (Kravitz et al., 2009; Weir, 2017). In case of lack of predictability in complicated movements, additional impressions or scans and modifications of attachments will be required, leading to an increase in the whole treatment course (Robertson et al., 2022). Furthermore, non-compliance with the recommended 20 to 22 hours of wearing per day makes it impossible to track tooth movement properly, rendering the treatment ineffective (Borda et al., 2020). At the same time, fixed appliances present a considerable biological risk but are irreplaceable for the management of complicated skeletal problems, impacted teeth, and multidirectional root movements. A detailed comparison of these aspects is presented in Table 1.

Table 1. Comparative summary of clinical complications, biological impacts, and mechanical performance between Clear Aligners and Fixed Appliances.

Clinical Complication / Parameter	Fixed Appliances (FAs)	Clear Aligners (CAs)	Primary Evidence Source
Periodontal Inflammation (PI, GI, PD)	High risk due to plaque retention around brackets and wires	Low risk; superior hygiene access due to appliance removability	Rossini et al., 2015; Lu et al., 2018
White Spot Lesions (WSLs)	High incidence (~25.6%); hindered salivary clearance	Low incidence (~1.2%); risk limited to "reservoir effect"	Azeem and Sadowsky, 2014; Jiang et al., 2021
External Apical Root Resorption (EARR)	Higher risk & severity (heavy continuous force systems)	Lower risk & severity (intermittent viscoelastic light forces)	Yi et al., 2018; Zheng et al., 2017
Pain Intensity & Analgesic Use	Higher pain peak at 24–48h; higher analgesic consumption	Lower overall pain intensity; reduced need for analgesics	White et al., 2017; Al-Sammali et al., 2022
Soft Tissue Trauma & Mucosal Ulcerations	Frequent traumatic ulcers from sharp brackets/wires	Extremely rare; smooth, polished custom polymer edges	Cardarelli et al., 2021

Oral Health Quality of Life (OHRQoL)	Lower initial scores; functional eating & speech friction	Higher scores; minimal daily activity interference	Javidi et al., 2017
TMD & Masticatory Muscle Activity	Neutral to variable impact on muscle relaxation	Splint-like effect; reduces masseter/temporalis EMG activity	Mampieri et al., 2020; Ferrara et al., 2022
Occlusal Settling & Posterior Contacts	Precise immediate intercuspation and cusp-to-fossa fit	Risk of posterior open bite (*bite-block effect*); needs settling	Giancotti et al., 2017; Pinho et al., 2020
Emergency Visits & Technical Failures	Frequent emergency visits (debonded brackets, poking wires)	Rare emergency visits (appliance fracture is uncommon)	Borda et al., 2020
Dependency on Patient Compliance	Low reliance (non-removable, continuous force delivery)	Critical reliance (requires strict 20–22h daily wear)	Borda et al., 2020; Robertson et al., 2022
Predictability of Complex Root Movements	High predictability for root torque, extrusion, and rotations	Moderate-to-low predictability; often requires refinements	Kravitz et al., 2009; Weir, 2017

4. CONCLUSION

While in recent years clear aligner therapy has become better understood, its exact comparative complication profile and biological safety boundaries remain topics that need clear clinical definition. The newest literature provides evidence for clear aligners to emerge as a biologically safer alternative, while conventional fixed appliances remain essential for specific complex malocclusions and severe skeletal discrepancies. Some of the indications where clear aligners offer significant safety benefits are: patients who have a high chance of developing periodontal diseases, patients with a high risk for enamel demineralization or white spot lesions, patients with a history of apical root resorption, situations where there is a need for minimal soft tissue injury, and people desiring minimal treatment pain along with better quality of life. Recent research indicates various clinical drawbacks and risks related to clear aligners. Some of these include the patient's absolute cooperation during treatment, potential inconsistency in root torqueing and extrusion in complicated extraction cases, and developing posterior open bite that requires occlusal adjustment after treatment. The field of orthodontics continues to develop very fast, and while clear aligners are showing good biological and periodontal features, more studies are necessary.

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Authors' Contributions

Conceptualization: Jakub Papierz, Stanisław Janczarski, Erwin Górski

Methodology: Jakub Papierz, Stanisław Janczarski, Erwin Górski, Katarzyna Cybulska, Julia Banaszczyk, Gabriela Królczyk, Aleksandra Pietrzyk, Mikołaj Cezary Krajewski

Software: Not applicable

Check: Jakub Papierz, Katarzyna Cybulska, Julia Banaszczyk, Gabriela Królczyk, Mikołaj Cezary Krajewski

Formal analysis: Jakub Papierz, Stanisław Janczarski, Erwin Górski, Aleksandra Pietrzyk

Investigation: Jakub Papierz, Stanisław Janczarski, Erwin Górski, Katarzyna Cybulska, Julia Banaszczyk, Gabriela Królczyk, Mikołaj Cezary Krajewski

Resources: Jakub Papierz, Stanisław Janczarski, Erwin Górski, Mikołaj Cezary Krajewski

Data curation: Erwin Górski, Katarzyna Cybulska, Julia Banaszczyk, Gabriela Królczyk, Aleksandra Pietrzyk

Writing - rough preparation: Jakub Papierz, Stanisław Janczarski, Erwin Górski, Katarzyna Cybulska, Julia Banaszczyk, Gabriela Królczyk, Aleksandra Pietrzyk, Mikołaj Cezary Krajewski

Writing - review and editing: Jakub Papierz, Stanisław Janczarski, Erwin Górski, Katarzyna Cybulska, Julia Banaszczyk, Aleksandra Pietrzyk
Visualization: Erwin Górski, Julia Banaszczyk, Gabriela Królczyk
Supervision: Stanisław Janczarski, Aleksandra Pietrzyk, Mikołaj Cezary Krajewski
Project administration: Jakub Papierz, Stanisław Janczarski, Erwin Górski

Informed consent
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Conflict of interest
The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and materials availability
All data associated with this study will be available based on the reasonable request to corresponding author.

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