The Development and Clinical Significance of the Curve of Spee in Orthodontics and Prosthodontics - Conventional and Digital Approaches

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Abstract

AIM: To enhance the understanding of the development of the curve of Spee, its significance in orthodontics and prosthodontics, and its management using conventional and digital orthodontics.
METHODS: Records were gathered from PubMed (279) and Google Scholar (421), along with four from supplementary methods. After eliminating 110 duplicates, 590 records were screened. Exclusion criteria removed studies on animals, seminar presentations, opinion pieces, and incomplete data. This process led to the inclusion of 16 articles after assessing potential relevance.
RESULTS: Insights into the historical context and development of the curve of Spee were addressed. Various methods of measuring the curve of Spee, including cast models, 3D models, lateral cephalograms, and CBCT, were briefly discussed. Its significance in prosthodontics and orthodontics was thoroughly explained. Methods for leveling the curve of Spee were examined in both conventional and digital orthodontics, along with their long-term stability.
CONCLUSION: Through a comprehensive review of the literature, several key findings have emerged that elucidate its historical development and role in both orthodontics and prosthodontics. Leveling the curve of Spee in orthodontics is critical, as orthodontists encounter it in nearly every case of treatment. It is recommended that further studies be conducted.

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Archive of Orofacial Data Science

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1 Introduction

Ferdinand Graf Spee, a German anatomist (1855–1937), was the first to report the Spee curve, an anatomical curvature. He published an original article in 1880, which was re-represented by Biedenbach et al. (1980). Graf Spee examined human skulls with eroded teeth to ascertain the occlusion line, defined as the line on a cylinder that touches the anterior edge of the condyle, extending to the occlusal surface of the second molar and the incisal edges of the mandibular incisors. Spee's predictions were developed through an examination of the skulls from a lateral perspective that is perpendicular to the midsagittal plane. He conducted his study based on three propositions (**Figure 1**).

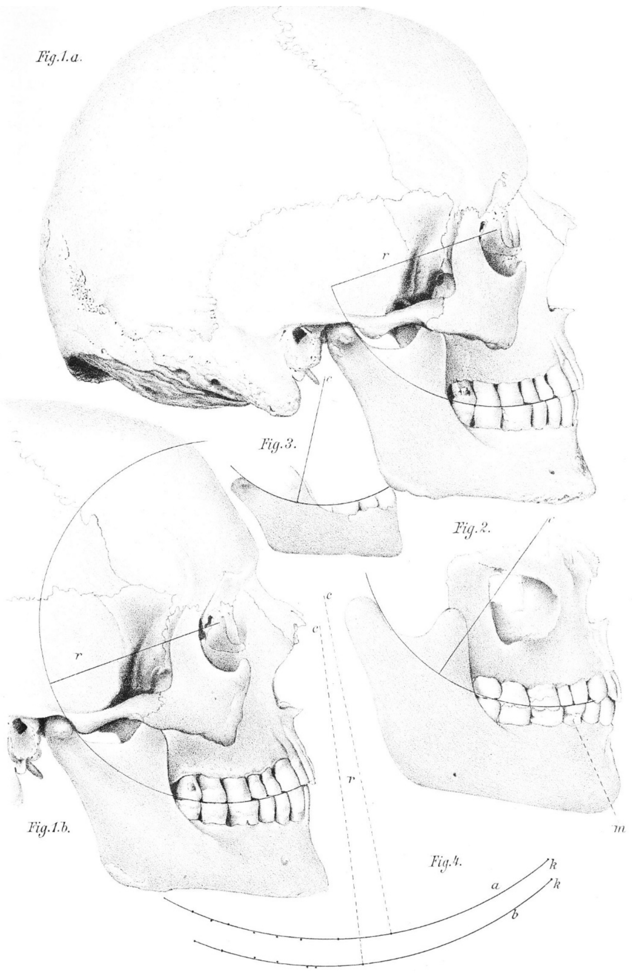

Figure 1. Description of the *path of mandibular displacement. "1a and 1b are images of the same skull, 1a in exact profile view, 1b somewhat from the front. The former shows the curve for the sagittal shift, the latter the curve of the occlusal surface without shortening. The dimensions are directly comparable because the images are shown at the same magnification."* Graf Spee (1880).

Proposition one: When viewed from the lateral aspect, Spee observed that the surfaces of the molars are positioned along the curve of a circle. This curve extends posteriorly and touches the anterior edge of the condyle. Proposition two: Demonstrating the curve using cases of tooth attrition is simpler than using cases with well-preserved cusps. Proposition three: If points other than molars are considered when measuring along the occlusal line, they can align with the condyle along a shared arc. Spee suggested that this geometric configuration delineated the optimal pattern for ensuring the highest degree of tooth contact during mastication, deeming it an indispensable principle in the fabrication of dentures. Monson's spherical theory on the optimal alignment of teeth in the dental arch was developed based on this description (Ramfjord & Ash, 1971).

The antero-posterior curve in the mandibular arch is seen in a clinical sagittal view as a concave line that contacts the buccal cusp tips and incisal edges of the premolar and molar teeth. The curvature extends from the anterior edge of the mandibular ramus to the most anterior part of the mandibular condyle (Hitchcock, 1983).

In orthodontics, the curved plane that, when viewed from the sagittal plane, meets the buccal cusp tips and incisal edges of the mandibular teeth is known as the curve of Spee. In the field of prosthodontics, the definition of this curve was altered by excluding the incisors and focusing solely on the section of the dental arch from the canine to the terminal molar (Van Blarcom, 2005). The curvature subsequently continues towards the posterior to meet the anterior surface of the condyle, as originally suggested by Spee (Ramfjord & Ash, 1971). The morphologic arrangement of teeth along this curve is determined by several anatomical and functional factors, such as joint inclination, overjet, molar cusp height, and the quality and quantity of posterior contacts (Mohl et al., 1988).

An occlusion often exhibits a variable-depth curve of Spee. An extensive assessment is necessary to achieve an accurate diagnosis and appropriate orthodontic treatment plan. Recently, there has been a suggestion that the curve of Spee has a biomechanical role in food processing (Osborn, 1987). It is thought to increase the ratio of crushing and shearing forces between the molars and enhance the effectiveness of chewing forces.

The leveling of the curve of Spee is a crucial initial stage in orthodontic treatment and is considered part of the sixth key of occlusion (Andrews, 1972). Leveling refers to the alignment of the incisal edges of the anterior teeth and the buccal cusps of the posterior teeth on a single horizontal plane (Van Blarcom, 2005). At the onset of orthodontic treatment, it is essential to correct the curvature known as the curve of Spee from the beginning.

The aim of this research is to improve our understanding of the significance of the curve of Spee in both conventional and digital orthodontics, along with the methods used to rectify it.

2 Methods

Two primary databases, PubMed and Google Scholar, are utilised, yielding 279 records from PubMed and 421 from Google Scholar. In addition to these databases, records are also identified through supplementary methods, encompassing websites, organisations, and citation searching, resulting in one record from websites, two from organisations, and one from citation searching. From the combined results of PubMed and Google Scholar 110 duplicates were eliminated (**Figure 2**).

In the selection process for articles relevant to this review, emphasis was placed on those that aligned with the designated objectives and included participants from all age groups. This approach facilitated a thorough full-text screening of research articles that are pertinent to the focus of the review.

On the other hand, specific exclusion criteria were established to refine the scope of the study. Research that involved animal subjects, seminar presentations, opinion pieces, and studies with incomplete data were excluded, as they did not meet the necessary standards for inclusion in the analysis.

A total of 590 records are screened by reviewing titles and abstracts to ascertain their relevance to the review's topic. From this screening, 223 records are excluded as they do not meet the initial inclusion criteria. Two records from the database search and two from the supplementary methods search are deemed potentially relevant and are sought for retrieval. However, 55 records from the database search and two from the supplementary methods search prove irretrievable, possibly due to access issues or other limitations.

Twelve records from the database search and four from the supplementary methods search are assessed in detail to determine if they meet the specific inclusion and exclusion criteria of the review. Finally 16 articles remained for inclusion into this study.

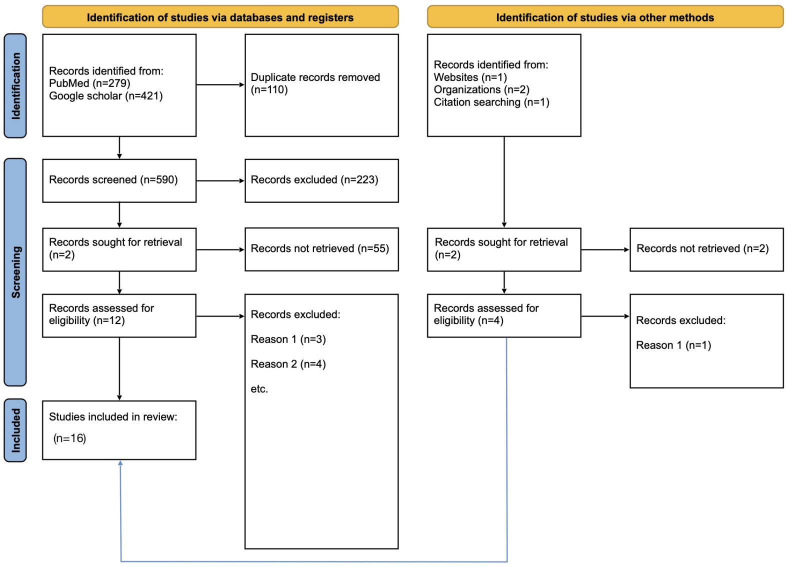

Figure 2. Representation of selection of articles through PRISMA framework.

2.1 Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyze the textual content of the included studies. It is important to note that, given the narrative nature of this study, regression analysis and meta-analysis techniques were not deemed suitable for the analytical framework.

3 Results

3.1 Measuring the curve of Spee

There is no consensus in the literature regarding the methodology for quantifying the Spee curve. Baldridge (1969) quantified the perpendicular distances on each side. Bishara et al. (1989) calculated the mean value of the total lengths that are perpendicular to each cusp point. Sondhi et al. (1980) utilized the summation of perpendiculars. Braun and Schmidt (1956) calculated the sum of the maximum distances on each side. Historically, these measurements were obtained from study plaster models or images using a divider or caliper (De Praeter et al., 2002) and a coordinate measuring machine (Braun et al., 1996).

With advancements in technology, the availability of new measuring devices, such as three-dimensional (3D) optical digitizers, has increased. These devices are capable of accurately measuring even the smallest changes. Currently, clinicians have the ability to utilise 3D virtual models alongside specialised software to carry out the required measurements.

Lateral cephalograms are commonly used to study craniofacial growth and orthodontic therapy, both clinically and in research. The teeth and muscles that supply the mandible's functional matrix influence the formation of each skeletal subunit (Sperber, 2001). The final shape of a fully developed mandible is the consequence of a complicated interaction between growth determinants and the functional environment that controls the mandible (Brodie, 1946). A few studies have carefully explored the influence of dentofacial morphology on the Spee curve. The research discovered that dental morphology has a greater impact on the curve of Spee than facial morphology. Additionally, the curve of Spee is often linked to a deep bite (Cheon et al., 2008). A deep curve of Spee is commonly associated with sagittal discrepancies, manifested in the mandibular teeth with mesially inclined first molars, depressed premolars, and elevated anterior teeth, as represented in the Angle class II dental pattern (Batham et al., 2013).

Most modern imaging techniques, such as cone beam computed tomography (CBCT), have the potential to eliminate the time-consuming and frequently uncomfortable procedure of obtaining impressions. However, the downsides of this approach include the absence of gingival tissues in the digital models and concerns regarding unnecessary overexposure to radiation (Lightheart et al., 2012).

3.2 Development of the curve of Spee

From a sagittal viewpoint, Spee established a connection between the anterior surfaces of the mandibular condyles and the occlusal surfaces of the mandibular teeth using an arc that was in contact with a cylinder positioned at a right angle to the sagittal plane. He proposed that this geometric arrangement signifies the most efficient structure for ensuring ideal tooth contact during mastication and regarded it as a fundamental element in denture design. Monson's spherical theory (Monson, 1932) is based on this description, which outlines the ideal positioning of teeth in the dental arch. According to this theory, the occlusal curvature of the teeth should be tangential to a sphere with a radius of approximately 4 inches, both in the sagittal and frontal planes.

According to Ferrario et al. (1997), when analysing a population sample, it is believed that occlusal curvature can be compared to the shapes of Spee's cylinder and Monson's sphere, with noticeable differences among individuals. The eruption of mandibular permanent teeth precedes the eruption of their maxillary antagonists, which may account for the formation of the Spee curve. This implies that Spee's curve primarily arises as a dental phenomenon rather than as a skeletal one. In simpler terms, the mandibular permanent first molars usually erupt one to two months earlier than the maxillary permanent first molars, while the mandibular permanent central incisors appear twelve months earlier than their maxillary counterparts. Furthermore, the mandibular second molars typically emerge six months before the maxillary second molars (Carlsen & Meredith, 1960; Sturdivant et al., 1962). The discrepancy in timing may enable the mandibular permanent first molars and incisors to erupt without encountering any opposing teeth, thereby extending beyond the established occlusal plane of the mandible. Subsequently, the emergence of the mandibular second molar may occur with limited opposition. Both of these scenarios would result in the curve becoming more pronounced. Indeed, the occurrence of mandibular permanent molars erupting before maxillary molars in dental development could potentially contribute to the evolutionary progression of the curve of Spee (Marshall et al., 2006).

The Spee curve may be influenced by craniofacial variation and its effects on biomechanics, in addition to the potential impact of eruption timing (Baragar & Osborn, 1987). The combination of heightened bite forces, increased chewing cycles, and the consumption of abrasive food during growth leads to a reduction in the depth of the curve of Spee (Laird et al., 2016). Contemporary diets play a role in shifting the occurrence of occlusion, leading to a notable rise in the frequency of malocclusion in present-day populations (Van Annum, 2018).

The dentition of most animals typically displays a Spee curve, and there is a connection between the forward inclination of the posterior teeth in the lower jaw and the alignment of the masseter muscle in numerous mammals (Spee, 1980; Osborn, 1987). Farella et al. (2002) discovered a correlation between the condylar height with respect to the occlusal plane and the anteroposterior position of the jaw in relation to the cranial base concerning the depth of the Spee curve. These findings may elucidate the aetiology of deep bite malocclusion, a condition characterised by the excessive eruption of mandibular permanent incisors in individuals with smaller mandibles. This excessive eruption leads to a deepening of the curve of Spee, which can potentially result in the impingement of the incisors on the anterior palate in severe cases of deep bite.

A comparison of the depth of the curve of Spee between the left and right sides in the dental arch of an individual revealed no significant differences. A separate study was conducted to compare the depth of the curve of Spee in Class I and Class II sides of Class II malocclusion. Similar techniques could be employed to level the curve of Spee on both sides of the mandibular arch (Veli et al., 2014).

The depth of the curve of Spee is minimal in the deciduous dentition. It begins to increase during the early mixed dentition stage, which is caused by the emergence of the permanent first molars and central incisors. The depth of the curve of Spee typically remains consistent until the eruption of the permanent second molars, at which point it reaches its maximum depth. From there, it generally remains relatively stable throughout late adolescence and early adulthood. These data support Ash's (1993) hypothesis that the deciduous teeth have a curve of Spee that varies from flat to mild, while the curve in adult teeth is more pronounced. These findings corroborate the results of Carter and McNamara (1998), and Bishara et al. (1989), which indicated that the curve of Spee tends to remain stable once established during adolescence.

3.3 Significance in prosthodontics and orthodontics

The Spee curve is commonly described as the curve formed by a curved surface that touches the biting edges and outer cusp points of the lower teeth when viewed from the side. Conversely, the prosthodontic specialty specifically excludes the incisors and focuses solely on the canine to the terminal molar as the dental arch section of the curve. The curve then continues towards the back to meet the front surface of the condyle, as suggested first by Spee (Ramfjord & Ash, 1971; Van Blarcom, 2005; Okeson, 2003). The Curve of Spee is essential for distributing strains evenly across the condyle, maxilla, and mandible, which improves the efficiency of chewing and reduces strain on the patient's oral cavity (Alkhalaf et al., 2023). Andrews discovered that the occlusal planes of individuals not receiving orthodontic treatment and those with normal occlusions exhibit a flat alignment curve. He linked the curve of Spee to the relapse of post-orthodontic treatment; however, he determined that not all normal occlusions have flat occlusal planes, achieving this should be a goal in orthodontic treatment (Andrews, 1972). After orthodontic treatment, there was a tendency for the curve of Spee to relapse. Some authors supported Andrews' viewpoint that establishing a level occlusal plane should be a goal of orthodontic treatment (Koyama, 1979; Okeson, 2003).

Prosthodontics. The objective of prosthodontic restoration is to establish a mutually protected occlusion, which guarantees that the posterior teeth disengage during eccentric functional movements. The Spee curve, along with the posterior cusp height, condylar inclination, and anterior guidance, plays a crucial role in determining the correct occlusal scheme (Okeson, 2003). Certain individuals employ the 4-inch Monson sphere to achieve an "idealised" reconstruction of their posterior teeth (Dawson, 1989). In order to avoid complications in patients with a retrognathic jaw and steep anterior guidance, it is recommended to design the occlusal plane with a radius shorter than the standard 4-inch radius suggested by Monson. In the case of Class III patients, the opposite is true; a larger and more level curve, usually with a radius of 5 inches, is considered more appropriate (Lynch & McConnell, 2002). Effective management is essential for the development of stable complete dentures and can impact the success of implant-supported restorations (Xu et al., 2004). Creating a Spee curve that aligns with condylar guidance, incisal guidance, the plane of occlusion, and the height of prosthetic tooth cusps is essential in complete denture prosthodontics to achieve a balanced articulation on both sides. It is widely believed that this alignment greatly improves the stability of dentures (Hanau, 1926).

Orthodontics. Andrews (1972), in his description of the six characteristics of normal occlusion, observed that occlusal planes in 120 non-orthodontically treated, apparently normal occlusions varied from generally flat to having a mild curve of Spee. He noted that the most optimal static intercuspation occurred when the occlusal plane was relatively flat. He hypothesised that orthodontic treatments aim to flatten the occlusal plane. Based on this discovery, he proposed that the existence of a curve of Spee may be linked to the reappearance of malocclusion following orthodontic treatment. There is a natural tendency for the curve of Spee to deepen over time due to the normal growth pattern of the lower jaw, which moves downward and forward. This can cause the lower anterior teeth, situated between the upper anterior teeth and lips, to be pushed backwards and upwards, potentially leading to crowding of the lower anterior teeth and/or a deeper overbite and curve of Spee. The presence of a pronounced curve of Spee may significantly hinder the attainment of a Class I canine relationship and may also lead to occlusal interferences.

There is a tendency for the occlusion to deepen after treatment. It seems logical to address the plane of occlusion until it is somewhat flat or even reversed to accommodate this tendency. In many cases, banding the second permanent molars is necessary to establish a stable foundation for effectively levelling the lower and upper planes of occlusion. A reverse curve of Spee represents an extreme form of overcorrection, providing excessive space for each tooth in intercuspation. These findings have been corroborated by various authors, and discussions centre around determining the levelling technique that achieves the most efficient correction of overbite and the most enduring treatment outcomes. Tweed (1966) espoused a unique philosophy in orthodontic treatment that involved the use of continuous archwires with a reverse curve of Spee to achieve flat occlusal planes. Another clinician recommended the extrusion of posterior teeth to flatten the curve of Spee and avoid intrusion of the lower incisors (Schudy, 1968). Another clinician employed intrusion springs to intrude lower anterior teeth with minimal side effects on posterior teeth (Burstone, 1977). Additionally, a group of clinicians recommended a combination of intrusion and flaring of lower anteriors to achieve levelling of the curve of Spee (Otto et al., 1980). In cases of deep bite where relapse occurs, the curve of Spee tends to return to a lesser extent than it was before orthodontic treatment (Carcara et al., 2001), and there is a mild relationship between relapse and the severity of the curve of Spee. Flattening the curve of Spee during orthodontic treatment appears to result in long-term stability (De Praeter, 2002). No significant differences were found in the amount of curve of Spee relapse between extraction and non-extraction cases (Shannon & Nanda, 2004). According to a study conducted by Ash (1993), the primary teeth usually exhibit a Spee curve that varies from flat to slight, while the permanent teeth tend to have a more prominent Spee curve.

Explanations for this observation include differences in cusp height between deciduous and permanent teeth, as well as the tendency for higher occlusal wear in deciduous teeth. Furthermore, it has been observed that once established in adolescence, the curve of Spee appears to be generally stable (Carter & McNamara, 1998; Bishara et al., 1989). There are certain cephalometric parameters that indicate individual differences in the depth of the curve of Spee; however, no definitive predictions can be made regarding biological variation. It appears that craniofacial shape is only one of many elements impacting its development (Farella et al., 2002; Shannon & Nanda, 2004; Salem et al., 2003; Baydas et al., 2004). Although orthodontists commonly encounter the curve of Spee in almost every patient, and prosthodontists establish it to achieve optimal functional occlusion, the existing literature lacks a comprehensive explanation of its origins and developmental processes.

3.4 Leveling the curve of Spee

Several researchers have evaluated treatment strategies for exaggerated Spee curves and their stability (Carcara et al., 2001; Wylie, 1944; Al-Buraiki et al., 2005; Weiland et al., 1996). It is suggested that the goal of orthodontic treatment should be to level and flatten the curve of Spee in order to enhance the biomechanical performance during chewing by improving the crush-to-shear ratio between posterior teeth, thus facilitating effective occlusal forces during mastication. The excessive Spee curve may alter muscular balance, resulting in incorrect functional occlusion and resistance to occlusal forces during mastication by the dentition (Kumar & Tamizharasi, 2012). A deep Spee curve renders Class I canine relationships nearly impossible, and it may also cause occlusal interferences that manifest during mandibular function (Upadhyay & Nanda, 2014).

Leveling the Spee curve is a crucial element of comprehensive orthodontic therapy. It is often performed via anterior intrusion or posterior extrusion. The occlusal plane must be levelled in almost every orthodontic treatment case. Gaining insight into the impact of a particular orthodontic device or procedure on the motion and response of teeth and other facial structures is essential. Multiple authors have suggested that leveling necessitates an increase in arch length (Baldrige, 1969; Braun et al., 1996), who found a direct correlation between arch circumference and the amount of leveling required. Their estimation indicated a ratio slightly below 1:1 between the depth of the Curve of Spee and the required amount of arch circumference to flatten the curve. Leveling is primarily achieved through the extrusion of the lower premolar teeth and the controlled intrusion of the mandibular incisors. A lack of consensus among experts was revealed when reviewing the literature regarding the different orthodontic treatments used to correct deep Spee curves (Wylie, 1994; Bench et al., 1977; Merritt, 1964; Schudy, 1966; Graber, 1969). The debate revolves around which leveling approach results in the most successful overbite correction and the most stable long-term treatment effects. To achieve flat occlusal planes, clinicians who follow the Tweed orthodontic treatment concept utilise continuous archwires with a reverse Spee curve. As a result, arch leveling is predominantly accomplished by the extrusion of the lower premolar teeth and the limited intrusion of the mandibular incisors.

3.5 Correction of a deep curve of Spee

Different strategies where followed to correct a deep curve of Spee, which can be achieved by the following tooth movements: (a) Extrusion of molars, (b) Intrusion of incisors, and (c) a combination of both movements.

Extrusion of posterior teeth. Continuous archwires are commonly used for posterior tooth extrusion in orthodontic treatments. Another common method involves the utilisation of a bite plate, which facilitates the emergence of posterior teeth. For patients with a short lower facial height and an excessive curve of Spee, it is advisable to perform the extrusion of posterior teeth. This procedure aims to achieve a balanced occlusal plane and enhance dental alignment and function. In individuals with a long face, the protrusion of the molars, which causes the jaw to rotate downwards and backwards, would adversely affect the proportions of facial height. For an adolescent patient with a horizontal or typical vertical growth pattern, posterior extrusion may be a more favourable choice. Extrusion of the upper or lower molars by one millimetre can effectively decrease the amount of overlap between the incisors by 1.5 to 2.5 millimetres. A common technique for accomplishing this method is by utilising continuous archwires (Weiland et al., 1996). A minor modification of this technique necessitates the use of a reverse curve wire in the mandibular arch and/or an exaggerated curve wire in the maxillary arch. Gradual increases in the degree of archwire curvature can also assist in levelling the curve of Spee. In addition, the use of bite plates is a common treatment aiding in the eruption of posterior teeth. These methods are designed to attain a harmonious occlusal plane and enhance overall dental alignment and function. This treatment is appropriate for individuals who have a reduced lower facial height, an accentuated curve of Spee, and a moderate to minimal amount of incisor show. However, stability remains uncertain in non-growing patients. Regular monitoring and appropriate retention strategies may be necessary to maintain treatment outcomes over time. The main disadvantages include excessive incisor display, an increase in the interlabial gap, and a worsening of the gingival smile, especially when it existed previously (Burstone, 1977; Nanda, 1981). Moreover, reverse curve wires often lead to the flaring of the incisors, which is a common drawback. The inherent drawback of using step bends in archwires for the purpose of levelling the curve of Spee is the potential inclination of the occlusal plane towards a more pronounced bite.

Intrusion of incisors. Intrusion of the upper and/or lower incisors is a preferred strategy for leveling the Spee curve in adolescent and adult patients, as demonstrated by several authors in the literature (Nanda et al., 1981; Melsen et al., 1988; Melsen, 1986). It is particularly recommended for patients with a significant vertical dimension, an extended incisal-stomion distance, or increased maxillary incisal display when the lips are at rest (normal value 3-4 mm) and a substantial inter-labial gap. To achieve incisor intrusion, it is advisable to refrain from using a posterior bite plate, as this will allow for posterior disclosure and extrusion, while simultaneously maximizing the effectiveness of the anterior bite plane. Nevertheless, if molar extrusion and mandibular rotation are undesirable, it may be beneficial to consider the use of a posterior bite plate. To avoid unwanted incisor proclination, archwires can be tightened at the distal end to prevent this negative outcome.

For an adult patient with well-developed muscles and potential for vertical growth, the most likely approach to leveling the dental arch is by intruding the anterior teeth within biological limits. Any attempt to extrude the posterior teeth in such a patient is likely to result in relapse. However, anterior intrusion does possess its own drawbacks. Apical root resorption is a prominent risk factor associated with anterior intrusion, as documented by several authors (Parker & Harris, 1998; Deshields, 1969; Harris, 2000; Linge, 1983; Harry, 1982; Ketcham, 1929). It has been suggested that to level each 1 mm of the Spee curve, a 1 mm gap in the horizontal direction is necessary (Rakosi et al., 1993). Several current studies and clinical trials have proposed that incisor intrusion increases the incidence of apical root resorption (Baumrind et al., 1996; Kaley & Phillips, 1991; Goerigk & Wehrbein, 1992; Dermaut & De Munck, 1986; Costopoulos & Nanda, 2011; Simons & Joondeph, 1973). On the other hand, they demonstrated that the average force applied by intrusion arches produces an acceptable biological reaction with minimal root resorption.

3.6 Side effects of levelling the curve of Spee

In a study conducted by Pandis et al. (2010), it was found that proclination of the mandibular incisors primarily leads to the flattening of the curve of Spee. Without the need to widen the dental arch, each 1 mm of levelling the curve of Spee resulted in a 4-degree proclination of the lower incisors. Nevertheless, another study conducted on pretreatment and post-treatment plaster models discovered that the estimation of requiring 1 mm of arch circumference to level each 1 mm of the curve of Spee was too high (Afzal & Ahmed, 2006). On the other hand, a separate study conducted over the long term using cephalometric analysis showed that the process of levelling the curve of Spee using the continuous archwire approach involves a combination of premolar extrusion and, to a lesser extent, incisor intrusion (Bernstein et al., 2007). This technique is highly efficient in correcting the curve of Spee in non-extraction patients with Class II Division I deep bite malocclusions, especially when the initial COS measurement is between 2 mm and 4 mm. Segmented arch mechanics have traditionally been used for anterior intrusion in such situations (Burstone, 1977). Essentially, this mechanism can be used for both anterior intrusion and posterior extrusion to level the dental arch without the effect of incisor proclination. In addition, levelling the curve of Spee does not usually result in an increase in arch length, while levelling a deep curve of Spee by molar uprighting can add 3 to 4 mm to the total arch length (Bench et al., 1977).

Rectangular versus round archwires. A study conducted by Al Qabandi et al. (1999) investigated the effects of full continuous archwires on levelling the curve of Spee by dividing them into two groups: rectangular and round archwires. The lower incisors showed uncontrolled tipping and proclination, which were found to occur in both groups. The explanation for these findings is likely due to the effect of intrusive forces applied by the archwire being labial to the centre of resistance of the lower incisors. The stability of the curve of Spee may be determined by the nature of the levelling technique. When the posterior extrusion technique is used, the stability of this extrusion is debatable. Many factors affect stability, such as the level of patient physical development, age during therapy, muscular strength, adaptation, and the initial situation of malocclusion. All these factors have been proposed as variables that influence the long-term stability of levelling the curve of Spee (Berg, 1983). A thorough assessment of the stability of incisor intrusion was conducted in a study by Burzin and Nanda (1993), which proposed that the maxillary incisors showed minimal relapse.

Digital set-up. The progressive demand for aesthetic orthodontic appliances and digital evolution has increased the widespread use of clear aligners. Orthodontic treatment with clear aligners has led to observations of reduced molar extrusion, especially when the aligners are worn throughout the day. The concept of the bite block effect suggests that teeth move within the aligners, and continuous occlusal forces exerted throughout the day aim to prevent vertical extrusion of posterior teeth (Harris et al., 2020). This reactive intrusion force can be considered biomechanically advantageous when addressing vertical excess in open bite patients. However, when treating vertical reduction in deep bite patients, the bite block effect can pose a significant limitation because it restricts dental correction to the anterior segment of the arch, focusing on incisor inclination and the intrusion of upper and lower teeth (Giancotti et al., 2008; Giancotti et al., 2014; Miller & Derakhshan, 2002; Rossini et al., 2015). The use of bite ramps, which function as anterior bite plates built into aligners, has revolutionised the approach to deep bite treatment. This innovation enhances treatment predictability and reduces the necessity for over-engineering in digital treatment planning (Cogan, 2018). Levelling the curve of Spee can be made more reliable by incorporating two reciprocal movements in different segments of the arch, combining anterior intrusion and posterior extrusion, as recommended in the literature (Liu & Hu, 2018; Simon et al., 2014).

When planning the digital setup, it is important to meticulously level the curve of Spee in all three dimensions of the dental arch, particularly:

- On the vertical plane: No extrusion is required for lower second molars, as they are considered reference points; however, extrusion should be planned for the first molars, second premolars, and, sometimes, first premolars. Intrusion should occur simultaneously from canine to canine (Zhao et al., 2019).
- On the sagittal plane: Distal tipping of the second and first molars will support the leveling of the curve of Spee in combination with reciprocal mesial tipping of the premolars and canines. This movement is synergistic, and distal tipping helps to partially extrude the molars (Greco & Rambola, 2022).
- On the transverse plane: Uprighting the premolars and molars to a torque close to zero degrees leads to a relative extrusion of the lateral segment, contributing to the formation of curve of Spee leveling and early posterior occlusal contacts (Kim & Gianelly, 2003). The planned posterior extrusion in the 3D setup will create significant occlusal contacts on the functional cusps of the molars in the digital plan. These premature contacts facilitate proper intercuspation clinically, ensuring that occlusal contacts are maintained throughout treatment and potentially resulting in mandibular clockwise rotation.

Ultimately, to facilitate mandibular rotation and correct intercuspation, Class II elastics with a vertical component directly integrated into the aligners will be advantageous. This approach aids in achieving both true and relative extrusion. The management of the curve of Spee and the control of posterior tooth movement are crucial elements in effectively treating severe deep bite with aligners. To better understand how different movements affect deep bite therapy, some authors recently classified deep overbite malocclusion features into primary and secondary components (El-Dawlatly, 2012). The primary components are characterised by a decreased gonial angle and a deep curve of Spee. The secondary components include front tooth inclination, maxillary incisor overeruption, and maxillary vertical growth. When correcting deep bite malocclusion, mandibular incisor intrusion should be paired with posterior segment extrusion using relative extrusive movements through torque and tip correction.

This method allows for significant anterior deep bite correction with only a minimal amount of true posterior extrusion as a result of adequate Spee curve leveling. It is important to consider that for every 1 mm of posterior extrusion, the bite expands by approximately 2.5 mm anteriorly (Castroflorio et al., 2013). The described biomechanical properties of bite ramps prevent the common tooth intrusion caused by aligner thickness and inter-occlusal contacts. The approach will be completed by lower arch leveling with anterior intrusion, which is accompanied by posterior relative extrusion or, at the very least, the maintenance of the vertical position of the posterior teeth. The consistent posterior disocclusion maintained during treatment with bite ramps facilitates substantial pure posterior extrusion, especially when combined with short Class II elastics and heavy posterior occlusal contacts. The slight pure extrusion linked to the relative extrusion expected from molar distal tipping and the uprighting of molar and premolar torque (3D leveling of the curve of Spee) will contribute to mandibular clockwise rotation.

Additionally, the precise placement of bite ramps will redirect the occlusal forces exerted by the muscles, creating anterior premature contacts to facilitate lower incisor intrusion. Furthermore, the use of these auxiliary features in aligners appears to influence vertical skeletal relationships, as indicated by improved cephalometric vertical measurements. No posterior intrusion or bite effects were observed at the end or during therapy. The overall change in the vertical position of the posterior teeth was minimal. However, as previously mentioned, literature data support that even a small amount of posterior real or relative extrusion induced by appliance biomechanics can lead to significant opening of the deep bite due to mandibular clockwise rotation. This underscores the effectiveness of bite ramps as a critical feature in treating deep bite malocclusion.

These aligner-embedded features, when paired with effective 3D planning of Spee curve leveling, along with the use of extrusion attachments and pressure areas on the lower arch, resulted in improved leveling of the curve of Spee and a more predictable treatment outcome (Greco & Rambola, 2022). There have been no studies published on the usage of bite ramps; the only study examining deep bite and aligners was conducted before the introduction of these specific features (Khosravi et al., 2017). Bite ramps are a critical component for managing the 3D leveling of the curve of Spee, combining anterior intrusion with posterior relative and actual extrusion; they still require further exploration, as no scientific studies have examined their application. Creating precise occlusal contacts during the digital setup is crucial to achieving proper posterior inter-cuspation by the end of treatment. Class II elastics directly attached to the aligners are beneficial for transmitting forces to ensure correct lower incisor proclination and to achieve optimal posterior intercuspation.

4 Discussion

The objective of the study is to investigate the development and significance of the curve of Spee in human dental occlusion. Its role in orthodontics and prosthodontics, as well as different leveling techniques in conventional and digital setups for orthodontic treatment and long-term stability, were addressed. The curve of Spee is an inherent characteristic that was initially documented by F. Graf von Spee in 1890 (Spee, 1980). The anteroposterior curve of the mandibular arch is a concave line that touches the incisal edges and buccal cusp tips of premolar and molar teeth. It stretches from the anterior edge of the mandibular ramus to the foremost part of the mandibular condyle.

There has been very little research on the characteristics of the Spee curve in the maxillary arch. A study conducted by Xu et al. (2004) revealed that the curvature was substantially flatter in the maxillary arch than in the mandibular arch. The depth of the curve of Spee is found to be minimal in deciduous dentition. A gradual increase occurs during the early mixed dentition as a result of the eruption of the permanent first molar and central incisor. This depth is maintained until it increases again to its maximum depth with the eruption of the permanent second molars, after which it remains relatively stable into late adolescence and early adulthood (Marshall et al., 2006). Some studies have demonstrated that there are no significant changes in the depth of the curve of Spee between the right and left sides of the mandibular arch or between different sex groups (Marshall et al., 2008; Currim & Wader, 2004). The relationships between the curve of Spee and dentofacial morphology were investigated using 3D virtual dental models and lateral cephalograms. The virtual model developed with the 3D reconstruction method has been shown to be accurate and reproducible in clinical dentistry, and its clinical usefulness is excellent because such measurements would be difficult to obtain from real patients (Cheon et al., 2008). There is a strong correlation between the forward inclination of the superficial masseter muscle and the forward tilt of molar teeth in the sagittal plane, which corresponds to the posterior end of the curve of Spee. The inclination of the Spee curve increases the ratio of crushing to shearing forces exerted on food by the back molars (Woods, 1986; Lynch & McConnell, 2002; Garcia, 1985; Currim & Waskar, 2004).

Orthodontics and Prosthodontics offer different perspectives on the clinical importance of the curve of Spee. Effective control of the curve of Spee is essential in prosthodontics for creating durable complete dentures and can also impact the outcomes of implant-supported restorations (Xu et al., 2004). Creating a curve of Spee that aligns with condylar guidance, incisal guidance, the plane of occlusion, and prosthetic tooth cusp height is crucial in complete denture prosthodontics to achieve a balanced occlusion on both sides. These factors are thought to play a significant role in maintaining optimal denture stability. Andrews (1972) observed that individuals with good occlusion exhibit a range of flat to mild curvature of Spee when describing the six characteristics of normal occlusion. Additionally, he noted that optimal static intercuspation was achieved when the occlusal plane was relatively level. Andrews suggested that achieving a flat occlusal plane should be a primary objective in orthodontic treatment.

An exaggerated curvature of the dental arch, known as the curve of Spee, is commonly linked to a heightened vertical overlap of the anterior teeth. The orthodontic correction of an overbite typically includes the adjustment of the curve of Spee through anterior intrusion, posterior extrusion, or a combination of both techniques. In certain instances, the inclination of the lower incisors has been employed to reduce the vertical overlap of the lower incisors by the upper incisors. The process of leveling the curve of Spee is a crucial stage in orthodontic treatment. While the orthodontic phase of achieving a leveled curve of Spee is a common objective in orthodontic treatments, there have been no studies comparing the outcomes of this phase when using fixed appliances versus clear aligners. The curve of Spee typically remains consistent following orthodontic treatment. Several investigators have described the relapse of the curve as a normal physiological process (Andrews, 1972; Koyama, 1979).

Some researchers have determined that an orthodontically leveled curve of Spee is a relatively stable procedure (De Praeter et al., 2002), whereas others have noted relapse tendencies (Carcara et al., 2001). However, there has been limited research on the extent of relapse and the identification of potential contributing factors. A study conducted by Carcara et al. (2001) discovered a statistically significant alteration in the curve of Spee subsequent to the elimination of retention appliances in Angle Class I and Class II cases. The observed relapse of the curve of Spee in these cases averaged 0.37 mm over a duration of 7 years and 5 months. The stability of the leveled curve of Spee can be ascertained by the characteristics of the correction. In addition, other factors, such as growth and neuromuscular adaptation, may contribute to relapse. In a 10-year post-retention study, Simons and Joondeph (1973) found that proclination of the lower incisors and clockwise rotation of the occlusal plane after treatment were major relapse variables. The stability of posterior extrusion is debatable. Variables such as the amount of development, the patient's age during therapy, muscular strength, adaptation, and the original malocclusion have all been proposed as contributing to the long-term stability of curve of Spee leveling (Berg, 1983). Leveling the curve of Spee is a highly stable treatment approach compared to incisor crowding and overbite (De Praeter et al., 2002). Neither the initial depth of the curve of Spee nor the initial irregularity index predicts the amount of relapse of the curve of Spee; the amount of leveling is not correlated with the relapse of the four tested parameters: the curve of Spee, the irregularity index, overjet, and overbite (Shannon & Nanda, 2004). Leveling the curve of Spee as a standard orthodontic procedure appears to be a very consistent treatment goal.

The curve of Spee can change physiologically with age or pathologically in conditions including tooth rotation, tilting, and extrusion. The curve of Spee changes significantly with age, and posterior disocclusion decreases during mandibular protrusion (Ahmad et al., 2011). However, if the curve of Spee is not maintained in these dentitions throughout full mouth rehabilitation, it may cause interferences in mandibular movements, jeopardising the health and efficiency of the masticatory system. Nanda et al. (1993) carefully evaluated the stability of incisor intrusion and discovered that the maxillary incisors exhibited negligible relapse. According to De Praeter et al. (2002), the process of leveling the curve of Spee in orthodontic treatment seems to maintain its stability over a prolonged period of time.

Conclusions

Understanding Spee's curve in orthodontics is critical, as orthodontists encounter it in almost every patient they treat. However, the literature contains very few studies that provide an in-depth explanation of its causes and development, as well as the contributing elements. It begins in the deciduous dentition, progresses through mixed dentition, and stabilises in adulthood. The clinical management of the curve of Spee by orthodontics and prosthodontics is quite different. Several methods for levelling the curve of Spee in conventional fixed orthodontics exist. Digital setup is crucial in treatment planning to achieve levelling of the curve of Spee in the treatment of deep bite patients with clear aligners. More studies are needed to understand the biomechanics and the effects of auxiliaries in clear aligners for deep bite cases. Few studies assess other occlusal curvatures, such as the curve of Monson and the curve of Wilson, since these curvatures, combined with the curve of Spee, influence dentofacial anatomy and other aspects of malocclusion. Hence, further studies are recommended to address the various occlusal curvatures individually and their impact on occlusion and the stability of treatment.

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Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Consent for publication

Not applicable.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

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