



RESEARCH ARTICLE

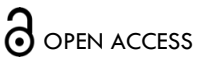
# Functional Incisal Loading Regulates Nasal Septum Cartilage Ossification

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## ABSTRACT

**Background:** The mechanisms guiding ossification of the nasal septal cartilage (NSC) remain unclear. This investigation examined whether functional incisal forces influence the extent of nasal septal ossification. **Methods:** De-identified Cone Beam Computed Tomography (CBCT) scans from 205 adult orthodontic patients were analyzed. Subjects were classified by overbite and mandibular plane angle into deep bite (n = 68), open bite (n = 67), and control (n = 70) groups. Midsagittal CBCT views were used to measure the areas of the nasal septal cartilage, perpendicular plate of the ethmoid (PPE), vomer, and maxillary process. The percentage area of the PPE relative to the total septal area was calculated. The linear contact length between the PPE and vomer, and the cartilage extension (CE) between them, were also measured. To assess biomechanics, impact force during cutting of hard food (carrot) was measured *in vitro* using an Instron machine. *In vivo*, acceleration and velocity during carrot biting at impact were recorded in 5 volunteers using high-speed video.

**Results:** Open bite patients demonstrated significantly greater ossification of the septal cartilage compared with deep bite patients. The contact length between the PPE and vomer was significantly shorter in deep bite cases, while CE length was significantly greater in deep bite cases compared with open bite cases. Gender, sagittal dental relationship, and overbite magnitude showed no significant influence on septal ossification. PPE-vomer contact was shortest when only the second molar was in occlusion, whereas CE length was greatest in patients with a reduced mandibular plane angle. Biomechanical analysis showed that incisal cutting of hard food generates high impact forces due to both bite force and rapid mandibular acceleration over a short distance, producing high-velocity impact loads. These forces were significantly reduced in hyperdivergent patients with an open bite greater than 5 mm. **Conclusion:** Functional incisal loading influences nasal septal development, with elevated incisal forces inhibiting endochondral ossification of the NSC. PPE-vomer contact length and CE length are useful indicators of the effect of incisor occlusion on septal ossification. These findings support a functional role of occlusion in shaping both the cartilaginous and bony nasal septum. **Keywords:** Nasal septal cartilage, nasal septum, cartilage ossification, functional loading, incisal forces, impact forces, biomechanics, occlusal forces, occlusion, deep bite, open bite, hyperdivergent mandibular plane, hypodivergent mandibular plane, mandibular loading, impact forces

## Introduction

During embryonic life, the nasal septum is completely cartilaginous and forms part of the chondrocranium that includes the cranial base.<sup>1,2</sup> As the cranial base gradually ossifies, the posterior part of the nasal septal cartilage goes through endochondral bone formation to form the perpendicular plates of the ethmoid bone. In contrast, the anterior part of the septum remains cartilaginous throughout life.<sup>3,4</sup> However, it is unclear why nasal septal cartilage undergoes extensive ossification in some individuals, while in others it remains mostly cartilaginous. Here, we evaluate ossification of nasal septal cartilage from a biomechanical perspective, with a focus on the role of incisor function.

The role of the nasal septum has been the center of contentious debates. Among the proposed functions of the nasal septum, the mechanical role stands out most prominently; however, different mechanical functions have been attributed to the nasal septal cartilage. Part of the confusion lies in the distinction between the mechanical role of the cartilaginous septum and the function of the bony septum, which is largely composed of ossified cartilage.

It has been established that occlusal forces are the main source of loading of the skull and affect the shape of the craniofacial structures.<sup>5-10</sup> The fact that masticatory forces can be transferred to the nasal septum has prompted many researchers to propose that the septum may act as a midline vertical strut that prevents the palate from collapsing under occlusal forces<sup>11,12</sup> or the nasal bones from collapsing under the weight of the skull and surrounding soft tissues.<sup>13</sup> Many midfacial growth studies support this view by showing the collapse of the nasal roof and floor when varying amounts of the septum were removed.<sup>14-24</sup> However, we propose that this structural support function of the nasal septum is carried out mostly by the posterior part of the septum, which is ossified, and not the cartilage component. Bones have enough compressive stiffness to resist the masticatory loads, but cartilage stiffness is much lower to support such a function.<sup>25</sup>

On the other hand, cartilage has characteristics that make it a suitable material for shock absorption. The cartilaginous septum has high compressive stress-relaxation properties and can withstand deformation during mastication, making it suitable for shock absorption.<sup>26</sup> Indeed, it has been shown that occlusal forces are significantly reduced before they are transferred to the nose.<sup>27</sup> This is especially important when it comes to occlusal forces generated by incisors. The cutting machinery in mammals has been designed with incisors located away from the TMJ, allowing the animal to open the mouth widely to capture larger prey and to achieve higher acceleration during jaw closure,

thereby producing higher impact forces. Higher-impact forces are delivered over a short period, which can be dangerous to the skull, especially when they occur in the mid-sagittal plane, where large spaces are present. Here, we propose that the presence of nasal septal cartilage can significantly dampen these high-impact forces, preventing any injury in the skull. The danger of high-impacted incisal forces on the maxilla can be especially appreciated, considering the palate has a cantilever structure. As the forces are applied farther forward from the maxilla's attachment to the skull, increasing the cantilever arm, the larger the moments generated, potentially increasing the risk of fracture. Higher moments also increase the palate's deflection during incisor force application. The presence of a cartilaginous nasal septum allows this deflection and dampens the effect of large moments. Another instance when the shock absorption property of the nasal septal cartilage is vital is in the case of high-impact forces generated by trauma to the skull.<sup>28</sup>

Based on the above discussion, the mechanical demand for cartilaginous and ossified nasal septal cartilage can vary among individuals. We argue that the high-impact forces of incisors stimulate the nasal septal cartilage to remain cartilaginous, while the low-impact force of posterior teeth during chewing promotes ossification. Our hypothesis is supported by previous observations showing that the endochondral bone formation process is sensitive to the magnitude of mechanical stimulation. In fact, the relationship between mechanical loading and endochondral ossification is well established in the musculoskeletal biology field. It has been shown that the effect of loading on cartilage-to-bone conversion is dose-dependent: moderate cyclic loading can promote ossification, while short-term, high-magnitude compressive loading can paradoxically suppress chondrocyte hypertrophy and retard ossification.<sup>29,30</sup>

To test this hypothesis, we studied the extent of ossification of the nasal septal cartilage in patients with a significant open bite throughout life compared with those with a normal or excessive overbite. In addition, the effect of the mandibular plane angle on the extent of ossification of the nasal septum was also evaluated, which can alter the magnitude of muscular force and, consequently, the magnitude of impact forces.

## Materials and Methods

### HUMAN SUBJECTS AND STUDY DESIGN

The Institutional Review Board of Pearl IRB, LLC (Fishers, IN) approved this retrospective, non-randomized, single-center, single-blinded clinical study. Two hundred and five CBCT scans were obtained from adult patients of both genders seeking orthodontic treatment, with no restriction on race or ethnicity, according to defined inclusion and exclusion criteria (Table I).

**Table I. Inclusion and exclusion criteria of the clinical study.**

Inclusion Criteria	Exclusion Criteria
Male and Female patients aged 18+	History of trauma, craniofacial syndromes, pathologies, previous orthodontic, orthopedic, or surgical treatment
CBCT taken as initial orthodontic records	CBCT taken at an external institution
Skeletal Class I, II, or III malocclusion	Patient with history of extraction (not wisdom teeth)
Patient with Class I, II, III molar or canine relation	Patient with periodontal disease
Absence systemic disease	Presence of systemic disease
Patient with mild or moderately proclined or retroclined anterior teeth	Patient with crowns, or any extensive restoration
Patient with asymmetry less than 5 mm	Significant asymmetry (more than 5 mm between upper and lower arch)
Patient with asymptomatic TMJ or mild TMD	Patient with severe TMD signs and symptoms
Patient with mild to moderate crowding or spacing	Patient with severe crowding, impacted teeth or severe overjet (more than 6 mm)
Patient with different dental arch forms	Patient who recently developed an open bite or deep bite
Patient with anterior or posterior crossbite which did not cause more than 5 mm shift	Patient with a severe posterior or anterior crossbite, which causes more than 5 mm shift

All subjects had completed standard pretreatment orthodontic records, including CBCT, lateral cephalometry, panoramic radiograph, and facial and intraoral photographs prior to enrollment. Patients were classified into three cohorts: normal occlusion (n = 70),

deep-bite malocclusion (n = 68), and open-bite malocclusion (n = 67). The average age was 34.7 years in the deep bite cohort, 29.2 years in the open bite cohort, and 33.3 years in the control group (Table II).

**Table II. General Characteristics of Different Groups.**

Variable	Control n = 70	Deep Bite n = 68	Open Bite n = 67
Gender (M/F)	34 / 36	30 / 38	28 / 39
Mean Age (years)	33.3	34.7	29.2
Skeletal form (I/II/III)	49 / 12 / 9	10 / 52 / 6	19 / 22 / 26
Incisal Overbite (mm)	2.4 ± 0.7	7.1 ± 1.2*	-5 ± 0.5 mm* #
Overjet (mm)	1.9 ± 0.8	2.56 ± 0.7	2.19 ± 0.9
Mandibular Plane Angle (deg)	32 ± 2.4	27 ± 2.1*	35 ± 1.3*

Each number represents the mean ± SEM of each group (\* significantly different from Control, p < 0.05, # significantly different from deep bite group, p < 0.03).

Skeletal Class I, II, and III malocclusions were defined based on Steiner and Wits' analysis of the patient's cephalometric radiograph. Deep bite classification was based on both skeletal and dental components: overbite of ≥ 90% and a mandibular plane angle of less than 28 degrees. Open bite classification required an anterior open bite of more than 4 mm with a mandibular plane angle exceeding 34 degrees. This dual-criterion approach was used to ensure that the vertical discrepancy reflected a genuine functional difference.

In this study, patients who had recently developed an open or deep bite were excluded (Table I). Similarly, any factor such as extraction or restoration that may affect the occlusion and change the bite was excluded. If the severity of malocclusion, such as severe crowding, severe overjet, crossbite, asymmetry, or impacted teeth, caused a significant shift of the jaw or impaired incisor function, the subjects were excluded from the study.

**CBCT PROTOCOL AND MEASUREMENTS**

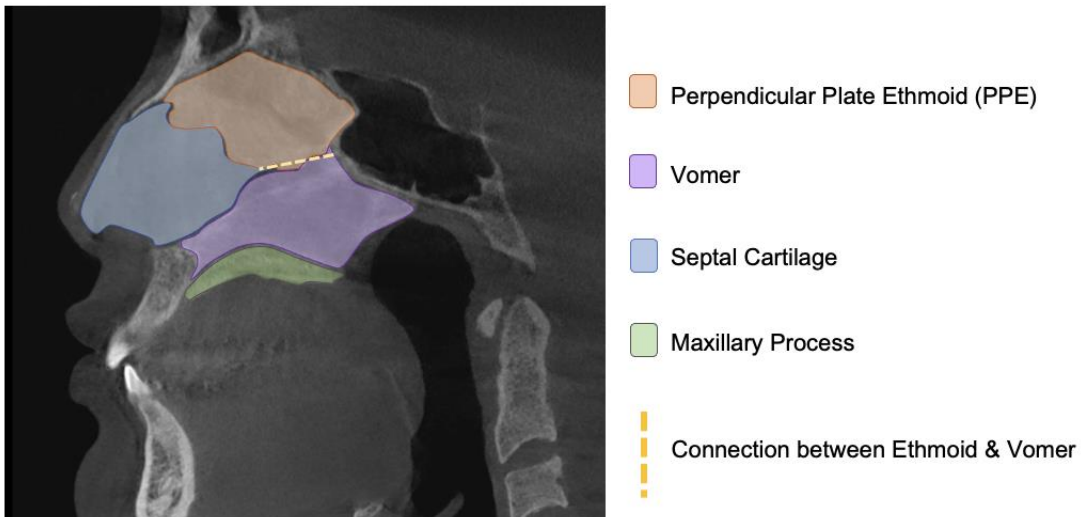
All CBCT scans were completed at the study institution using a Vatech PaX-i3D Green scanner (PHT-60CFO) with voxel sizes of 0.25 or 0.3 mm. Scans were reconstructed and evaluated using Ez3D-i dental imaging

processing software. All measurements were performed in the midsagittal plane, with each scan first oriented to a standardized head position before landmark identification.

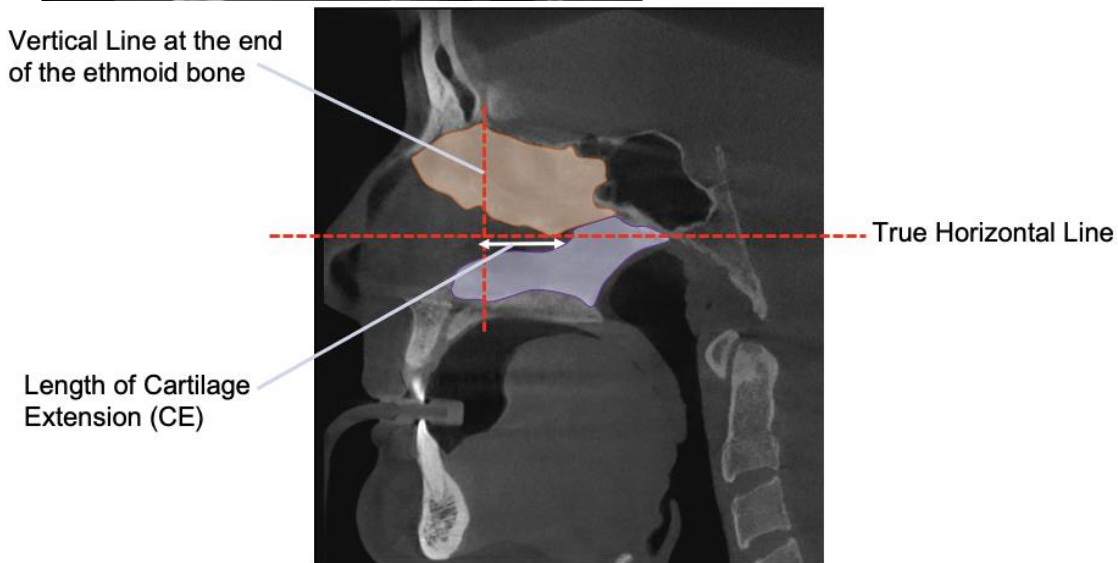
Area measurements were performed as previously described.<sup>31</sup> Briefly, the midsagittal view of CBCT images was selected, and the area of each component of the nasal septum (Nasal Septal Cartilage, Perpendicular Plate of the Ethmoid, Vomer, Maxillary Process) was delineated and the area measured. The percentage of the area of the perpendicular plate of the ethmoid in comparison with the total area of the nasal septum was calculated.

In addition, the length of the contact between the vomer and the perpendicular plate was measured on a straight line drawn between the two bones (Figure 1A). The length of the cartilage extension (CE) between the vomer and ethmoid process was measured on a straight line parallel to the true horizontal, between the end of the contact point between the PPE and vomer and a perpendicular line that passes through the end of the ethmoid bone (Figure 1B).

A



B



**Figure 1: Midsagittal structures area identification and linear measurements.** Midsagittal CBCT view illustrating the anatomical regions analyzed on a representative slice (A): The perpendicular plate of the ethmoid (orange), vomer (purple), septal cartilage (blue), and nasal crest of the maxilla (green). The red dashed line indicates the vomer–PPE contact length (A). The sphenoid process length was measured from the end of vomer–PPE contact along a horizontal line to a perpendicular projection at the end of the ethmoid bone (B).

**Measuring Impact Forces**

The impact force was calculated using an Instron testing machine 5542 with Blue Hill Universal software (Illinois Tools Work, Inc, Norwood, MA) and a 500 N load cell at a displacement rate of 10 mm/s. A carrot was used to evaluate incisor impact force during food cutting. A replica of human incisors was fabricated to mimic the area of contact of the normal teeth in the Instron (Figure 2A & 2B). A similar thickness carrot was used to measure the impact force on humans. Time and distance of movement were recorded using a Sony A7Riii camera at 50 fps (frames per second) in 5 volunteers during carrot biting. Impact force was calculated using the following formula:

$$F_{imp} = \frac{mv^2}{2s}$$

Where “ $F_{imp}$ ” is the impact force (N), “ $m$ ” is the mass of the mandible (kg), “ $v$ ” is the velocity of the mandible at

the time of impact, and “ $s$ ” is the slow-down deformation distance, in this example, the distance that the lower incisors traveled into the carrot during biting. The weight of the mandible (including teeth) was measured in 5 dry skulls, and the weight of the wet mandible with soft tissue was estimated based on the previously published articles.<sup>32</sup> The acceleration was measured by the following formula:

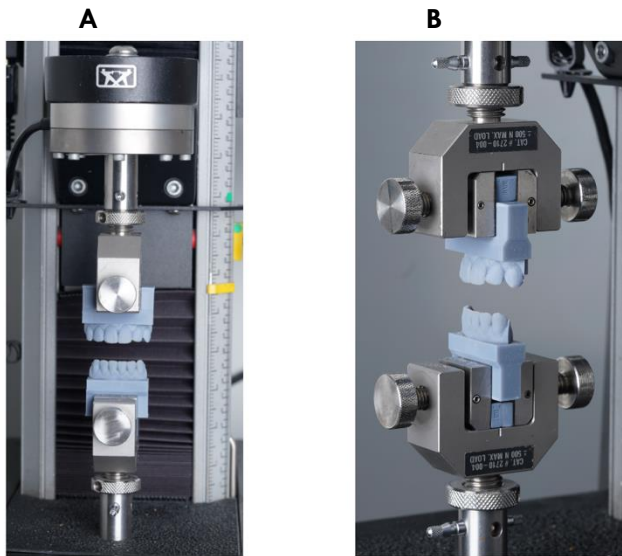
$$F_{bite} = m.a$$

Where “ $F_{bite}$ ” is the bite force in each group, and “ $m$ ” is the mass (weight) of the mandible. The maximum incisor bite force for the open bite, deep bite, and control groups was calculated using previous reports.<sup>33</sup> The velocity at the time of impact was measured as follows:

$$v = a.t$$

Where “ $t$ ” is the time of contact after the mandible travels the distance  $x$ .

$$t = \sqrt{(2x/a)}$$



**Figure 2: In vitro measurement of incisor impact force.** An Instron Machine was used to evaluate the cutting action of the incisor teeth and the bite forces generated. A customized indentation tool was fabricated by scanning and 3D printing human incisors. Front view (A) and lateral view (B) of the setup on the Instron machine.

### Statistical Analysis

Two examiners completed all morphological quantifications. The random and systematic errors were calculated using a formula described by Dahlberg and Houston. Both random and systematic errors were small for intra-observer (0.5 and 0.7 mm, respectively) and inter-observer (0.9 and 0.7 mm, respectively).

Significant differences between test groups and controls were assessed by analysis of variance (ANOVA). A pairwise multiple comparison analysis was performed using Tukey's post hoc test. Two-tailed p-values were calculated;  $p < 0.05$  was set as the level of statistical significance.

### Results

#### PATIENT DEMOGRAPHICS

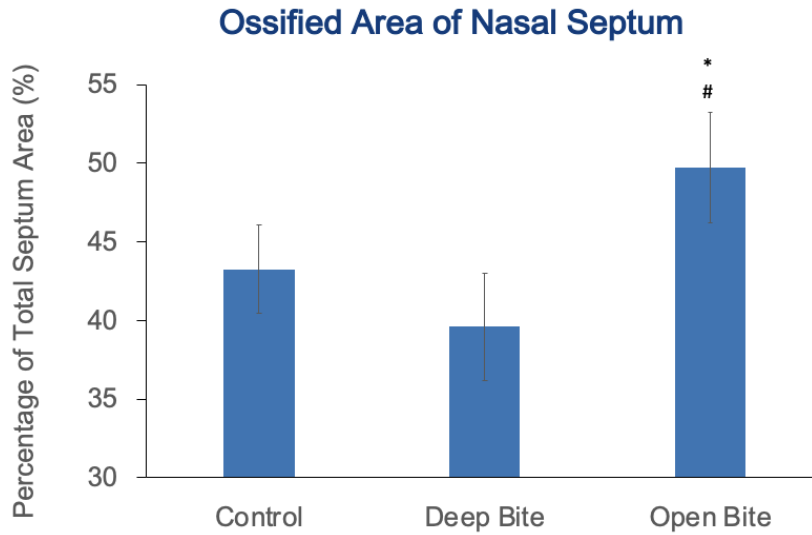
Across the 205 subjects, the deep bite group ( $n = 68$ ) comprised 30 males and 38 females, with a mean age of 34.7 years. By sagittal skeletal relationship, this cohort included 10 Class I, 52 Class II, and 6 Class III cases. Mean overbite was ( $7.1 \pm 1.2$  mm), mean overjet was  $2.56 \pm 0.7$  mm, and the mean mandibular plane angle was  $24 \pm 2$  degrees. The open-bite cohort ( $n = 67$ ) consisted of 28 males and 39 females, with a mean age of 29.2 years, distributed across 19 Class I, 22 Class II,

and 26 Class III cases. Mean open bite measured  $5 \pm 0.5$  mm, overjet  $2.19 \pm 0.9$  mm, and the mandibular plane angle averaged  $35 \pm 1.3$  degrees. The Control group was composed of 29 males and 41 females, distributed by 49 Class I, 12 Class II, and 9 Class III skeletal patterns, with a mean overbite of  $2.4 \pm 0.7$  mm and overjet of  $1.9 \pm 0.8$  mm (Table II).

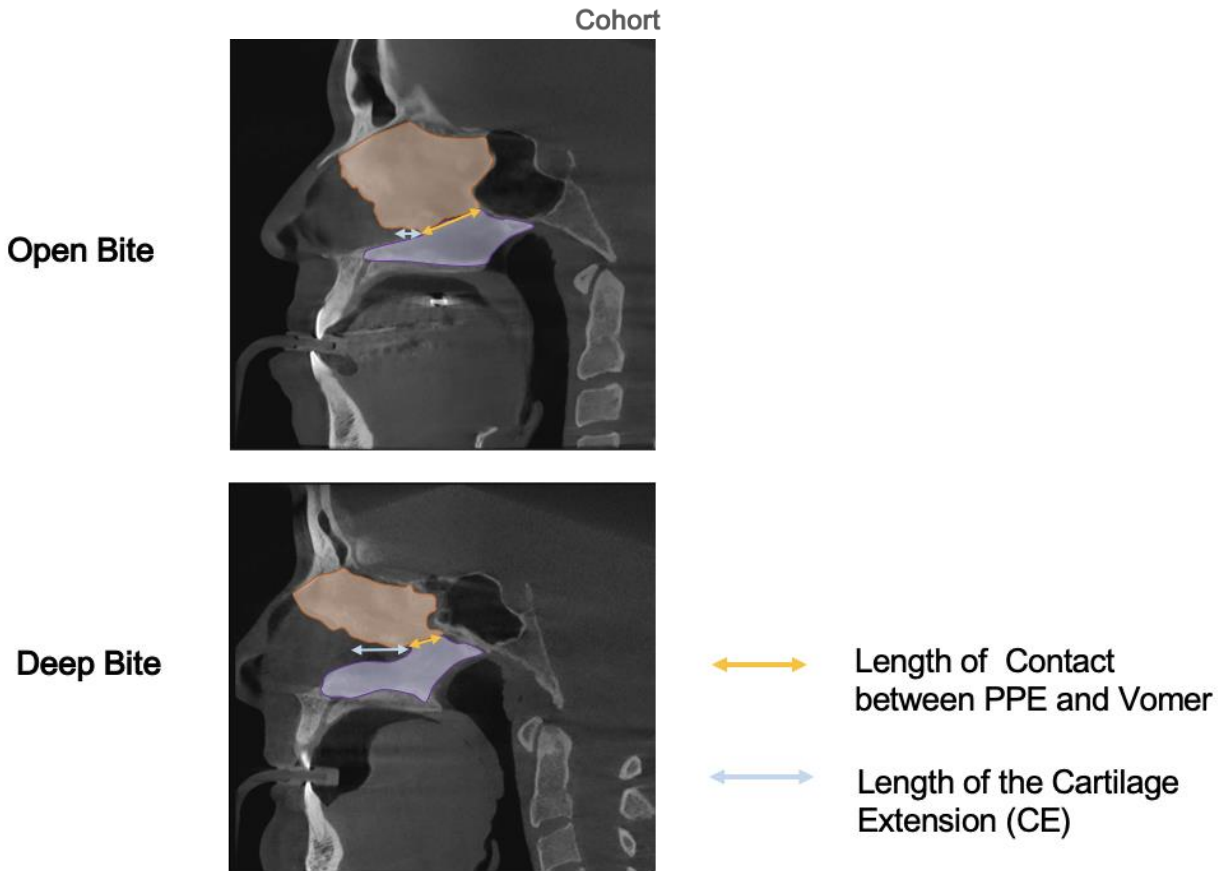
#### AREA OF OSSIFICATION

The area of ossification was significantly greater in open-bite cases in comparison with the control ( $p < 0.05$ ) and deep bite groups ( $p < 0.03$ ) (Figure 3A). However, while the average of ossification in deep bite cases was lower compared with the control, no statistical difference was observed between the control and deep bite groups. The length of contact between the vomer and the PPE, and the length of the CE were measured for all groups using CBCT images (Figure 3B). The length of the contact between the PPE and the vomer was larger in the open bite group compared with both the control ( $p < 0.05$ ) and the deep bite group ( $p < 0.03$ ) (Table III), while the length of the sphenoid process was longer in deep bite cases in comparison with open bite group which was statistically significant ( $p < 0.05$ ) (Table III). However, no significant difference was observed between the length of the sphenoid process between the deep bite and the control group ( $p > 0.05$ ).

A



B



**Figure 3: Extent of nasal septum cartilage ossification.** Percentage of ossified cartilage area relative to total nasal septum area was calculated to normalize for individual size (A); values are mean ± SEM (\*p < 0.03 vs control; #p < 0.03 vs deep bite). Midsagittal CBCT images show the length of contact between the PPE and vomer (yellow arrow) and the CE length (blue arrow) in open- and deep-bite cases (B).

**Table III: Length of the contact between the perpendicular plate of the Ethmoid and the Vomer, and the length of the cartilage extension (CE).**

Cohorts	Length between PPE and Vomer (mm)	Length of Cartilage Extension (mm)
Control	15.2 ± 2.1	11.8 ± 3.8
Deep Bite	11.6 ± 2.4	18.2 ± 3.5 <sup>^</sup>
Open Bite	22.7 ± 2.7* <sup>#</sup>	7.4 ± 3.3

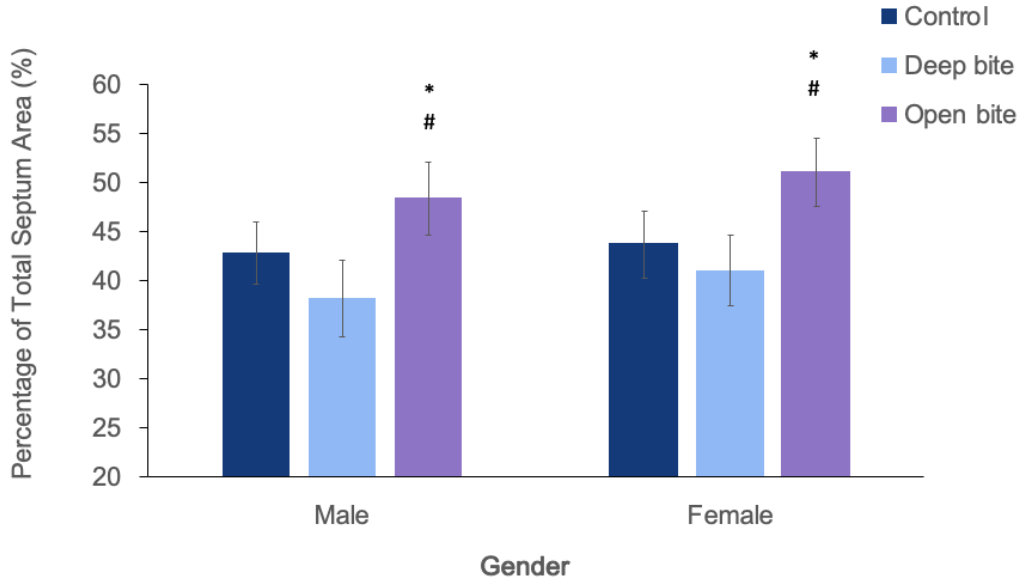
Each number represents the mean ± SEM of each group (\* significantly different from Control, p < 0.05, # significantly different from deep bite group, p < 0.03, <sup>^</sup> significantly different from open bite group, p < 0.05).

**EFFECT OF GENDER ON OSSIFICATION OF NASAL SEPTUM**

Sex variability did not significantly affect (p > 0.05) the area of cartilage ossification (Figure 4A). Similarly, the

length of contact between the vomer and the PPE, and the length of the CE, did not differ between men and women (data not shown).

### Ossified Area of the Nasal Septum



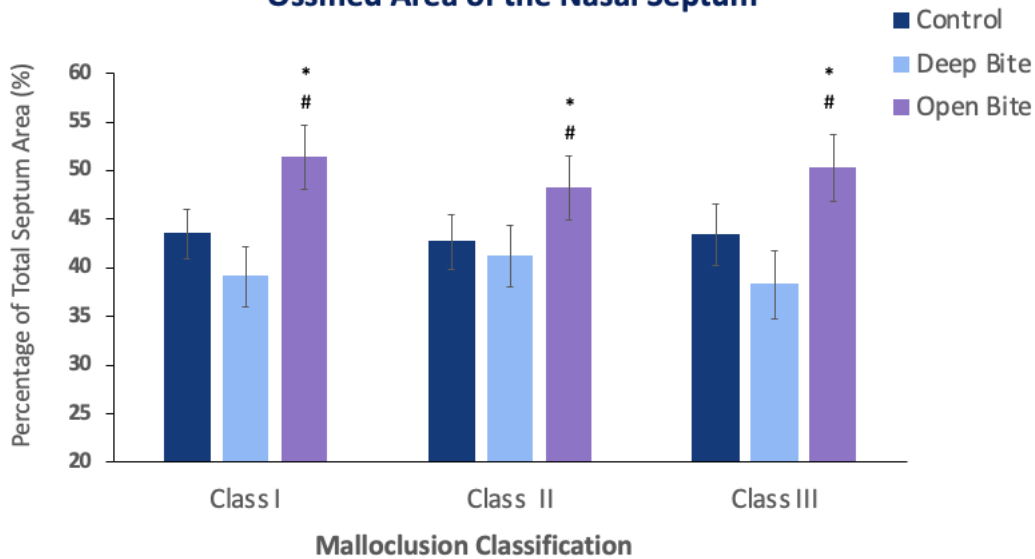
**Figure 4: Effect of gender on the ossification of the nasal septum.** Percentage of nasal septal cartilage ossification was assessed in males and females across control, deep bite, and open bite groups. No significant gender differences were found within any group. Values are mean ± SEM (\*p < 0.05 vs control within the same gender; #p < 0.05 vs deep bite within the same gender).

#### EFFECT OF SAGITTAL SKELETAL RELATIONSHIP ON NASAL SEPTAL CARTILAGE

Next, we evaluated whether the horizontal relationship between the upper and lower arches affected the magnitude of ossification of the nasal cartilage across the different groups. To our surprise, the sagittal skeletal relation between the upper and lower arch did not have any effect on the magnitude of ossification (p < 0.05)

(Figure 5). Similarly, skeletal relation did not affect the length of contact between the PPE and the vomer, nor did it affect the length of the CE (Data not shown) in subjects with different skeletal jaw relations. These data suggest that, as long as the transfer of occlusal forces (cutting or chewing) in individuals remains the same, regardless of the horizontal relation between the jaws, the magnitude of ossification of cartilage will be similar.

### Ossified Area of the Nasal Septum



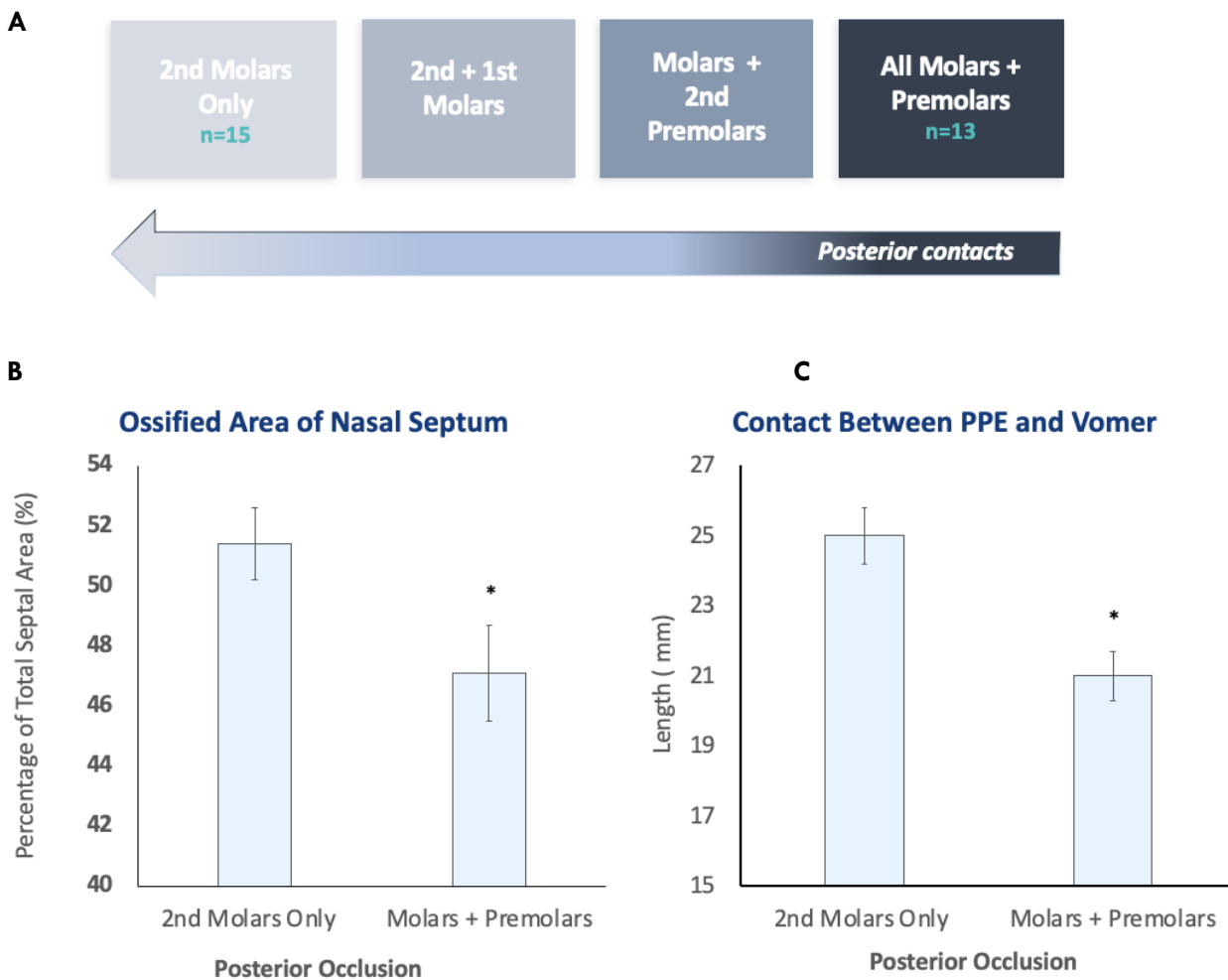
**Figure 5: Effect of sagittal skeletal relation on the ossification of the nasal septum.**

Percentage of nasal septal cartilage ossification was evaluated in Class I, II, and III subjects across control, deep bite, and open bite groups. No significant differences were observed among skeletal classes. Values are mean ± SEM (\*p < 0.05 vs control; #p < 0.05 vs deep bite within the same skeletal relation).

EFFECT OF POSTERIOR OCCLUSION ON OSSIFICATION OF NASAL SEPTUM

While individuals in the open bite group share the commonality of lacking anterior contact at the incisors, they differ in the magnitude of their posterior occlusal contact. While some subjects bite only on second molars, others bite on second molars and first molars, or on all molars and second premolars, or on all posterior teeth, including first premolars (Figure 6A). However, none of the subjects had contact with canines. We evaluated the differences in ossification between patients who could only bite on the second molar and patients who could bite on all posterior teeth, including the first premolars. We identified 15 patients who could bite only on second

molars and 13 who could bite on all posterior teeth. We study the difference in the magnitude of ossification of the nasal septal cartilage within the open bite group with these extreme posterior occlusions. The group of individuals who could only bite on second molars demonstrated a larger area of ossification than the group with occlusal contacts on all posterior teeth (Figure 6B), and this difference was statistically significant ( $p < 0.05$ ). Similarly, the length of contact between PPE and vomer in these individuals was significantly different ( $p < 0.05$ ) from that of individuals who bite only on the second molars, which showed a longer contact between the perpendicular plate and the vomer (Figure 6C).



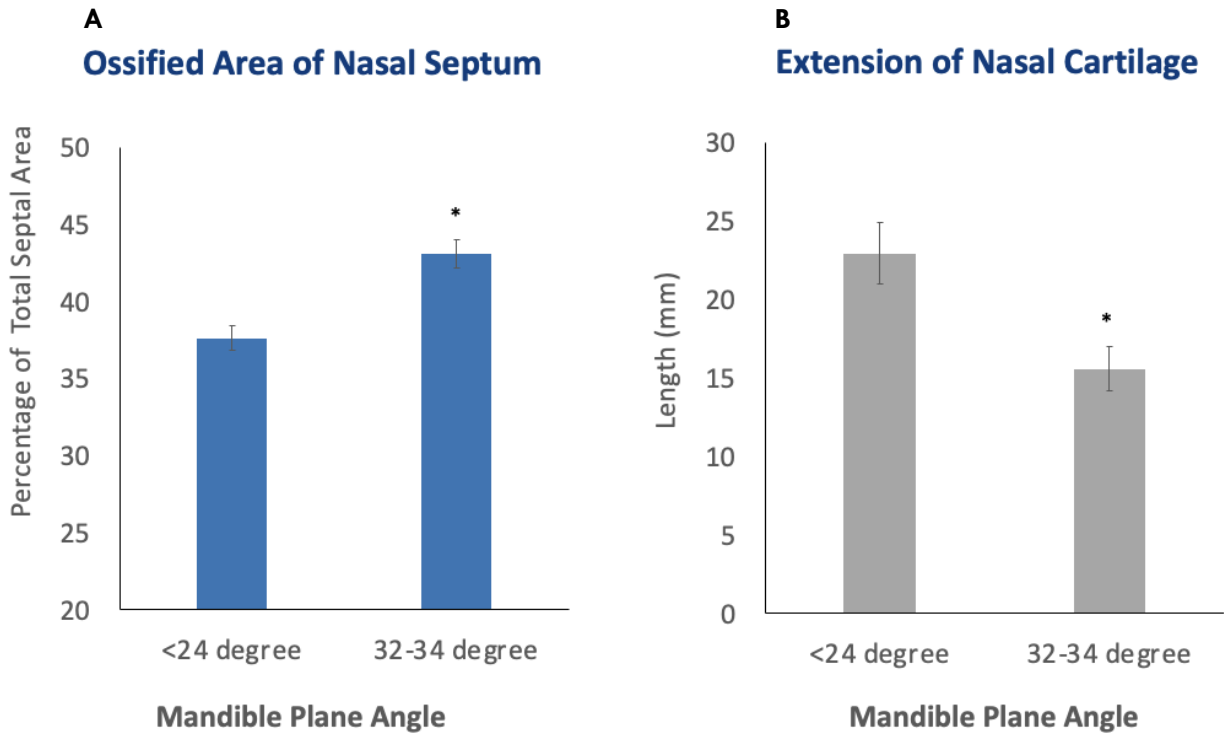
**Figure 6: Effect of posterior occlusion on ossification of the nasal septum.**

Schematic showing the spectrum of posterior occlusion in open bite subjects (A). Intra-group comparisons were made between patients with occlusion only on second molars and those with full posterior contacts including premolars, assessing ossification percentage (B) and PPE–vomer contact length (C). Values are mean ± SEM (\* $p < 0.05$  vs second molar–only contact group).

EFFECT OF THE MANDIBULAR PLANE ANGLE ON OSSIFICATION OF THE NASAL SEPTUM

Our results show that the magnitude of deep bite can affect ossification, but this effect was not significantly different from that of the control ( $p > 0.05$ ). However, it was not clear if the magnitude of the skeletal deep bite could affect the cartilage ossification. Therefore, to study the effect of mandibular plane angle on cartilage ossification, individuals with extremely low mandibular plane angles were compared with those with normal

mandibular plane angles. In this regard, 14 individuals with an extreme mandibular plane angle (< 24 degrees in the deep bite group) were identified and compared with 20 individuals with a mandibular plane angle of 32–34 degrees from the control group. Groups with an extremely low mandibular plane angle demonstrate lower ossification magnitude (Figure 7A) and a longer CE (Figure 7B) than individuals with a normal mandibular plane angle, with both measurements being statistically significant ( $p < 0.05$ ).

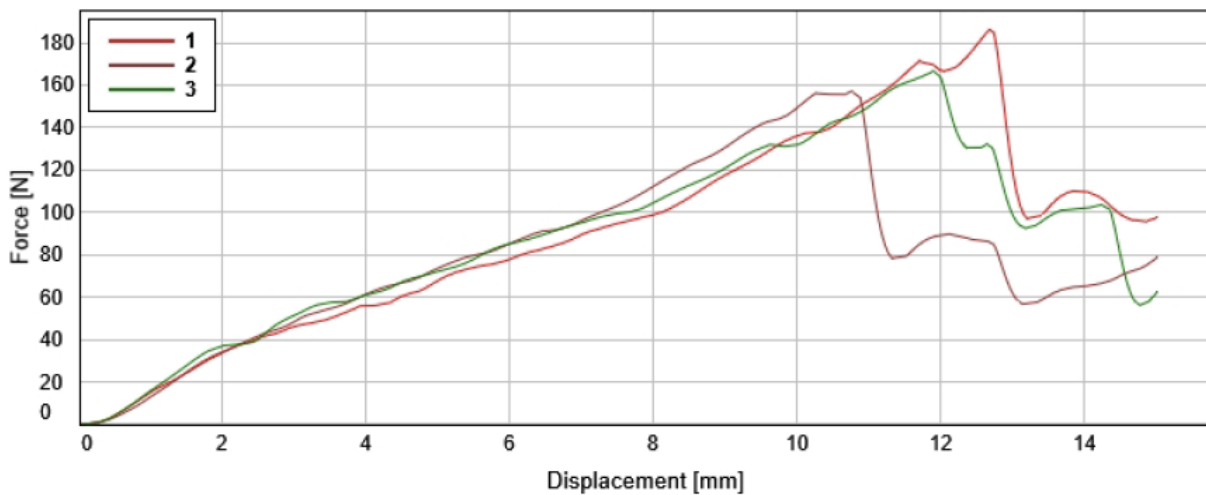


**Figure 7: Effect of the mandibular plane angle on ossification of the nasal septum.** Deep bite subjects with extremely low mandibular plane angles (<24°) were compared with control subjects (28–30°). CE length and percentage of nasal septal cartilage ossification were evaluated. Values are mean ± SEM (\*p < 0.05 vs extreme low mandibular plane angle group).

**IMPACT FORCES**

The impact force required to bite into a carrot was measured *in vitro* and estimated *in vivo* in humans. An *in vitro* study demonstrated that the impact force required to cut a carrot (diameter of 20 mm) using an Instron universal test machine and an incisor-shaped replica as the shear tool is 163 ± 12 N (Figure 8). This level of impact force was achievable *in vivo*, with an acceleration of 714 ± 143 mm/s<sup>2</sup> for an average mandibular weight

of 175 g and a bite force range of 100 to 150 N. To achieve a similar impact force with a smaller or larger mandible, it would require a higher or lower acceleration, respectively. This acceleration must produce a velocity of 1.4 m/s at impact to generate the magnitude of impact force required to break a carrot. The difference in acceleration can be compensated by the difference in the distance the mandible travels during biting to produce the same velocity.



**Figure 8: In vitro force registration during cutting of a carrot.** Example of a force displacement graph obtained using an Instron Machine and a bite simulation of the cutting action of incisor teeth. Bite forces were measured during three repeated trials (Sample 1, Sample 2, Sample 3). Testing was performed with a 500 N load cell at a displacement rate of 10 mm/s.

For food larger than 5 mm in thickness, considering the reported bite forces for hypodivergent and hyperdivergent cases, the required acceleration to generate such forces varied significantly (Table IV). This means that, in open-bite cases, to achieve the required

velocity, the mandible should travel farther than in deep-bite cases. For food less than 5mm in thickness in open bite cases, the magnitude of impact force reaches zero due to the open bite being more than 5 mm.

**Table IV. Incisor bite force and acceleration in hyperdivergent and hypodivergent mandibles.**

Mandible Divergence	Average Reported Bite Force	Estimated Acceleration
Hyperdivergent	137.285 N	782.85 m/s <sup>2</sup>
Hypodivergent	180.555 N	1028.57 m/s <sup>2</sup>

Averaged bite force was calculated based on a previous report,<sup>33</sup> while the estimated acceleration was calculated based on bite force and the average reported weight of the mandible.

## Discussion

The nasal septum is composed of different components, including nasal septal cartilage (NSC), Vomer, the perpendicular plate of the ethmoid (PPE), and the nasal crest of the maxilla.<sup>31</sup> Together, these components form the bony and cartilaginous part of the septum. While the vomer and the maxillary part of the septum are created through intramembranous bone formation,<sup>34-36</sup> the perpendicular plate of the ethmoid is created through endochondral bone formation of the nasal septal cartilage.<sup>37,38</sup>

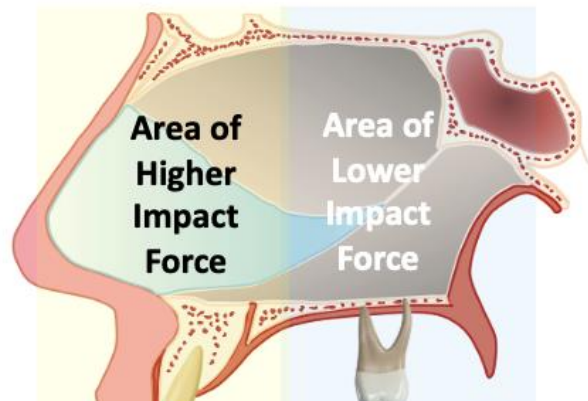
The total area of the nasal septum does not change significantly with age; however, the total area of ossified cartilage increases with age.<sup>39</sup> This may be due to the fact that the growth of the nasal septum shows a rapid decrease after birth and almost no change after age 10, while the ossification process is more prominent during the first 10 years of life and then continues throughout life at a much lower rate.<sup>40</sup> The perpendicular plate of the ethmoid and vomer makes a connection at age six to eight. Since cartilage reaches its maximum size at age 2, while ossification continues, the cartilaginous area gradually decreases, while the PPE increases.<sup>38</sup>

The range of PPE areas in our study is similar to that reported previously in adults.<sup>31,39,41</sup> However, the average PPE area in previous reports is closer to our measurement in the control group than to the extreme area observed in the open-bite or deep-bite subjects. This may be due to the fact that none of the previous studies used stratification by occlusal type and incisor function. Since normal incisor occlusion or mild to moderate deep bite occlusion is more common than open bite or severe deep bite cases, it is more likely that previous studies included patients with normal incisor function or mild/moderate deep bite. The minor discrepancies between the studies also might be due to the use of different methods to measure the septal area and the inclusion of different subjects, such as cadavers or CT or MRI images of living subjects. It should be emphasized that, due to nasal septal deviation, the

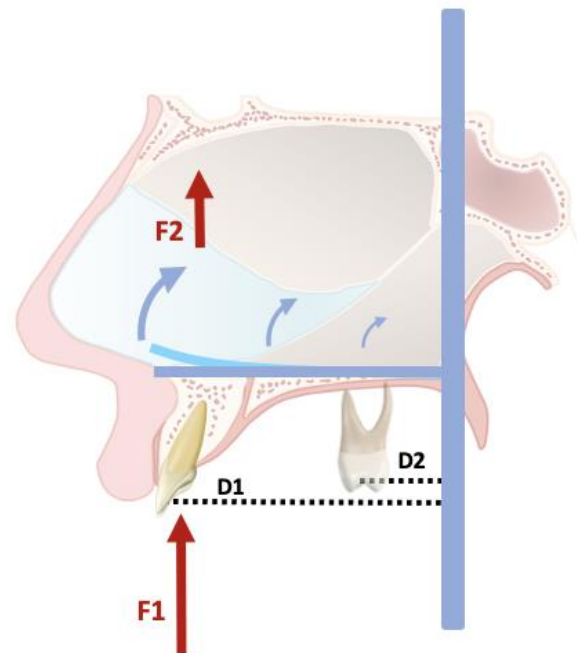
perpendicular plate of the ethmoid area may be slightly over- or under-estimated, as we measured the area in 2D mid-sagittal CBCT images.

Nasal septal cartilage is exposed to significant mechanical stimulation produced by occlusal forces.<sup>26,42</sup> This can explain why nasal septal cartilage, earlier in life, is made of cartilage that then gradually undergoes endochondral bone formation. Endochondral bone formation is usually observed in areas where, due to high mechanical demand, intermembranous ossification is not possible, and a cartilage analog is necessary to protect the bone-forming process during skeletogenesis, as observed in long bones.<sup>2</sup> But is the mechanical stimulation applied to the nasal septum by occlusion, homogeneous in the posterior and anterior areas of the cartilage? Here, we argue that due to differences in acceleration of the teeth during bite closure, the anterior and posterior areas of the nasal septum are exposed to different biomechanical environments. Incisors have significantly higher acceleration, which produces higher impact forces suitable for cutting, while posterior teeth have lower acceleration during closure and lower impact forces (Figure 9A). Furthermore, molars are bilateral structures away from the nasal septum, which decreases the effect of their impact forces on the nasal septum. On the contrary, anterior teeth are mid-sagittal structures that increase the direct effect of their impact forces on the nasal septum. In addition, the maxilla is a cantilever structure; therefore, the further the teeth are located from the fulcrum (posterior part of the maxilla), the larger the moments produced by the bite forces. Larger moments are associated with the larger amplitude of movements of the anterior part of the maxilla, in comparison with the posterior part of the maxilla (Figure 9B). The differences in the magnitude of impact forces and the magnitude of movement of the anterior and posterior parts of the nasal septum define the pattern of endochondral bone formation in the nasal septum. As discussed earlier, in response to high-impact forces, the cartilage will mostly remain cartilaginous, while lower-impact forces stimulate endochondral bone formation.

A



B



**Figure 9: Different areas of the nasal septum are exposed to different impact forces and moments.** Sagittal schematic illustrating nasal septum and midline skeletal structures. The anterior nasal septum is exposed to higher impact forces due to anterior teeth, compared with the posterior maxilla (A). The maxilla acts as a cantilever, generating greater moments anteriorly than posteriorly (B). D1 and D2 represent distances from anterior and posterior teeth to the palatal fulcrum, respectively; blue arrows indicate resulting moments, with anterior forces (F1) attenuated to F2 through the nasal septum toward the ethmoid and cranial base.

Our study demonstrated that incisors can produce high-magnitude impact forces through a combination of bite force, acceleration, and the range of opening in a very short period of time (milliseconds). Hypodivergent patients can produce these forces with a lower opening magnitude due to a higher acceleration, whereas hyperdivergent patients require much more opening to compensate for a lower acceleration. In hyperdivergent cases with an open bite, if they use only incisors to bite the food with a diameter smaller than the open bite, the impact force approaches zero, and they need to use either canines or premolars to cut their food. However, for food larger than the magnitude of the open bite, no difference in the magnitude of the impact force was observed.

Interestingly, after correction of their open bite with orthodontic treatment, some patients still report discomfort when biting hard foods with their front teeth (our clinical observation). We speculate that part of this discomfort may be due to insufficient cartilage serving as a shock absorber, since the ossification of nasal septal

cartilage extends anteriorly and is permanent and irreversible. This clinical observation supports the important role of the nasal septal cartilage in the biomechanics of the maxilla and the need to address malocclusions as early as possible to normalize function. However, this hypothesis has not been tested in this study.

The effect of impact forces decreases as the bite forces are transferred posteriorly closer to the fulcrum of the maxillary cantilever. Therefore, one expects the impact forces of incisors to be larger than those of premolars, and the impact forces of premolars to be larger than those of molars. Our data confirms this effect on the impact forces generated during mastication. While cartilage extension of the nasal septum was increased in patients with normal incisor function, in comparison with those with open bite, patients with open bites who could still bite on premolars demonstrated less ossification in comparison with those open bite patients who could only bite more posteriorly on the second molars.

Previous studies have shown that patients with lower mandibular angles produce higher occlusal forces.<sup>43,44</sup> We demonstrated that patients with an extremely low mandibular plane angle have larger nasal septal cartilage areas, perhaps to protect all structures from high occlusal forces. On the other hand, open-bite patients with a high mandibular plane angle demonstrate lower occlusal force magnitudes than patients with a normal mandibular plane angle.<sup>45-47</sup> It should be emphasized that the lack of contact between anterior teeth during occlusal loading does not eliminate the force on anterior teeth, but significantly reduces their impact force due to the limitation imposed by the open bite during cutting activity.<sup>48</sup> One can argue that the observation that the extent of the nasal septal cartilage in many mammals is greater than in humans<sup>1</sup> may be due to the importance of incisor function in those animals with longer snout projections (longer maxilla).

One may find the above argument contradictory to previous studies that measured the magnitude of incisor forces relative to molar forces and reported lower incisor forces than molar forces.<sup>49</sup> However, registering the bite forces of incisors is not representative of the impact force of incisors since, during normal bite force registration, the acceleration of incisors has been ignored.

Due to higher impact forces and high amplitude of movement, the anterior part of the nasal septum needs to have shock-absorbing properties. It has been shown that cartilage acts as the best shock absorber.<sup>50-52</sup> Biomechanical characterization of nasal septal cartilage has confirmed that its viscoelastic properties, particularly its high stress-relaxation under rapid loading, are well-suited for absorbing sudden impact forces, the kind generated during incisor function.<sup>42</sup>

One question remains: if cartilage is so important as a shock absorber, what is the need for ossification? The role of ossification of the PPE is unclear. Some believe that ossification does not play a role in the physiology of the nasal septum and is merely a genetic variation that progresses gradually with age.<sup>37</sup> However, being a primary cartilage does not mean that endochondral bone formation is a genetically scripted, clock-driven process that responds only to systemic factors. The fact that our data, similar to other investigators' data, demonstrate significant variability in the magnitude of ossification even within similar age groups, argues against this possibility. This variability, in our opinion, is a strong signal that functional or environmental factors are modulating the rate and extent of the ossification process.

We suggest that ossification of the nasal septum posteriorly can support the nasal bones under the stress produced by the weight of the skull and associated soft tissues, and simultaneously prevent the nasal floor collapse due to posterior occlusion that produces large moments in mid-sagittal structures. Our animal studies previously demonstrated how occlusal forces can affect the nasal floor and the bony nasal septal structures.<sup>53</sup> We showed that changes in the direction of posterior forces and moments can cause canting of the nasal floor and deviation of the nasal septum.

It should be emphasized that the ossification pattern of nasal septal cartilage is not always straightforward and therefore should not be used as a sole diagnostic tool to evaluate the effect of occlusal forces on the topology of the nasal septal cartilage ossification. For example, a change in status from open bite to deep bite, or vice versa, during an individual's lifetime may leave its mark on the nasal septal ossification pattern and confuse the clinician. Since ossification is irreversible, if a patient has an open bite and then gradually develops a normal bite, the magnitude of ossification will be similar to that of open-bite patients. On the other hand, if the patient recently developed an open bite, the previous normal function of incisors may have kept the cartilage unossified. To avoid this confusion, we restricted our sample to patients who reported an open bite throughout their lives or none at any stage of their lives. However, since patient reports may not be accurate, caution is required in interpreting our data.

The magnitude of overbite (how much the upper incisors cover the lower incisors) did not affect the magnitude of ossification of the cartilage, arguing that the mere presence of incisor contact is enough to maintain a large cartilaginous septum ideal for shock-absorbing activities. In other words, as long as a minimum threshold of high but fast incisal forces is reached, the cartilage extends posteriorly, and there is limited ossification. On the other hand, if the magnitude of muscle forces increases significantly due to a lower mandibular plane angle, the cartilage area of the septum will be affected. In our samples, the extent of CE differed between patients with severe low mandibular plane angle (skeletal deep bite) and the control group. To the best of our knowledge, there is no report on the length of CE in different individuals. The increase in the length of the CE in patients with low mandibular plane angles and its extension between the vomer and the PPE may not only protect the maxilla but also the bony septum from impact forces. In the absence of heavy incisal force, this function is not necessary; therefore, the process is much shorter, or even absent.

In our studies, patients with periodontal problems, extractions, or restorations were excluded, as these factors can alter occlusal forces, obscuring the effect of incisors' impact forces on nasal septal ossification. Similarly, due to possible changes in force distribution, patients with severe crowding, severe jaw constriction, or crossbite, which could cause significant jaw asymmetry, were excluded from our study. On the other hand, patients with mild/moderate crowding were included in the study, as this level of crowding does not significantly alter occlusal forces.

Our study demonstrates that sagittal skeletal or dental relations alone did not significantly affect the magnitude of ossification of the nasal septal cartilage, suggesting that posterior and anterior forces were the controlling factors rather than the sagittal relation between the jaws or the teeth. As long as the skeletal relation does not significantly change the anterior or posterior forces, the anterior teeth's function will determine the extent of

cartilage ossification. In the current study, we exclude patients with overjet of more than 3 mm, positive or negative, to prevent overjet from obscuring incisor function. However, it is possible that both class III and class II extreme cases may affect the nasal septum similarly to open-bite and deep-bite cases, respectively.

Previous studies have shown that males have a larger cartilage area than females.<sup>50,54-56</sup> One would expect the area of ossification to be, therefore, larger in men than in women. However, in our study, no difference in ossification percentage was observed between men and women within each group (deep-bite or open-bite). The effect of the larger cartilage size may be offset by differences in the magnitude of bite force between men and women, as it has been shown that bite force in men is stronger than that in women.<sup>44,57</sup>

It should be emphasized that this was a retrospective, cross-sectional study, and therefore, causality cannot be definitively inferred. Although we propose that functional loading drives differences in ossification, it remains possible that genetically determined skeletal morphology influences both occlusal pattern and septal development. Longitudinal studies, particularly those evaluating patients before and after orthodontic interventions that correct the open bite, would be necessary to establish a causal relationship.

## Conclusion

The foundation of this work is the innovative idea that the nasal and oral cavities influence one another. While nasal cavity obstruction can significantly affect the development of the oral cavity through changes in muscular function, for example, as observed during mouth breathing, forces and moments that originate from the oral cavity may play a significant role not only in the shape of the nasal cavity, the nasal floor, and the nasal septum, but also in the extent of ossification of the nasal septal cartilage. The nasal septal cartilage, positioned at the interface between occlusal forces and the skull, plays a significant role in the safe transfer of these forces to the remaining structures of the craniofacial complex. Therefore, it remains very moldable to mechanical stimulation. In response to the brief but high-impact forces from incisors, it remains cartilaginous by inhibiting endochondral bone formation. However, in the presence of posterior cyclic and low-impact forces, it can transform into a larger osseous structure through endochondral bone formation, providing the necessary stability.

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## References

- Baddam P, Kung T, Adesida AB, Graf D. Histological and molecular characterization of the growing nasal septum in mice. *J Anat.* Mar 2021;238(3):751-764. doi:10.1111/joa.13332
- Mackie EJ, Ahmed YA, Tatarczuch L, Chen KS, Mirams M. Endochondral ossification: how cartilage is converted into bone in the developing skeleton. *Int J Biochem Cell Biol.* 2008;40(1):46-62. doi:10.1016/j.biocel.2007.06.009
- Verwoerd CD, Verwoerd-Verhoef HL. Rhinosurgery in children: developmental and surgical aspects of the growing nose. *GMS Curr Top Otorhinolaryngol Head Neck Surg.* 2010;9:Doc05. doi:10.3205/cto000069
- Yamamoto M, Hayashi S, Honkura Y, et al. Nasal capsule ossification: A histological study using human fetuses to find an association between the foetus and adult morphologies of the nasal wall. *J Anat.* Sep 2023;243(3):517-533. doi:10.1111/joa.13867
- Vilmann H, Kirkeby S, Moss ML. Skull development in the muscular dystrophic mouse. *Eur J Orthod.* Aug 1989;11(3):206-13. doi:10.1093/oxfordjournals.ejo.a035987
- Varrela J. Effects of attritive diet on craniofacial morphology: a cephalometric analysis of a Finnish skull sample. *Eur J Orthod.* May 1990;12(2):219-23. doi:10.1093/ejo/12.2.219
- Kiliaridis S. Masticatory muscle influence on craniofacial growth. *Acta Odontol Scand.* Jun 1995;53(3):196-202. doi:10.3109/00016359509005972
- Katsaros C. Masticatory muscle function and transverse dentofacial growth. *Swed Dent J Suppl.* 2001;(151):1-47.
- Katsaros C, Berg R, Kiliaridis S. Influence of masticatory muscle function on transverse skull dimensions in the growing rat. *J Orofac Orthop.* Jan 2002;63(1):5-13. doi:10.1007/s00056-002-9903-0
- Larsson E, Øgaard B, Lindsten R, Holmgren N, Brattberg M, Brattberg L. Craniofacial and dentofacial development in pigs fed soft and hard diets. *Am J Orthod Dentofacial Orthop.* Dec 2005;128(6):731-9. doi:10.1016/j.ajodo.2004.09.025
- Badoux DM. Framed structures in the mammalian skull. *Acta Morphol Neerl Scand.* 1966;6(3):239-50.
- Badoux D. Cremona diagrams of framed structures in skull of *Canis familiaris* and *Sus scrofa scrofa*. *Koninkl Nederl Akad van Wetenschappen C.* 1968;71:229-244.
- Clark GM, Wallace CS. Analysis of Nasal Support. *Archives of Otolaryngology.* 1970;92(2):118-123. doi:10.1001/archotol.1970.04310020016005
- Sarnat BG, Wexler MR. Growth of the face and jaws after resection of the septal cartilage in the rabbit. *Am J Anat.* May 1966;118(3):755-67. doi:10.1002/aja.1001180306
- Sarnat BG, Wexler MR. The snout after resection of nasal septum in adult rabbits. *Arch Otolaryngol.* Oct 1967;86(4):463-6. doi:10.1001/archotol.1967.00760050465021
- Sarnat BG, Wexler MR. Rabbit snout growth after resection of central linear segments of nasal septal cartilage. *Acta Otolaryngol.* May 1967;63(5):467-78. doi:10.3109/00016486709128781
- Sarnat BG, Wexler MR. Postnatal growth of the nose and face after resection of septal cartilage in the rabbit. *Oral Surg Oral Med Oral Pathol.* Nov 1968;26(5):712-27. doi:10.1016/0030-4220(68)90444-1
- Sarnat BG, Wexler MR. Longitudinal development of upper facial deformity after septal resection in growing rabbits. *Br J Plast Surg.* Oct 1969;22(4):313-23. doi:10.1016/s0007-1226(69)80133-5
- Oyama K. Experimental study on growth and development of dentofacial complex after resection of cartilaginous nasal septum. *Bull Tokyo Med Dent Univ.* Jun 1969;16(2):157-79.
- Kvinnslund S, Breistein L. Regeneration of the cartilaginous nasal septum in the rat, after resection. Its influence on facial growth. *Plast Reconstr Surg.* Feb 1973;51(2):190-5. doi:10.1097/00006534-197302000-00016
- Kvinnslund S. Partial resection of the cartilaginous nasal septum in rats; its influence on growth. *Angle Orthod.* Apr 1974;44(2):135-40. doi:10.1043/0003-3219(1974)044<0135:Protcn>2.0.Co;2
- Nordgaard JO, Kvinnslund S. Influence of submucous septal resection on facial growth in the rat. *Plast Reconstr Surg.* Jul 1979;64(1):84-8. doi:10.1097/00006534-197907000-00015
- Stenström SJ, Thilander BL. Effects of nasal septal cartilage resections on young guinea pigs. *Plast Reconstr Surg.* Feb 1970;45(2):160-70. doi:10.1097/00006534-197002000-00010
- Moss ML, Bromberg BE, Song IC, Eisenman G. The passive role of nasal septal cartilage in mid-facial growth. *Plast Reconstr Surg.* Jun 1968;41(6):536-42. doi:10.1097/00006534-196806000-00004
- Mow VC, Wang CC. Some bioengineering considerations for tissue engineering of articular cartilage. *Clin Orthop Relat Res.* Oct 1999;(367 Suppl):S204-23. doi:10.1097/00003086-199910001-00021
- Al Dayeh AA, Rafferty KL, Egbert M, Herring SW. Deformation of nasal septal cartilage during mastication. *J Morphol.* Oct 2009;270(10):1209-18. doi:10.1002/jmor.10750
- Ross CF. In vivo function of the craniofacial haft: the interorbital "pillar". *Am J Phys Anthropol.* Oct 2001;116(2):108-39. doi:10.1002/ajpa.1106
- Lee SJ, Liang K, Lee HP. Deformation of nasal septum during nasal trauma. *Laryngoscope.* Oct 2010;120(10):1931-9. doi:10.1002/lary.21072
- Miyamoto S, Yoshikawa H, Nakata K. Axial mechanical loading to ex vivo mouse long bone regulates endochondral ossification and endosteal mineralization through activation of the BMP-Smad pathway during postnatal growth. *Bone Reports.* 2021;15
- Wong M, Carter DR. Mechanical stress and morphogenetic endochondral ossification of the sternum. *J Bone Joint Surg Am.* Aug 1988;70(7):992-1000.

31. Jin J, Yi C-H, Park H. Clinical Adaptation According to Anatomical Types of Nasal Septum. *International Journal of Morphology*. 10/01 2023;41:1439-1444. doi:10.4067/S0717-95022023000501439
32. Zhang F, Peck CC, Hannam AG. Mass properties of the human mandible. *Journal of Biomechanics*. 2002/07/01/ 2002;35(7):975-978. doi:[https://doi.org/10.1016/S0021-9290\(02\)00057-X](https://doi.org/10.1016/S0021-9290(02)00057-X)
33. Singh A, Tandon P, Singh GK, Nagar A, Shastri D. Maximum Voluntary Molar and Incisor Biting Force and Morphological Variables in Subjects With Different Vertical Skeletal Patterns. *Journal of Indian Orthodontic Society*. 2022;56(4):374-379. doi:10.1177/03015742211044856
34. Cunningham C, Scheuer L, Black S. Chapter 5 - The Skull. In: Cunningham C, Scheuer L, Black S, eds. *Developmental Juvenile Osteology (Second Edition)*. Academic Press; 2016:43-148.
35. Fawcett. The Development of the Human Maxilla, Vomer, and Paraseptal Cartilages. *J Anat Physiol*. Jul 1911;45(Pt 4):378-405.
36. Müller F, O'Rahilly R. The human chondrocranium at the end of the embryonic period, proper, with particular reference to the nervous system. *Am J Anat*. Sep 1980;159(1):33-58. doi:10.1002/aja.1001590105
37. Hur MS, Won HS, Kwak DS, Chung IH, Kim IB. Morphological Patterns and Variations of the Nasal Septum Components and Their Clinical Implications. *J Craniofac Surg*. Nov 2016;27(8):2164-2167. doi:10.1097/scs.0000000000002974
38. Kim IS, Lee MY, Lee KI, Kim HY, Chung YJ. Analysis of the Development of the Nasal Septum according to Age and Gender Using MRI. *Clin Exp Otorhinolaryngol*. Mar 2008;1(1):29-34. doi:10.3342/ceo.2008.1.1.29
39. Kim J, Cho JH, Kim SW, Kim BG, Lee DC, Kim SW. Anatomical variation of the nasal septum: Correlation among septal components. *Clin Anat*. Nov 2010;23(8):945-9. doi:10.1002/ca.21045
40. Schultz-Coulon HJ, Eckermeier L. [Postnatal growth of nasal septum]. *Acta Otolaryngol*. Jul-Aug 1976;82(1-2):131-42. Zum postnatalen Wachstum der Nasenscheidewand.
41. Miles BA, Petrisor D, Kao H, Finn RA, Throckmorton GS. Anatomical variation of the nasal septum: analysis of 57 cadaver specimens. *Otolaryngol Head Neck Surg*. Mar 2007;136(3):362-8. doi:10.1016/j.otohns.2006.11.047
42. Al Dayeh AA, Herring SW. Compressive and tensile mechanical properties of the porcine nasal septum. *J Biomech*. Jan 3 2014;47(1):154-61. doi:10.1016/j.jbiomech.2013.09.026
43. Braun S, Bantleon HP, Hnat WP, Freudenthaler JW, Marcotte MR, Johnson BE. A study of bite force, part 2: Relationship to various cephalometric measurements. *Angle Orthod*. 1995;65(5):373-7. doi:10.1043/0003-3219(1995)065<0373:Asobfp>2.0.Co;2
44. Koc D, Dogan A, Bek B. Bite force and influential factors on bite force measurements: a literature review. *Eur J Dent*. Apr 2010;4(2):223-32.
45. Proffit WR, Fields HW, Nixon WL. Occlusal forces in normal- and long-face adults. *J Dent Res*. May 1983;62(5):566-70. doi:10.1177/00220345830620051201
46. Bakke M, Michler L. Temporalis and masseter muscle activity in patients with anterior open bite and craniomandibular disorders. *Scand J Dent Res*. Jun 1991;99(3):219-28. doi:10.1111/j.1600-0722.1991.tb01888.x
47. Miyawaki S, Araki Y, Tanimoto Y, et al. Occlusal force and condylar motion in patients with anterior open bite. *J Dent Res*. Feb 2005;84(2):133-7. doi:10.1177/154405910508400205
48. Lone IM, Zohud O, Midlej K, et al. Anterior Open Bite Malocclusion: From Clinical Treatment Strategies towards the Dissection of the Genetic Bases of the Disease Using Human and Collaborative Cross Mice Cohorts. *Journal of Personalized Medicine*. 2023;13(11):1617.
49. Clark JJ, Charters EK, Cheng K, et al. Quantifying Bite Forces for Solid Foods: Implications for Patients Postmandibular Reconstruction. *Head Neck*. Feb 2026;48(2):346-356. doi:10.1002/hed.70031
50. Baddam P, Bayona-Rodriguez F, Campbell SM, El-Hakim H, Graf D. Properties of the Nasal Cartilage, from Development to Adulthood: A Scoping Review. *Cartilage*. Jan-Mar 2022;13(1):19476035221087696. doi:10.1177/19476035221087696
51. Stovin JS. The importance of the membranous nasal septum. *AMA Arch Otolaryngol*. May 1958;67(5):540-1. doi:10.1001/archotol.1958.00730010554006
52. Perkins SW, Dayan SH. Management of nasal trauma. *Aesthetic Plast Surg*. Nov 2002;26 Suppl 1:S3. doi:10.1007/s00266-002-4307-5
53. Mani Alikhani EU-Q, Daniel L, Garzón DVM, Chinapa Sangsuwon, Jeanne Nervina, Fanar Abdullah, Mona Alikhani, Nuria Galindo-Solano, Janeth Serrano-Bello, Lucia Pérez-Sánchez, Guillermo Villagómez-Olea, Francisco J. Marichi-Rodríguez, Cristina C. Teixeira. Maxillary constriction causes nasal septum deviation and deformity of the nasal floor. *PLOS One*. 2026;In Press
54. Vetter U, Pirsig W, Heinze E. Growth Activity in Human Septal Cartilage: Age-Dependent Incorporation of Labeled Sulfate in Different Anatomic Locations. *Plastic and Reconstructive Surgery*. 1983;71(2)
55. Park SW, Choi J, Park HO, et al. Are gender differences in external noses caused by differences in nasal septal growth? *Journal of Cranio-Maxillofacial Surgery*. 2014/10/01/ 2014;42(7):1140-1147. doi:<https://doi.org/10.1016/j.jcms.2014.01.045>
56. Vetter U, Pirsig W, Heinze E. Postnatal Growth of the Human Septal Cartilage: Preliminary Report. *Acta Oto-Laryngologica*. 1984/01/01 1984;97(1-2):131-136. doi:10.3109/00016488409130973
57. Waltimo A, Könönen M. A novel bite force recorder and maximal isometric bite force values for healthy young adults. *Scand J Dent Res*. Jun 1993;101(3):171-5. doi:10.1111/j.1600-0722.1993.tb01658.x