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# Comparison of Tooth and Arch Dimensions in Dental Crowding, Spacing, and Normal Dentition: A Cross-Sectional Study from a Tertiary Orthodontic Centre in Nepal

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## ABSTRACT

### Background

Dental crowding and spacing are the most common malocclusions worldwide, arising from imbalance between mesiodistal tooth size and dental arch dimensions (TSALD), yet Nepalese comparative morphometric data are limited. This study aimed to compare MD tooth dimensions, arch perimeter, IC, IP, IM widths, arch depth, and TSALD across crowded, normal, and spaced dentitions in maxillary and mandibular arches

### Methods

This cross-sectional study analyzed 138 pretreatment orthodontic casts (age 19-34 years) from College of Medical Science-Teaching Hospital, Nepal. Based on TSALD, samples were categorized into crowded (≤ −4 mm; n=22), normal (0 ± 3 mm; n=22), and spaced (≥ +4 mm; n=94). MD widths of all permanent teeth (excluding second and third molars) were measured using a digital Vernier caliper. Arch perimeter was assessed using a brass-wire method. One-way ANOVA with Tukey post-hoc tests was applied (α=0.05).

### Results

Total maxillary tooth material was highest in crowded cases (75.62 ± 5.46 mm) and lowest in spaced cases (69.52 ± 4.75 mm; p<0.001). Maxillary arch perimeter increased significantly from crowded (70.73 ± 5.35 mm) to normal (76.91 ± 3.28 mm) and spaced groups (78.90 ± 4.69 mm; p<0.001). A similar trend was observed in the mandible (62.09 ± 3.18 mm; 65.41 ± 3.35 mm; 67.73 ± 4.52 mm; p<0.001). TSALD values confirmed classification in both arches (maxilla: −4.89 to +9.38 mm; mandible: −2.30 to +6.88 mm; p<0.001). IC width showed no significant intergroup differences.

### Conclusions

Both tooth size and arch dimensions contribute to TSALD, with arch perimeter showing a stronger discriminatory role. Independent assessment of maxillary and mandibular TSALD is essential for arch-specific orthodontic treatment planning in Nepalese patients.

**Keywords:** Crowding; Spacing; Tooth size; Arch perimeter; TSALD; Malocclusion; Nepal

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## INTRODUCTION

Malocclusion is among the most prevalent oral health conditions globally, with dental crowding and dental spacing constituting its two most common spatial forms. Crowding insufficient arch length for proper alignment is estimated to affect 30-50% of individuals in industrialised populations and is increasing with dietary and secular changes in arch form.[1, 2] It impairs plaque control and increases susceptibility to caries and periodontal disease. [3] Dental spacing, defined by interdental gaps due to insufficient tooth material, also has functional and aesthetic consequences, including reduced smile aesthetics and self-esteem.[4] Both conditions are primarily explained by tooth-size arch-length discrepancy (TSALD), defined as the difference between arch perimeter and the sum of mesiodistal (MD) crown widths.[5, 6] Lundström demonstrated the relationship between tooth-width ratios and arch morphology,[7] while Bolton's interarch analysis provided a diagnostic framework for tooth-size discrepancies.[8] TSALD reflects stable, heritable tooth dimensions[9] interacting with variable arch parameters such as intercanine (IC), interpremolar (IP), intermolar (IM) widths, arch perimeter, and arch depth, all influenced by functional and environmental factors.[10] Sanin and Savara highlighted significant population variation in MD tooth widths, relevant for orthodontic planning. [11] Crowding and spacing develop early in mixed dentition and often persist into adulthood. Hunter and Smith reported that mandibular spacing crowding patterns between 9 and 16 years predict adult arch status,[12] indicating long-term morphological stability. Howe et al. confirmed that crowded dentitions show larger tooth widths and reduced arch perimeter.[13] In Nepal, evidence remains limited. Jaiswal et al. reported a high prevalence of malocclusion in Parsa district, [14] while Mishra et al. found anterior tooth-size discrepancies to be common in Nepalese subjects.[15] Parajuli et al. also demonstrated ethnic variation in MD crown dimensions among Indo-Aryan and Tibeto-Burman groups.[16] However, most studies use a two-group (crowded vs. non-crowded) design, excluding spaced dentitions and potentially biasing results. No Nepalese study has simultaneously evaluated crowded, normal, and spaced dentitions using standardized cast measurements of both arches. This study addresses this gap by comparing MD tooth dimensions, arch morphology, and TSALD across three dentition types in a tertiary orthodontic population in Chitwan, Nepal. The primary aim was to compare MD dimensions of permanent teeth (excluding second and third molars) among groups. Secondary objectives included comparison of arch parameters (IC, IP, IM widths, arch perimeter, arch depth, TTM) and TSALD in both arches.

## METHODS

### Study design

This was a cross-sectional, institution-based study conducted in the Department of Orthodontics and Dentofacial Orthopedics, College of Medical Sciences and Teaching Hospital (COMS-TH), Bharatpur, Chitwan, Nepal.

### Study area

The study was carried out in the Department of Orthodontics and Dentofacial Orthopedics at the College of Medical Sciences and Teaching Hospital, Bharatpur, Chitwan, Nepal,

### Study population

The study population consisted of pre-treatment orthodontic study casts from patients aged 19-34 years attending COMS-TH. A final sample of 138 casts that met the inclusion criteria was included, comprising 22 crowded, 22 normal, and 94 spaced cases. Group classification was based on TSALD values calculated for each arch using the formula TSALD = Arch Perimeter − Σ(MD widths of 10 teeth per arch, excluding second and third molars), with thresholds defined as normal (0 ± 3 mm), crowded (≤ −4 mm), and spaced (≥ +4 mm), and the maxillary TSALD used as the primary grouping variable.

### Sample size

The minimum required sample size was calculated using the formula $n = (z^2\sigma^2)/d^2$, where $z = 1.96$ for 95% confidence, $\sigma = 1.969$, and $d = 1.12$, resulting in a minimum requirement of 38 casts per group and a total target sample of 114 casts. A post-hoc power analysis based on the observed effect size for arch perimeter (Cohen's f = 0.63) confirmed that the final sample of 138 provided more than 99% statistical power at $\alpha = 0.05$, indicating that the study was adequately powered for the primary outcomes.

**Sampling technique**

A total of 138 pre-treatment orthodontic study casts were selected from institutional records based on predefined inclusion and exclusion criteria, using an availability-based institutional sampling approach, where eligible cases meeting diagnostic and data completeness requirements were included in the final analysis.

**Data collection tools and technique**

All measurements were performed on plaster study casts by a single calibrated examiner (NS) using a calibrated digital Vernier caliper accurate to 0.01 mm, ensuring measurement precision and consistency. Intra-examiner reliability was assessed by repeating measurements on a randomly selected 10% subsample after two weeks, yielding a mean absolute technical error of less than 0.2 mm across all variables. Key measurements included mesiodistal crown widths of permanent teeth (excluding second and third molars), arch perimeter measured using the brass wire technique along the occlusal curve, intercanine, interpremolar, and intermolar widths, arch depth, and total tooth material (TTM). Data cleaning was performed prior to analysis, during which two extreme erroneous values were excluded due to clear data entry errors.

**Variables/Measurements**

The study variables included mesiodistal crown widths, arch perimeter, intercanine width, interpremolar width, intermolar width, arch depth, and total tooth material (TTM), along with arch classification based on TSALD values. TSALD was calculated using the formula TSALD = Arch Perimeter − Σ(MD widths of 10 teeth per arch), and was used to classify cases into normal (0 ± 3 mm), crowded (≤ −4 mm), and spaced (≥ +4 mm) groups.

**Statistical analysis used**

Descriptive statistics (mean ± standard deviation) were computed for all variables, and the Shapiro Wilk test was used to assess normality of data distribution. One-way ANOVA was applied for intergroup comparisons, and when statistically significant differences were observed ($p < 0.05$), Tukey Honestly Significant Difference (HSD) test was used for pairwise comparisons. All analyses were performed using Python 3.12 with SciPy version 1.11, and statistical significance was set at $\alpha = 0.05$.

**Ethical consideration**

Ethical approval for the study was obtained from the Institutional Review Committee , College of Medical Science-Teaching Hospital (Ref. No.: COMSTH-IRC/2024/131) prior to the commencement of data collection. Confidentiality of patient information was strictly maintained, and all data were used solely for research purposes. The collected data were securely stored and accessed only by the research team to ensure privacy and compliance with ethical research standards.

## RESULTS

The study sample comprised 138 pretreatment orthodontic study casts from patients aged 19-34 years attending COMS-TH. By sex, 87 participants were female (63.0%) and 50 were male (36.2%); one record had missing sex data. By dentition type, 94 casts were classified as spaced (68.1%), 22 as crowded (15.9%), and 22 as normal (15.9%). Sex distribution by group was: crowded, 11 female and 11 male; normal, 17 female and 4 male; spaced, 59 female and 35 male. The unequal group distribution reflects the institutional referral case-mix and is addressed as a limitation. Arch perimeter was the strongest discriminating variable across groups (Table 1). In the maxillary arch, the crowded group had the smallest perimeter (70.73 ± 5.35 mm), significantly less than both the normal (76.91 ± 3.28 mm; Tukey: $p < 0.001$) and spaced groups (78.90 ± 4.69 mm; Tukey: $p < 0.001$); the normal and spaced groups did not differ significantly from each other ($p = 0.165$; $F = 28.10$, $p < 0.001$ overall). In the mandibular arch, arch perimeter was similarly smallest in the crowded group (62.09 ± 3.18 mm) and largest in the spaced group (67.73 ± 4.52 mm; $F = 17.16$, $p < 0.001$); Tukey

HSD confirmed crowded-vs-normal ($p = 0.025$) and crowded-vs-spaced ($p < 0.001$) differences, while normal-vs-spaced did not reach significance ($p = 0.052$). The maxillary TSALD confirmed group classification with a highly significant overall effect ($F = 220.35$, $p < 0.001$). Mean values were: crowded, −4.89 ± 4.02 mm; normal, +2.68 ± 1.22 mm; spaced, +9.38 ± 2.99 mm. All three pairwise comparisons were significant (Tukey: all $p < 0.001$). The mandibular TSALD exhibited a parallel pattern ($F = 33.75$, $p < 0.001$): crowded, −2.30 ± 4.00 mm; normal, +1.50 ± 4.18 mm; spaced, +6.88 ± 5.47 mm. Tukey HSD confirmed crowded-vs-spaced ($p < 0.001$), normal-vs-spaced ($p < 0.001$), and crowded-vs-normal ($p = 0.038$) differences. Notably, the absolute magnitude of the mandibular discrepancy in the crowded group (−2.30 mm) was less severe than the maxillary discrepancy (−4.89 mm), suggesting arch-specific variation in the expression of crowding. Total tooth material (TTM) was significantly greatest in the crowded group and lowest in the spaced group in both arches (Maxilla: $F = 20.41$, $p < 0.001$; Mandible: $F = 9.08$, $p < 0.001$). Tukey analysis indicated that the normal and crowded groups did not differ from each other in TTM in either arch (all $p > 0.55$); the significant omnibus effects were driven entirely by the spaced group exhibiting markedly smaller tooth material (Tukey: normal-vs-spaced $p < 0.001$; crowded-vs-spaced $p < 0.001$ for both arches). Mandibular IP width was significantly greater in the spaced group relative to both the normal (Tukey: $p < 0.001$) and crowded groups (Tukey: $p < 0.001$; $F = 13.60$, $p < 0.001$ overall). Maxillary IP width differed significantly between crowded and spaced groups (Tukey: $p = 0.042$; $F = 3.34$, $p = 0.038$). Maxillary IM width was significantly greater in the spaced group compared with the crowded group (Tukey: $p = 0.039$; $F = 3.20$, $p = 0.044$). After removal of the data-entry outlier (one value of 444.11 mm), mandibular IM width was 45.24 ± 4.09 mm ($n = 21$) in the normal group; no significant inter-group difference was found ($F = 0.33$, $p = 0.723$). Maxillary arch depth was significantly greater in the spaced group than in the normal (Tukey: $p = 0.028$) and crowded groups (Tukey: $p = 0.001$; $F = 8.46$, $p < 0.001$). IC width and mandibular arch depth did not differ significantly among groups in either arch (all $p > 0.09$).

**Table 1. Arch dimension measurements and tooth-size arch-length discrepancy (mean ± SD) by dentition group (n=138).**

| Variable | Normal (n=22) | Crowded (n=22) | Spaced (n=94) | F | p | Tukey HSD (significant pairs) |
|---|---|---|---|---|---|---|
| IC Width-Maxilla (mm) | 35.49 ± 2.33 | 36.08 ± 3.15 | 34.53 ± 3.47 | 2.394 | 0.095 | — |
| IC Width-Mandible (mm) | 25.69 ± 2.51 | 25.92 ± 2.54 | 27.01 ± 4.16 | 1.583 | 0.209 | — |
| IP Width-Maxilla (mm) | 37.01 ± 3.81 | 35.90 ± 3.15 | 38.24 ± 4.26 | 3.339 | 0.038* | C < S* |
| IP Width-Mandible (mm) | 30.42 ± 2.94 | 29.99 ± 2.56 | 33.05 ± 3.11 | 13.6 | <0.001*** | N < S***; C < S*** |
| IM Width-Maxilla (mm) | 48.08 ± 3.22 | 46.47 ± 3.51 | 49.20 ± 5.15 | 3.204 | 0.044* | C < S* |
| IM Width-Mandible (mm)† | 45.24 ± 4.09 | 43.91 ± 3.59 | 44.16 ± 6.78 | 0.325 | 0.723 | — |
| Arch Perimeter-Maxilla (mm) | 76.91 ± 3.28 | 70.73 ± 5.35 | 78.90 ± 4.69 | 28.1 | <0.001*** | N > C***; C < S*** |
| Arch Perimeter-Mandible (mm) | 65.41 ± 3.35 | 62.09 ± 3.18 | 67.73 ± 4.52 | 17.16 | <0.001*** | N > C*; C < S*** |
| Arch Depth-Maxilla (mm) | 26.34 ± 3.41 | 25.50 ± 4.78 | 28.49 ± 3.15 | 8.464 | <0.001*** | N < S*; C < S** |
| Arch Depth-Mandible (mm) | 21.59 ± 2.72 | 22.16 ± 9.33 | 22.79 ± 3.62 | 0.607 | 0.546 | — |
| TTM-Maxilla (mm) | 74.23 ± 3.38 | 75.62 ± 5.46 | 69.52 ± 4.75 | 20.41 | <0.001*** | N > S***; C > S*** |
| TTM -Mandible (mm) | 63.91 ± 3.79 | 64.39 ± 3.66 | 60.86 ± 4.46 | 9.08 | <0.001*** | N > S**; C > S** |

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|---|---|---|---|---|---|---|
| TSALD-Maxilla (mm) | +2.68 ± 1.22 | −4.89 ± 4.02 | +9.38 ± 2.99 | 220.3 | <0.001*** | All pairs *** |
| TSALD-Mandible (mm) | +1.50 ± 4.18 | −2.30 ± 4.00 | +6.88 ± 5.47 | 33.75 | <0.001*** | N > C*; N < S***; C < S*** |

*IC = intercanine; IP = interpremolar; IM = intermolar; TTM = total tooth material (MD widths of teeth 15–25 or 35–45); TSALD = tooth-size arch-length discrepancy (arch perimeter − TTM). Positive TSALD = spacing; negative = crowding. Tukey HSD: N = normal, C = crowded, S = spaced. * p < 0.05; ** p < 0.01; *** p < 0.001.*

The maxillary and mandibular TSALD classifications were concordant in the majority of subjects; however, a subset of cases exhibited arch-level discordance that is, classification as crowded in one arch and normal or spaced in the other. In the crowded group (classified by maxillary TSALD), the mean mandibular TSALD was −2.30 ± 4.00 mm, which, while negative, fell within the 0 ± 3 mm normal range for several individual subjects. Conversely, among subjects classified as spaced by maxillary TSALD, a minority presented with near-normal mandibular TSALD values. This discordance underscores the clinical importance of quantifying TSALD independently for each arch rather than relying on a single summary measure, as treatment strategies for crowding or spacing may need to be applied selectively to the affected arch. Results for all 24 measured teeth are presented in Table 2. In the maxillary arch, statistically significant inter-group differences were identified for 11 of 12 teeth; only the left canine (tooth 23; p = 0.085) did not reach significance. The dominant pattern was crowded ≥ normal > spaced, driven primarily by crowded-vs-spaced and normal-vs-spaced contrasts rather than by crowded-vs-normal differences. After exclusion of the data-entry outlier (28.0 mm) from the crowded group, tooth 25 yielded a mean of 6.93 ± 1.05 mm (n = 21), with the crowded group significantly larger than the spaced group (Tukey: p < 0.001). In the mandibular arch, significant inter-group differences were found in 8 of 12 teeth. The right and left lateral incisors (32, 42), central incisors (31, 41 approached significance for some pairs), and second premolars (35, 45) discriminated most consistently between groups. The mandibular right central incisor (41), bilateral first premolars (34, 44), and bilateral first molars (36, 46) did not reach statistical significance. As in the maxilla, the dominant pairwise contrast was crowded-vs-spaced or normal-vs-spaced; crowded and normal groups rarely differed from each other, consistent with earlier reports by Gilmore and Little on mandibular incisor dimensions in crowded versus non-crowded arches.

**Table 2. Mean (± SD) mesiodistal crown widths (mm) by tooth and dentition group ( n=138).**

| FDI | Tooth | Normal | Crowded | Spaced | p | Tukey HSD |
|---|---|---|---|---|---|---|
| 16 | Max R 1st Molar | 10.21±0.53 | 9.91±0.71 | 9.79±0.59 | 0.014* | N>S* |
| 15 | Max R 2nd Premolar | 6.55±0.60 | 6.56±0.38 | 6.03±0.91 | 0.003** | N>S*; C>S* |
| 14 | Max R 1st Premolar | 7.03±0.52 | 7.16±0.64 | 6.62±0.59 | <0.001*** | N>S**; C>S*** |
| 13 | Max R Canine | 7.75±0.75 | 7.94±0.64 | 7.40±0.64 | 0.001** | C>S** |
| 12 | Max R Lateral Incisor | 7.08±0.78 | 7.03±0.63 | 6.54±0.74 | 0.001** | N>S**; C>S* |
| 11 | Max R Central Incisor | 8.65±0.66 | 8.84±0.58 | 8.11±0.83 | <0.001*** | N>S*; C>S*** |
| 21 | Max L Central Incisor | 8.58±0.56 | 8.61±0.71 | 8.21±0.74 | 0.014* | C>S* |
| 22 | Max L Lateral Incisor | 7.23±0.56 | 6.93±0.69 | 6.49±0.76 | <0.001*** | N>S***; C>S* |
| 23 | Max L Canine | 7.68±0.47 | 7.64±0.63 | 7.40±0.68 | 0.085 | ns |
| 24 | Max L 1st Premolar | 7.12±0.54 | 7.03±0.56 | 6.72±0.59 | 0.004** | N>S* |
| 25 | Max L 2nd Premolar† | 6.55±0.54 | 6.93±1.05 | 6.07±0.65 | <0.001*** | N>S*; C>S*** |
| 26 | Max L 1st Molar | 9.97±0.85 | 10.08±0.70 | 9.66±0.71 | 0.023* | C>S* |
| 36 | Mand L 1st Molar | 10.91±0.85 | 11.13±0.63 | 10.72±0.69 | 0.040* | C>S* |
| 35 | Mand L 2nd Premolar | 6.93±0.59 | 7.03±0.55 | 6.46±0.64 | <0.001*** | N>S**; C>S*** |
| 34 | Mand L 1st Premolar | 7.02±0.57 | 6.89±0.57 | 6.78±0.53 | 0.142 | ns |
| 33 | Mand L Canine | 6.74±0.56 | 6.82±0.49 | 6.47±0.65 | 0.020* | C>S* |

| | | | | | | |
|---|---|---|---|---|---|---|
| 32 | Mand L Lateral Incisor | 5.88±0.69 | 5.90±0.56 | 5.52±0.73 | 0.018* | trend C>S |
| 31 | Mand L Central Incisor | 5.40±0.53 | 5.61±0.55 | 5.05±0.63 | <0.001*** | N>S*; C>S*** |
| 41 | Mand R Central Incisor | 5.25±0.63 | 5.43±0.58 | 5.11±0.88 | 0.224 | ns |
| 42 | Mand R Lateral Incisor | 5.96±0.57 | 6.07±0.62 | 5.47±0.66 | <0.001*** | N>S**; C>S*** |
| 43 | Mand R Canine | 6.75±0.51 | 6.85±0.62 | 6.50±0.50 | 0.008** | C>S* |
| 44 | Mand R 1st Premolar | 7.03±0.80 | 6.83±0.40 | 6.89±0.62 | 0.536 | ns |
| 45 | Mand R 2nd Premolar | 6.96±0.60 | 6.96±0.55 | 6.60±0.61 | 0.007** | N>S*; C>S* |
| 46 | Mand R 1st Molar | 10.91±0.89 | 10.66±0.69 | 10.65±0.79 | 0.39 | ns |

*All measurements in mm. Max = maxillary; Mand = mandibular; R = right; L = left. * p < 0.05; ** p < 0.01; *** p < 0.001; ns = not significant. Tukey HSD: N = normal, C = crowded, S = spaced; > denotes significantly larger. †One outlier (28.0 mm) excluded from crowded group; n = 21.*

## DISCUSSION

The present study compared MD tooth dimensions and arch-morphology parameters across crowded, spaced, and normal dentitions in a Nepalese institutional sample. The principal findings were: (i) arch perimeter was the strongest discriminant between crowded and normal dentitions in both jaws; (ii) spaced dentitions exhibited smaller individual teeth and wider arch dimensions at the premolar-molar level; (iii) both TTM and arch dimensions contributed independently to TSALD in both arches; and (iv) IC width did not differ significantly among groups. These results are consistent with foundational studies by Howe et al.[13] and extend prior Nepalese data to include the spaced dentition phenotype for the first time.

The most statistically robust inter-group differences were observed for arch perimeter, which was significantly smallest in the crowded group in both arches ($p < 0.001$). Consistent with Majeed et al., [2] who identified arch length as the principal determinant of crowding, and with Selmani et al.,[18] who confirmed that arch dimensions independently predict mandibular anterior crowding, the present data suggest that arch morphology is a primary determinant of TSALD severity. Critically, Tukey analysis demonstrated that maxillary arch perimeter did not differ between the normal and spaced groups ($p = 0.165$), implying that the transition from normal to spaced dentition is driven primarily by tooth-size reduction rather than continued arch expansion a clinically important distinction that supports different management strategies for these two conditions.

This study is the first in the Nepalese literature to report TSALD values independently for both the maxillary and mandibular arches across all three dentition groups. The maxillary TSALD gradient (crowded −4.89 mm → normal +2.68 mm → spaced +9.38 mm; $F = 220.35$, $p < 0.001$) was steeper and more statistically robust than the mandibular gradient (crowded −2.30 mm → normal +1.50 mm → spaced +6.88 mm; $F = 33.75$, $p < 0.001$). This arch-level difference aligns with the clinical observation that mandibular crowding frequently presents at a lower severity threshold than maxillary crowding, possibly because the less-compliant mandibular bone offers less developmental accommodation of tooth size.[19] The discordance between arches identified in a subset of subjects reinforces the recommendation that TSALD be quantified independently for each arch in clinical practice.

The crowded group exhibited the highest TTM in both arches, while the spaced group showed the lowest, forming an orderly gradient (crowded > normal > spaced) consistent with Amara et al. [19] and Al-Khatieeb et al.[9] Importantly, Tukey post-hoc testing confirmed that crowded and normal groups did not differ significantly from each other in TTM in either arch; the omnibus ANOVA effect was driven entirely by the spaced group having distinctly smaller tooth material. This finding indicates that tooth-size reduction rather than tooth-size enlargement is the primary tooth-dimension contributor to TSALD in this sample, and that a reduction in arch perimeter is what separates crowded from normal dentitions.

Significant inter-group differences in MD widths were found for 11 of 12 maxillary teeth and 8 of

12 mandibular teeth. The pattern crowded ≥ normal > spaced, with crowded and normal rarely differing from each other was highly consistent across tooth types and aligns with data from Younus et al. [5] and Sharma et al.[21] Gilmore and Little demonstrated that mandibular incisor dimensions are reliably larger in crowded arches,[17] a finding replicated here for teeth 31, 42, and 43. The non-significance of the mandibular right central incisor (41), bilateral first premolars (34, 44), and bilateral first molars (36, 46) is consistent with the known lower variability of these tooth groups across malocclusion types.

No significant differences in IC width were observed in either arch (Maxilla: $p = 0.095$; Mandible: $p = 0.209$). This contrasts with findings by Sharma et al.,[21] who reported narrower buccal IC widths in Nepalese crowded patients compared with non-crowded patients. The discrepancy may reflect the three-group design employed here versus the two-group design used by Sharma et al., or differences in the age distribution of the samples. Longitudinal data by Bishara et al. demonstrated that mandibular IC width is established by approximately 8 years of age and shows only a slight decline thereafter; [20] in adults, therefore, IC width may represent a relatively fixed morphological parameter that does not reliably differentiate dentition types. Clinically, the absence of a significant IC difference implies that isolated transverse expansion at the canine level is unlikely to resolve TSALD; arch-perimeter modification at the premolar-molar level or overall arch development is required.

IP and IM widths were significantly greater in the spaced group, particularly in the mandibular arch (IP: $F = 13.60$, $p < 0.001$). These findings confirm that spaced arches are dimensionally wider at multiple transverse levels, not merely longer. The absence of a significant mandibular IM width difference after outlier correction despite significant maxillary IM width may reflect the greater dimensional variability of the mandibular molar region or genuine arch-level differences in transverse expression of the spaced phenotype.

The study sample was 63% female, which is representative of the patient profile at the institution but introduces potential confounding. Rupesh et al.[6] reported that tooth-size and arch-dimension contributions to crowding differed significantly between males and females in a Southern Indian population, with the significant effects confined to males. Similarly, Parajuli et al.[16] documented sex-related differences in MD crown dimensions within Nepalese ethnic groups. In the present study, the crowded group was equally distributed between sexes (11 female, 11 male), while the normal group was predominantly female (17 female, 4 male) and the spaced group was two-thirds female. This imbalance may have influenced the magnitude of group differences in arch dimensions, as males typically exhibit larger arch dimensions and tooth sizes.[6, 16] Gender-stratified analyses were not performed and represent a limitation; future work should specifically test for sex-by-group interaction effects.

The Nepalese population is ethnically heterogeneous, with major dental morphology differences described between Indo-Aryan (Brahmin, Chhetri) and Tibeto-Burman (Magar, Gurung) groups.[16] Mishra et al. demonstrated that anterior tooth-size discrepancy was more prevalent than overall interarch ratio discrepancy in Nepalese subjects,[15] suggesting that Nepalese-specific normative data may differ from Bolton's original Western sample.[8] The present findings specifically the lower absolute TTM values in the spaced group should be interpreted within this ethnic context. Comparison with Indian data from Rupesh et al.[6] and Pakistani data from Majeed et al.[2] suggests broadly similar dimensional patterns across South Asian populations, but the Nepalese spaced group in the present study had notably small individual tooth sizes relative to published South Asian normatives, an observation warranting further characterisation in population-based studies.

Clinical Implications

TSALD should be assessed separately for maxillary and mandibular arches, as discrepancies between arches can influence arch-specific treatment planning. Arch perimeter is more clinically relevant than tooth size for managing crowding; thus, non-extraction approaches aimed at increasing arch length should be prioritized in borderline cases. Spaced cases, with wider transverse dimensions, require careful long-term retention planning to minimize relapse.

## Limitations

This study has several limitations. Unequal group sizes may have reduced statistical power and introduced referral bias. Single-operator measurements limit assessment of inter-examiner reliability. Use of plaster casts and brass-wire technique may reduce measurement precision compared to 3D digital methods. The cross-sectional design prevents causal inference. Lack of gender stratification and absence of cephalometric data limit evaluation of confounding and skeletal influences. Finally, the ±4 mm TSALD cut-off may affect comparability with studies using different thresholds.

## Conclusions

Three main conclusions arise from this cross-sectional study of 138 pretreatment orthodontic casts in a Nepalese population. First, total tooth material (TTM) was highest in crowded dentitions and lowest in spaced cases, but no significant difference was observed between crowded and normal groups, indicating that tooth size alone does not distinguish malaligned from well-aligned arches. Second, arch perimeter was the most important discriminating factor, being significantly reduced in crowded arches compared to normal and spaced arches, while intercanine width showed no significant group differences, suggesting that arch length rather than anterior expansion is the key determinant. Third, TSALD was assessed separately for maxillary and mandibular arches, demonstrating meaningful intra-individual variation and underscoring the need for independent arch-based evaluation in treatment planning. Future studies using 3D digital analysis, cephalometry, and stratified sampling are recommended to establish robust normative data for the Nepalese population.

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**Availability of data and materials:** All data analyzed during this study will be available from the corresponding author upon reasonable request.

## Authors' Contributions

**Conceptualization:** Natasha Shrestha, Anisha Bhattarai, Swati Singh Shahi, Shakti Sharma
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