Does treating proximal cavities in primary molars non-restoratively affect intra-arch space and alignment of successor teeth negatively? A 4-year longitudinal study

Rafael T Gomide [Corresp., 1], **Jo E Frencken** [2], **Jorge Faber** [3], **Anne Marie Kuijpers-Jagtman** [4, 5, 6]

[1] Department of Pediatric Dentistry, Universidade de Brasília, Brasília, Distrito Federal, Brazil

[2] Department of Dentistry - Oral function and Prosthetic Dentistry, Radboud University Nijmegen, Nijmegen, Netherlands

[3] Unaffiliated, Brasília, Brazil

[4] Department of Orthodontics, University Medical Center Groningen, University of Groningen, Groningen, Netherlands

[5] Department of Orthodontics and Dentofacial Orthopedics, School of Dental Medicine/Medical Faculty, University of Berne, Berne, Switzerland

[6] Faculty of Dentistry, Universitas of Indonesia, Jakarta, Indonesia

Corresponding Author: Rafael T Gomide
Email address: rafael_gomide@hotmail.com

Background. Removing plaque with toothbrush and toothpaste from proximal cavities in primary molars without restoring them follows sound cariological principles. But does this treatment affect space for and alignment of their permanent successors negatively?

Hypothesis. There is no difference in impaction and displacement of the premolars, as well as in the D+E space in quadrants with three different statuses of the proximal surface of primary molars over a 4-year period.

Methods. 936 quadrants (466 maxillary and 470 mandibular quadrants) in 233 children were assessed. Treatment of cavities in the proximal surfaces of the primary molars consisted of amalgam and ART restorations using high-viscosity glass-ionomer cement, and cleaning of open large- and medium-sized cavities with toothbrush and toothpaste (UCT) under supervision for 220 days per year over 3 years. Dental casts were made at baseline, and after two, three, and four years. The D+E spaces were measured digitally. Status of the proximal surface of the primary molars was assessed by two calibrated examiners, and quadrants were grouped into normal anatomy, defective restoration, and proximal cavity. ANCOVA, ANOVA and LSD tests were applied.

Results. There was a statistically significant difference between groups (p<=0.001) and between evaluation times (p<0.001), for the D+E space in both the maxilla and mandible. A sex difference related to the D+E space in the maxilla was found (p=0.007). For boys quadrants in the maxilla of the group 'proximal cavity' showed a significant shorter D+E space when compared to quadrants of the group 'normal anatomy' at the 3- and 4-year evaluation time. For girls the difference between the 2 groups was only present at the 3-year evaluation time. There was no significant difference between the D+E space in quadrants with defective restorations and those with normal anatomy in the mandible and in the maxilla. Displacement and impaction of the premolars showed no significant difference between groups.

Conclusion. Primary molars with open proximal cavities that are cleaned with toothbrush and toothpaste do not result in displacement and impaction of the successor teeth, neither do primary molars with defective restorations in proximal tooth surfaces.

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6 Rafael Gomide[1]*, Jo E. Frencken[2], Jorge Faber[3], Anne Marie Kuijpers-Jagtman [4,5,6]

8 [1] Division of Pediatric Dentistry, University of Brasilia Dental School, Brasilia, Brazil. Campus
9 Darcy Ribeiro, 70910-900, Brasília, Brazil

10 [2] Department of Dentistry - Oral Function and Prosthetic Dentistry, Radboud University Medical
11 Center, Nijmegen, The Netherlands. Philips van Leydenlaan 25, 6525 EX Nijmegen, The
12 Netherlands

13 [3] Private practice

14 [4] Department of Orthodontics and Dentofacial Orthopedics, School of Dental Medicine/Medical
15 Faculty, University of Bern, Freiburgstrasse 7, CH-3010 Bern, Switzerland

16 [5] Department of Orthodontics, University Medical Center Groningen, University of Groningen,
17 Hanzeplein 1, 9713 GZ Groningen, The Netherlands

18 [6] Faculty of Dentistry, Universitas Indonesia, Campus Salemba, Jalan Salemba Raya 4, Jakarta
19 10430, Indonesia

21 Corresponding Author:
22 R. Gomide, Division of Pediatric Dentistry, University of Brasilia Dental School, Brasilia,
23 Brazil.
24 Email: rafael_gomide@hotmail.com

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33   **Abstract**

34

35   **Background.** Removing plaque with toothbrush and toothpaste from proximal cavities in

36   primary molars without restoring them follows sound cariological principles. But does this

37   treatment affect space for and alignment of their permanent successors negatively?

38   **Hypothesis.** There is no difference in impaction and displacement of the premolars, as well as in

39   the D+E space in quadrants with three different statuses of the proximal surface of primary

40   molars over a 4-year period.

41   **Methods.** 936 quadrants (466 maxillary and 470 mandibular quadrants) in 233 children were

42   assessed. Treatment of cavities in the proximal surfaces of the primary molars consisted of

43   amalgam and ART restorations using high-viscosity glass-ionomer cement, and cleaning of open

44   large- and medium-sized cavities with toothbrush and toothpaste (UCT) under supervision for

45   220 days per year over 3 years. Dental casts were made at baseline, and after two, three, and four

46   years. The D+E spaces were measured digitally. Status of the proximal surface of the primary

47   molars was assessed by two calibrated examiners, and quadrants were grouped into normal

48   anatomy, defective restoration, and proximal cavity. ANCOVA, ANOVA and LSD tests were

49   applied.

50   **Results.** There was a statistically significant difference between groups ($p <= 0.001$) and between

51   evaluation times ($p < 0.001$), for the D+E space in both the maxilla and mandible. A sex

52   difference related to the D+E space in the maxilla was found ($p = 0.007$). For boys quadrants in

53   the maxilla of the group 'proximal cavity' showed a significant shorter D+E space when

54   compared to quadrants of the group 'normal anatomy' at the 3- and 4-year evaluation time. For

55   girls the difference between the 2 groups was only present at the 3-year evaluation time. There

56   was no significant difference between the D+E space in quadrants with defective restorations and

57   those with normal anatomy in the mandible and in the maxilla. Displacement and impaction of

58   the premolars showed no significant difference between groups.

59   **Conclusion.** Primary molars with open proximal cavities that are cleaned with toothbrush and

60   toothpaste do not result in displacement and impaction of the successor teeth, neither do primary

61   molars with defective restorations in proximal tooth surfaces.

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67 **1   INTRODUCTION**
68

69 Untreated caries in primary teeth is very frequently observed, as shown in a report on the most

70 prevalent oral conditions globally (*Marcenes et al., 2013)*. Out of 291 oral conditions, open

71 cavities in primary teeth ranked number 10, with 621 million children affected worldwide during

72 the period 1990–2010.

73   Dental caries, in principle, is a preventable disease. The fact that millions of children live

74 with open cavities is a burden for the children and their families, the dental and medical

75 profession, and nations around the world. Factors that contribute to this undesirable situation

76 include lack of attention to oral diseases in global health policies and failure tackling their known

77 social and commercial determinants; emphasis on traditional restorative care as the predominant

78 treatment; and treatment costs that exceed available resources in many low- and middle-income

79 countries (*Peres et al., 2019; Watt et al., 2019)*.

80   Preventing carious lesion formation can be achieved by regular disturbance of the biofilm

81 on enamel and dentine. This cariological principle is the basis for caries prevention and cavity

82 treatment (*Kidd & Fejerskov, 2004)*. The common treatment of cavitated teeth is restoring them.

83 However, it is known that traditional restorative care frequently causes dental anxiety; leads to

84 low restoration-survival percentages, particularly in approximal surfaces; and is expensive.

85 Another, more causal, cavity treatment concerns the removal of biofilm from open tooth cavities

86 in primary molars *(Mijan et al., 2014)*. This kind of treatment has become the basis of cavity

87 treatment in the guidelines of pediatric dental care in the Netherlands, with effect from January

88 2021 (*KIMO, 2020*).

89   The effectiveness of removing the biofilm from open cavities in primary canines and

90 molars was investigated in a three-arm quasi-randomized clinical trial. The experimental group

91 was termed Ultra-Conservative Treatment (UCT) and treatment consisted of cleaning accessible

92 medium- and large-sized cavities with toothbrush and fluoride containing toothpaste and

93 restoring small cavities according to the Atraumatic Restorative Treatment (ART) method using

94 high-viscosity glass-ionomer cement (HVGIC) (*Mijan et al., 2014*). UCT was compared with

95 amalgam and ART/HVGIC, with symptomless exfoliation of primary canines and molars as the

96 outcome variable. After 3.5 years, no differences were observed between the three types of

97   treatment, indicating that cavities in primary teeth left open and cleaned do not necessarily lead

98   to a higher percentage of premature tooth loss than restored cavities (*Mijan et al., 2014)*. This

99   result questions the need for traditional restorative care as the predominant treatment for

100   managing cavities in primary teeth.

101   UCT offers advantages as its cavity-cleaning component is a causal disease treatment, but

102   it relies on good cooperation between the child/parents and the professional in achieving this. It

103   is child-friendly and improves oral hygiene in permanent teeth (*Hilgert et al., 2017)*. However,

104   these positive aspects are nullified if proximal cavities that are left open and cleaned eventually

105   lead to orthodontic problems in the permanent dentition.

106   It has been suggested that extensive cavities in proximal surfaces of primary teeth are

107   associated with a decrease of space in the primary molar region, known as the D+E space

108   (*Northway & Wainright, 1980; Gomide et al., 2020b)*. Decrease of the D+E space may have

109   orthodontic implications (*Stahl & Grabowski, 2004)*, since it tends to reduce the available space

110   for the eruption of the permanent canine and the premolars, which may affect alignment of the

111   successor teeth and/or cause tooth impaction (*Northway, 2001)*. If this event proves likely, the

112   loss of space due to extensive cavities may also have important financial implications through an

113   increase in the cost of providing orthodontic treatment for millions of patients globally.

114   By the same token, if cavitated lesions in proximal surfaces of primary molars do not lead

115   to an increase in malalignment, more treatment options for proximal carious lesions in the

116   primary molars can be considered. Instead of prioritizing treatment methods that restore the

117   contact point, one might consider, for example, restorative strategies that prioritize health, cost

118   reduction, and patient comfort, all included in the UCT method.

119   Limited information is available on the effect on intra-arch distances when cavitated

120   primary molars are subjected to the ultra-conservative treatment protocol (UCT) A pilot

121   investigation into the effect of proximal grinding of carious lesions of primary molars on the

122   available space showed no clinically relevant space loss, but in this study the intention was to

123   leave at least a point of contact between the ground primary molar and the adjacent tooth (*Ingers*

124   *et al., 1982)*. At the same time, we were not able to find studies that focused on the association of

125   restoration failure or proximal cavities with intra-arch distances. In the current study, we tested

126   the null-hypothesis that there is no difference in the D+E space as well as in impaction and

127   displacement of the premolars in quadrants with three different statuses of the proximal surface

128   of primary molars over a 4-year period. The aim of the study was to assess the association

129   between different statuses of the proximal surface of the primary molars and the D+E space, and

130   displacement and impaction of the premolars over a 4-year follow-up period.

131

132   **2   MATERIALS AND METHODS**

133

134   **2.1   Study design**

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136   The Research Ethics Committee of the University of Brasília Medical School approved the study

137   (ref nr 081/2008). The trial was registered in the Netherlands Trial Registry (NTR; ref number

138   1699). The study design and restorative treatment methods that were used in the present

139   investigation have been described in detail elsewhere (*Mijan et al., 2015*). A brief description is

140   presented below.

141   In the original trial, the exfoliation and survival percentages of primary molars submitted

142   to three restorative treatment strategies were assessed over a 3.5-year period (*Mijan et al., 2014;*

143   *Mijan et al., 2015*). The treatment protocols consisted of 1) conventional restorative treatment

144   using amalgam (CRT); 2) ART; and 3) UCT. The UCT protocol consisted of restoring small

145   dentine cavities using the ART method and increasing access to medium-sized cavities with a

146   hatchet, with the child then brushing medium and large cavities under supervision during school

147   hours (220 days/year for 3 years) for biofilm removal using toothbrush and fluoride-containing

148   toothpaste.

149   The investigation was set up as a quasi-randomized, controlled clinical trial with a

150   parallel group design. The subjects were nested in an oral health epidemiological survey that was

151   carried out on 6- and 7-year-old children attending six public primary schools in a socially

152   deprived suburban area of Brasilia, Brazil, in April and May 2009 (*Mijan et al., 2014*). Only

153   healthy children, having at least two cavitated dentine carious lesions in primary molars without

154   pain and pulp involvement, and whose parents/guardians had signed the informed consent were

155   considered eligible for inclusion in the study (*Mijan et al., 2014*).

156

157   **2.2   Dental cast analysis and outcome measures**

158

159   Data were collected as previously described (*Gomide et al., 2020a)*. Immediately after

160   completion of the restorative treatment, alginate impressions (Avagel®, Dentsply, Petrópolis,

161   Brazil) of both jaws were made with autoclavable mouth trays (Morelli®, Sorocaba, Brazil) and

162   a wax bite was made. The impressions were poured in plaster (Asfer®, São Caetano, Brazil)

163   within one hour. The same procedure was followed after two (T2), three (T3), and four years

164   (T4).

165   Measurements were carried out digitally on standardized occlusal pictures of the plaster

166   casts. The method to obtain the occlusal pictures have been described elsewhere (*Gomide et al.,*

167   *2020b)*.

168

169   *Intra-arch variables*

170   Measurements were performed on the occlusal pictures of the upper and the lower dental

171   arch using a morphometric program (Digimizer v. 4.2, MedCalc Software, Belgium) by one

172   calibrated examiner (RG). The examiner performed the measurements under standardized

173   conditions for about 10 weeks between 8 and 10 am every day at the same location under the

174   same lighting conditions. The D+E spaces were measured at baseline (T0), and after two (T2),

175   three (T3), and four years (T4). Tooth displacement and impaction of the premolars were

176   assessed on the final cast (T4). To assess the intra-observer reliability, 29 dental casts were re-

177   assessed after a period of 2 months.

178   The following variables were measured for both arches and for each quadrant separately:

179   *D+E space*: measured from the most mesial point of the first permanent molar to the

180   most distal point of the primary canine in each dental arch (in millimetres) in both quadrants. If

181   the first permanent molar was absent, the most distal point of the second primary molar or

182   premolar was considered. If the primary canine was absent, the most mesial point of the first

183   primary molar or premolar was considered. The distance was disregarded if all teeth were

184   missing *(Gomide et al., 2020a)*.

185   *Displacement of the premolars*: The distance was measured between anatomical contact

186   points when the teeth deviated from the line of the arch (*Richmond et al., 1992)*. The largest

187   contact point displacement in each quadrant was recorded. Displacements between contact points

188   of rotated teeth were disregarded (*Richmond et al., 1992)*. Assessment took place at the final

189   evaluation point (T4) only.

190   *Impaction of premolars*: This involves the space measured between two teeth situated at

191   both sides of an unerupted tooth. A premolar was considered impacted when the distance

192   between the two teeth was equal to or shorter than 4 mm (*Richmond et al., 1992)*. Tooth

193   impaction was assessed at the final evaluation point (T4) only.

194

195   *Status of the proximal tooth surface*

196   The presence of cavitated dentine carious lesions at the distal surface of the canine and the

197   proximal surfaces of primary molars was determined from digital standardized occlusal pictures

198   of the dental casts at baseline and at all evaluation points with a magnification between two and

199   eight times (Samsung Galaxy Note 10.1, Suwon, South Korea) by two calibrated examinors (RG,

200   JF) independently. Differences were discussed until consensus was reached. To assess the inter-

201   observer reliability, 248 photographs were re-assessed by both observers after a period of two

202   weeks.

203   The quadrants were grouped according to the condition of the proximal tooth surface

204   between the primary molars (Figure 1). The canines were not considered.

205   - *Normal anatomy:* quadrants with sound proximal surfaces of the primary molars or with

206   intact (proximal) restorations in primary molars in contact with an adjacent tooth, measured at

207   baseline (T0) and all other evaluation points (T2, T3, T4).

208   - *Defective restorations:* quadrants with restored proximal surfaces at baseline that were

209   assessed as defective at T2 and had lost contact with the adjacent tooth surface, showing an

210   open proximal cavity with and without remnants of restorative material. The defective

211   restorations were not re-restored between T2 and T4.

212   - *Proximal cavity:* open proximal cavity with or without contact with the adjacent tooth surface

213   at all evaluation points. The cavities had been cleaned with toothbrush and toothpaste under

214   supervision during schooldays for three years.

215

216   **2.3   Statistical analyses**

217

218   The sample size for the present sub-study had been calculated for the controlled clinical trial. In

219   brief, the sample size was set at 88 individuals for each of the 3 treatment groups (CRT, ART,

220   UCT) on the basis of a power of 80%, a significance level of 0.05, a 10% correction for

221 dependency on treatments within a child, and an 8% estimated annual loss of children (*Mijan et*
222 *al., 2014).*

223   Kappa statistics was applied to determine the interobserver reproducibility for assessing
224 the status of the proximal tooth surfaces. The intra-examiner reliability for the D+E spaces and
225 tooth displacement was expressed as Pearson's correlation coefficients. Paired sample t-tests
226 were applied to identify systematic differences between the first and second measurement.

227   Descriptive statistics were calculated, and outliers received the same value as the mean
228 for the dependent variable (D+E space or tooth displacement). Mean and 95% confidence
229 interval of the D+E spaces in both arches were calculated at each evaluation point. ANOVA's at
230 T0, T2, T3 and T4 contrasted differences between groups (normal anatomy, defective
231 restoration, and proximal cavity). Post-hoc LSD tests were used when necessary. A mixed model
232 ANCOVA analysis was performed to assess the effect of age (covariate), sex, evaluation time
233 (T0, T2, T3 and T4) and group (normal anatomy, defective restorative and proximal cavity) on
234 the D+E space. A mixed model ANCOVA analysis was performed to assess the effect of age
235 (covariate), sex and group (normal anatomy, defective restorative and proximal cavity) on tooth
236 displacement at the end of the study (T4). Post-hoc LSD tests were used when necessary. Chi-
237 square tests were used to assess the association of group with tooth impaction at the end of the
238 study (T4). The alpha level was set at 5%.

239
240 **3   RESULTS**
241
242 **3.1   Sample distribution**
243 The Consort diagram is presented in Figure 2. From the original sample of 277 children included
244 in the clinical trial, 5 children were excluded because they had tooth anomalies (supernumerary
245 or missing lateral primary incisor). It was impossible to obtain maxillary impressions of two
246 children because they experienced severe nausea. At baseline, 37 pairs of casts could not be
247 measured as they had been either damaged or lost during transportation, or the casts did not
248 match the respective children. A total of 233 pairs of casts (130 boys and 103 girls) and 2
249 mandibular casts were measured at baseline. Every child that remained in the cohort study had
250 the mouth split in four corresponding quadrants and these were assessed independently.
251 Quadrants were excluded if the children were not followed up for four years, if new proximal

252 cavities in the primary molars were present or when premature primary molar loss occurred, and

253 if restorations failed after two years.

254

255

256 **3.2   Method error**

257 The kappa-coefficient for the inter-examiner agreement for assessing the status of the proximal

258 tooth surfaces was 0.80, which indicated substantial agreement between the two examiners.

259 The intra-examiner agreement is presented in Table 1. Pearson's correlation coefficient for the

260 intra-examiner agreement ranged from moderate (0.67 for tooth displacement) to very high (0.99

261 for D+E space). There was a statistically significant difference between first and second

262 measurement for tooth displacement, but the difference was small (mean diff = 0.14 mm).

263

264 **3.3   D+E space in the maxillary and mandibular dental arch**

265 The mixed model ANCOVA results revealed a statistically significant difference between groups

266 (maxilla p=0.001; mandible p<0.001) and between evaluation times (p<0.001), for the D+E

267 space for both the maxilla and mandible. A sex difference related to the D+E space for the

268 maxilla was found (p=0.007) and therefore the results regarding the maxilla are presented

269 separately for boys and girls

270 *Maxilla*. Figure 3 presents the relationships between group and D+E space by evaluation time for

271 boys. The relationships for girls are presented in figure 4. There was no statistically significant

272 difference between groups for the D+E space for boys at baseline, and T2. At T3 and T4 the

273 difference was statistically significant. Boys belonging to the proximal cavity group had a shorter

274 D+E space (T3: 15.66 ± 0.98mm; T4: 15.18 ± 0.97mm) than boys belonging to the normal

275 anatomy group (T3: 16.40 ± 1.08mm; T4: 16.01 ± 1.23mm). For girls there was a statistically

276 significant difference for the D+E space between the normal anatomy group and the proximal

277 cavity group at T3 only.

278 *Mandible*. Figure 5 presents the relationships between group and D+E space by evaluation time

279 for the mandible of boys and girls combined. At all evaluation points, the D+E space was

280 statistically significantly shorter for children belonging to the proximal cavity group compared to

281 those of the normal anatomy group. At T4 the mean score was 15.94 ± 1.07mm (proximal cavity

282 group) and 16.86 ± 1.41mm (normal anatomy group).

283   There was no significant difference between the D+E space in quadrants with defective

284   restorations and those with normal anatomy in the mandible and in the maxilla.

285

286   **3.4   Tooth displacement**

287   The mean score and 95% confidence interval of tooth displacement by group is presented in

288   Table 2. No significant difference among groups in the maxilla (p=0.948) and mandible

289   (p=0.057) was observed. The mixed model ANCOVA results showed that sex was associated to

290   tooth displacement in the maxilla (p<0.001) (Table 3). Girls had larger tooth displacement scores

291   (mean score: 2.11 ± 0.35mm) when compared to boys (mean score: 1.38 ± 0.31mm). In the

292   mandible, no association was found (Table 3).

293

294   **3.5   Tooth impaction**

295   No differences between groups were found (chi-square test) for impaction of the premolars

296   neither in the maxilla nor in the mandible (Table 4).

297

298   **4   DISCUSSION**

299

300   **4.1   Methodology**

301

302   This sub-study was nested in a clinical trial and relied for its sample size on that of the main trial

303   (*Mijan et al, 2014)*. As no other study had investigated the effect of the status of the proximal

304   tooth surface on the intra-arch variables, no basic information was available to estimate the

305   optimal sample size for such a study. In addition, attrition of the sample over the four-year period

306   was substantial due to loss-to-follow-up or exclusion of quadrants, which reduced the power of

307   the study. In the fourth year many children left the primary school for a school with a higher

308   level of education. Intense efforts were made to trace these children, but many could not be

309   recalled. Exclusion was mainly due to quadrants in which the status of the approximal surfaces

310   of the primary molars changed; for example, quadrants with primary molars that had belonged to

311   the normal anatomy group at baseline but developed a proximal cavity, received a restoration, or

312   became prematurely lost in the years following. To avoid differences between groups due to the

313   large number of loss-to-follow-up, only quadrants that were followed up for four years were

314   included in the study. Therefore, the results of the current study provide the basis for calculating

315   an adequate sample size for future studies on this topic in an environment such as the current

316   one.

317   The number of dental casts in the defective restorations and the proximal cavity groups

318   proved to be lower than the number of casts in the normal anatomy group. The normal anatomy

319   group was composed of two conditions, a true sound proximal primary molar surface and a

320   proximal primary molar surface cavity restored with ART/HVGIC or amalgam with proximal

321   contact to an adjacent tooth. Combining these two surface conditions was permitted because no

322   statistically significant difference existed between these two surface conditions and the intra-arch

323   orthodontic variables tested. The group with defective restorations reflects a common situation in

324   pediatric dental care as many defective restorations in primary molars are not re-restored,

325   particularly at this age with the exfoliation time approaching and the substantial percentage of

326   primary molars with defective restorations that exfoliate without symptoms (*Hilgert et al., 2016*).

327   The number of casts in the proximal cavity group was lower due to the loss of casts in the UCT-

328   group, that consisted predominantly of open proximal cavities, during transportation at the start

329   of the study.

330   The mixed model ANCOVA and the LSD test that follow it are common statistical tests

331   for a study such as the present one. There is, therefore, no reason to doubt the outcomes of the

332   present study as performed under the prevailing conditions. Nevertheless, a larger sample size,

333   particularly for the defective restorations and proximal cavity groups, would have been an asset

334   and should be strived for in future investigations on this topic.

335   Measuring variables accurately is essential for constructing a reliable database. Outcomes

336   of reproducibility tests showed that the calculation of the D+E spaces and the determination of

337   the components of the status of the proximal tooth surface were performed at a high level of

338   accuracy.

339

340   **4.2   Main findings**

341

342   The null hypothesis was partially accepted. There is neither a difference in the mean scores of

343   impaction and displacement of the premolars in both arches between groups nor for the D+E

344   space in quadrants with defective restorations and those with normal anatomy in the mandible

345 and in the maxilla. But there were significant differences for the D+E space between quadrants

346 with proximal cavity and those with normal anatomy in the mandible and in the maxilla for boys

347 after 3 and 4 years, and for girls after 3 years. This is the first study to investigate the effect of

348 defective restorations and left 'open' proximal cavities in primary molars on intra-arch space and

349 on malocclusion. It means that, in addition to the absence of a significant difference in

350 exfoliation of symptom-free primary molars between restored and 'open' proximal cavities as

351 earlier reported *(Mijan et al., 2014),* there is now also absence of proof that keeping proximal

352 cavities open and cleaning them regularly with toothbrush and toothpaste causes tooth

353 displacement and tooth impaction of premolars at age 10–11 years. It is also worth mentioning

354 that the outcome is alike for both boys and girls. The only difference was that girls had no

355 difference between groups while boys showed a statistical difference for the D+E space between

356 normal anatomy quadrants and proximal cavity quadrants. However, this difference might not

357 have important clinical implications since no difference in tooth displacement and impaction was

358 observed. In addition, the present study provided proof that re-restoring defective restorations in

359 primary molars is not necessary for preventing space loss for the permanent successors, which is

360 an important finding in relation to reduction of the burden of dental care and costs.

361 The study findings may have major implications for the manner tooth cavities in primary

362 molars can be treated in future. While restoring cavities with amalgam or resin composite was

363 the only treatment available some two decades ago, these days tooth cavities can be treated

364 successfully through applying silver diamine fluoride (SDF) (*Seifo et al., 2019*), placing a Hall-

365 crown (*Innes et al., 2017*), restoring with ART/HVGIC (*Frencken, Liang & Zhang, 2021)*, and

366 brushing them plaque-free as part of the UCT method. Because the UCT method investigated the

367 use of hand instruments for increasing access to initially insufficiently wide proximal cavities,

368 this treatment can be carried out in countries with meagre financial resources and the consequent

369 limited dental equipment. It is also advocated for use in well-resourced countries because it

370 reduces dental anxiety among children compared to the treatment with the bur, but enlarging of

371 initially insufficiently wide proximal cavities can, off course also be performed with the bur

372 (*Santamaria et al., 2015)*.

373 These more recently introduced treatments are considered child-friendly and may

374 increase access to dental care for child populations if professional education, knowledge, and

375 adequate dental products are available among the dental profession *(Banerjee et al., 2017; Innes*

376 *et al., 2017; Seifo et al., 2019; Frencken, Liang & Zhang, 2021)*. Their application also offers the

377 opportunity to operate in tandem with parents/caregivers, which may lead them to a much better

378 understanding of how to keep the primary and, particularly, the permanent dentition free from

379 carious lesions. This may prevent extraction of primary molars at an early age. Overall, the

380 outcome of the present study shows that increased need for orthodontic treatment is not to be

381 expected, while cleaning open proximal cavities in primary molars with toothpaste and

382 toothbrush may contribute to a reduction in healthcare costs for governments and patients.

383   The total loss of space in the maxilla and mandible was relatively small at the end of the

384 follow-up period (T4), and tooth displacement and tooth impaction of premolars among the

385 groups were comparable. No other study was found that associated tooth impaction and tooth

386 displacement with cavitated dentine carious lesions, but some cross-sectional studies associated

387 the increase of crowding, asymmetry of antero-posterior canine relationship, and lower midline

388 deviation with cavitated dentine carious lesions (*Ben-Bassat, Harari, & Brin, 1997; Caplin,*

389 *Evans & Begole, 2015)*. In a 6-year follow-up study, Northway and Wainright (*Northway &*

390 *Wainright, 1980)* reported that large open cavities were associated with a decrease in the D+E

391 space of between 0.5 and 1.0 mm, but the difference was only statistically significant for 9-year-

392 old children in the maxilla and 10-year-olds in the mandible. The authors suggested that this

393 difference occurred at this age, because cavitated primary molars exfoliated one year earlier than

394 carious lesion-free primary molars (*Northway & Wainright, 1980)*. This finding was also

395 observed in the main clinical trial (*Mijan et al., 2014)*.

396   Future studies with larger sample sizes should be designed to confirm our findings and to

397 expand the analysis to the vertical and transverse dimensions.

398

399

400 **5   CONCLUSIONS**

401

402 Compared to quadrants with a normal anatomy those with open proximal cavities of the primary

403 molars showed a tendency to a shorter D+E space in the mandible over a 4-year follow-up

404 period. The same was applicable for quadrants in the maxilla for boys after 3 and 4 years, and for

405 girls after 3 years. However, the shorter D+E space had no negative implication regarding

406 impaction and displacement of the successor teeth. Primary molars with open proximal cavities

407   that are cleaned with toothbrush and toothpaste do not result in displacement and impaction of

408   the successor teeth, neither do primary molars with defective restorations in proximal tooth

409   surfaces.

410

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417

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497

498

Figure 1

Illustration showing different *"status of the proximal surface",* grouped into normal anatomy, defective restoration and proximal cavity.

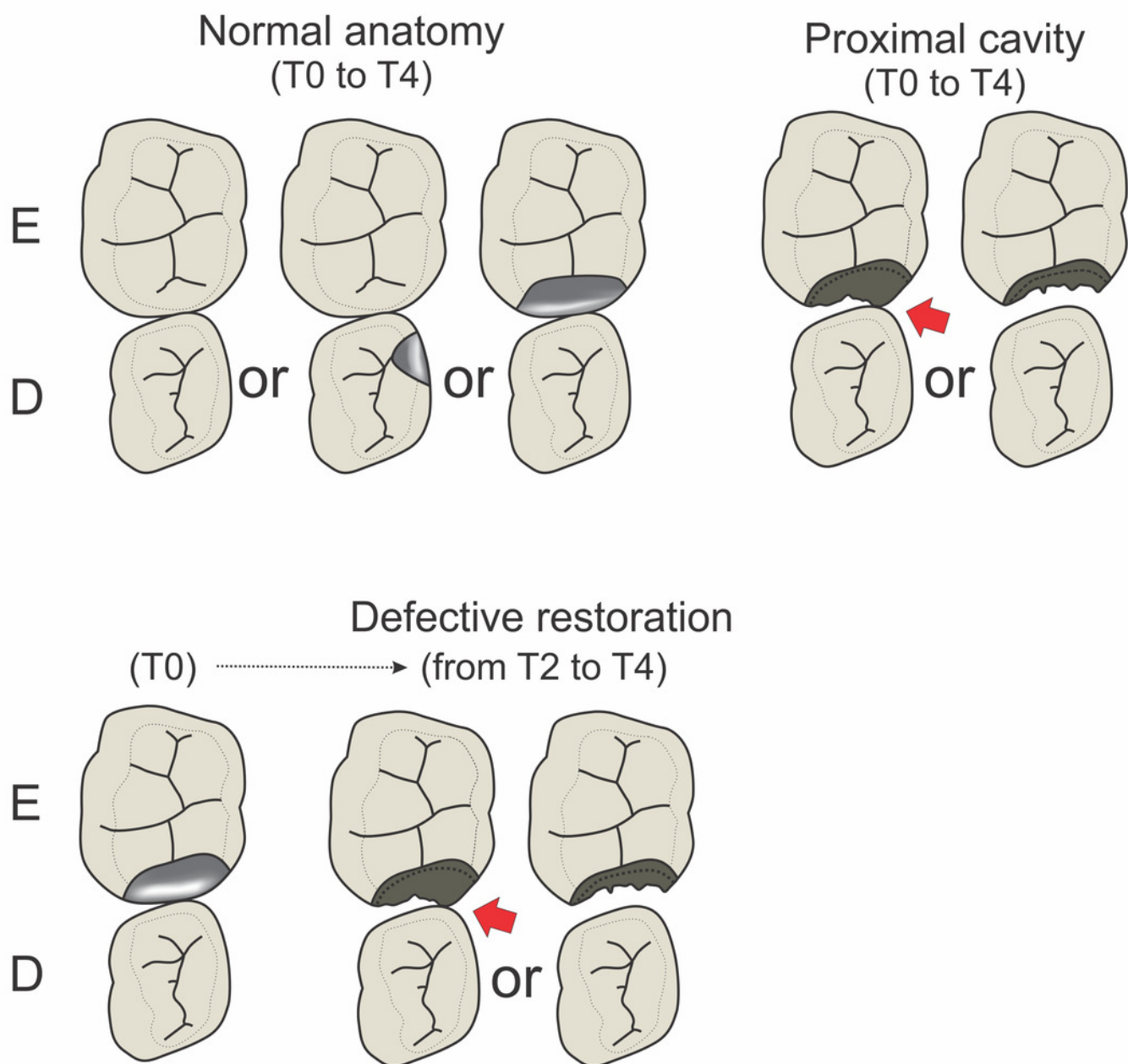



Figure 2

Consolidated Standards of Reporting Trials (CONSORT) flow diagram.

277 schoolchildren

5 pairs had tooth anomalies;
5 pairs did not match the children;
32 pairs were lost or damaged; 2
upper impressions could not be
obtained

233 pairs of casts
2 lower casts

466 max. quadrants
470 mand. quadrants

Condition of the
proximal tooth
surface

Normal anatomy
group
216 max. quadrants
159 mand. quadrants

Defective restoration
group
37 max. quadrants
53 mand. quadrants

Proximal cavity
group
97 max. quadrants
95 mand. quadrants

Lost to follow-up:
moved from school or
not reachable

Dropped out:
70 max. quadrants
65 mand. quadrants

Dropped out:
14 max. quadrants
23 mand. quadrants

Dropped out:
38 max. quadrants
31 mand. quadrants

Changed between
groups

Excluded:
78 max. quadrants
52 mand. quadrants

Excluded:
2 max. quadrants
3 mand. quadrants

Excluded:
31 max. quadrants
35 mand. quadrants

Baseline
(T0)

68 max. quadrants
(45 boys and 23 girls)
42 mand. quadrants

21 max. quadrants
(10 boys and 11 girls)
27 mand. quadrants

28 max. quadrants
(16 boys and 12 girls)
29 mand. quadrants

Four years
follow-up
(T4)

68 max. quadrants
(45 boys and 23 girls)
42 mand. quadrants

21 max. quadrants
(10 boys and 11 girls)
27 mand. quadrants

28 max. quadrants
(16 boys and 12 girls)
29 mand. quadrants

Max = maxilla and mand = mandible

Figure 3

Mixed model ANCOVA results of the D+E space (mean score and 95% C.I.) for the 3 groups by evaluation time for boys in the maxilla. Significant difference between groups at each evaluation time are denoted by different letters (A to C).

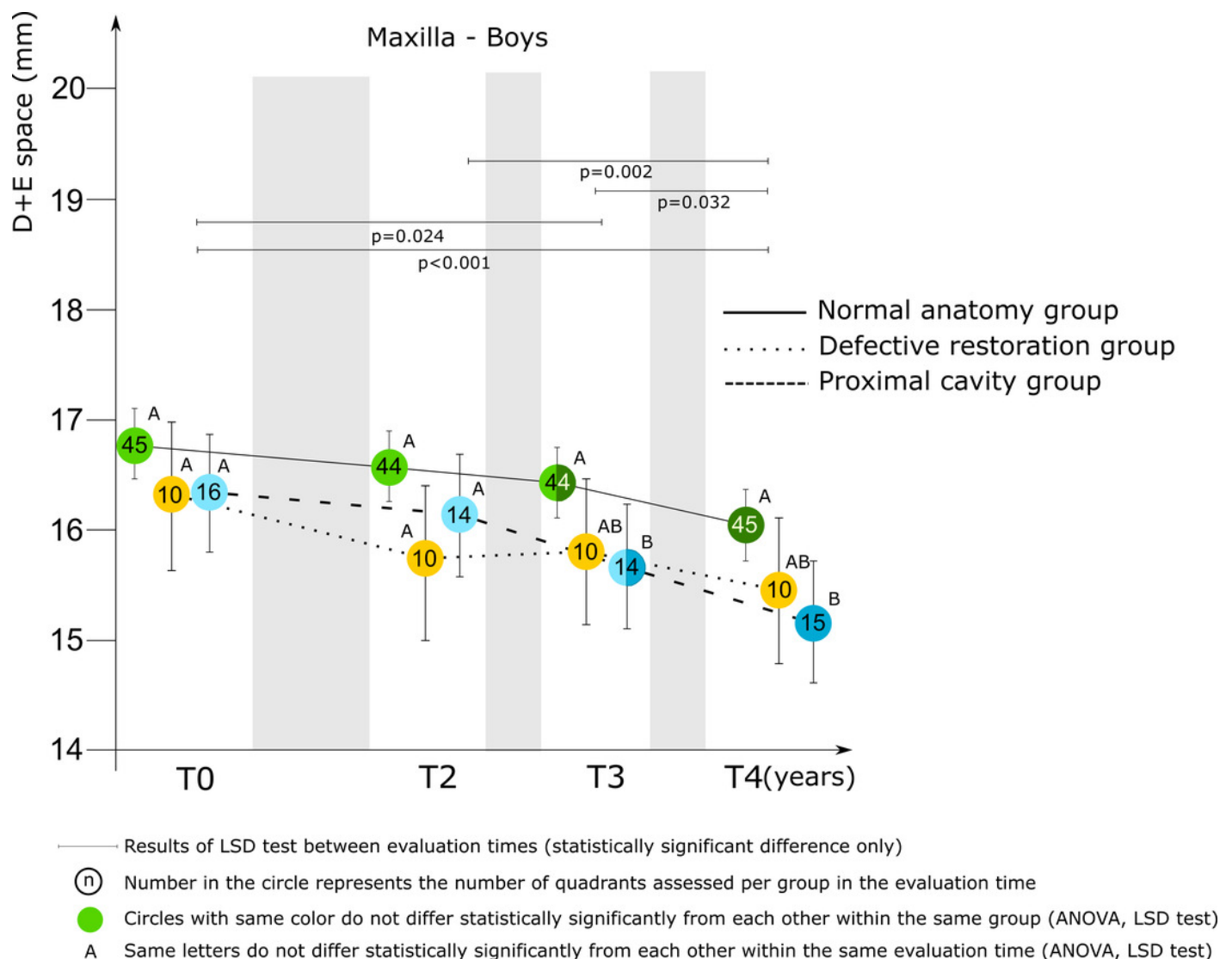



Figure 4

Mixed model ANCOVA results of the D+E space (mean score and 95% C.I.) for the 3 groups by evaluation time for girls in the maxilla. Significant difference between groups at each evaluation time are denoted by different letters (A to C).

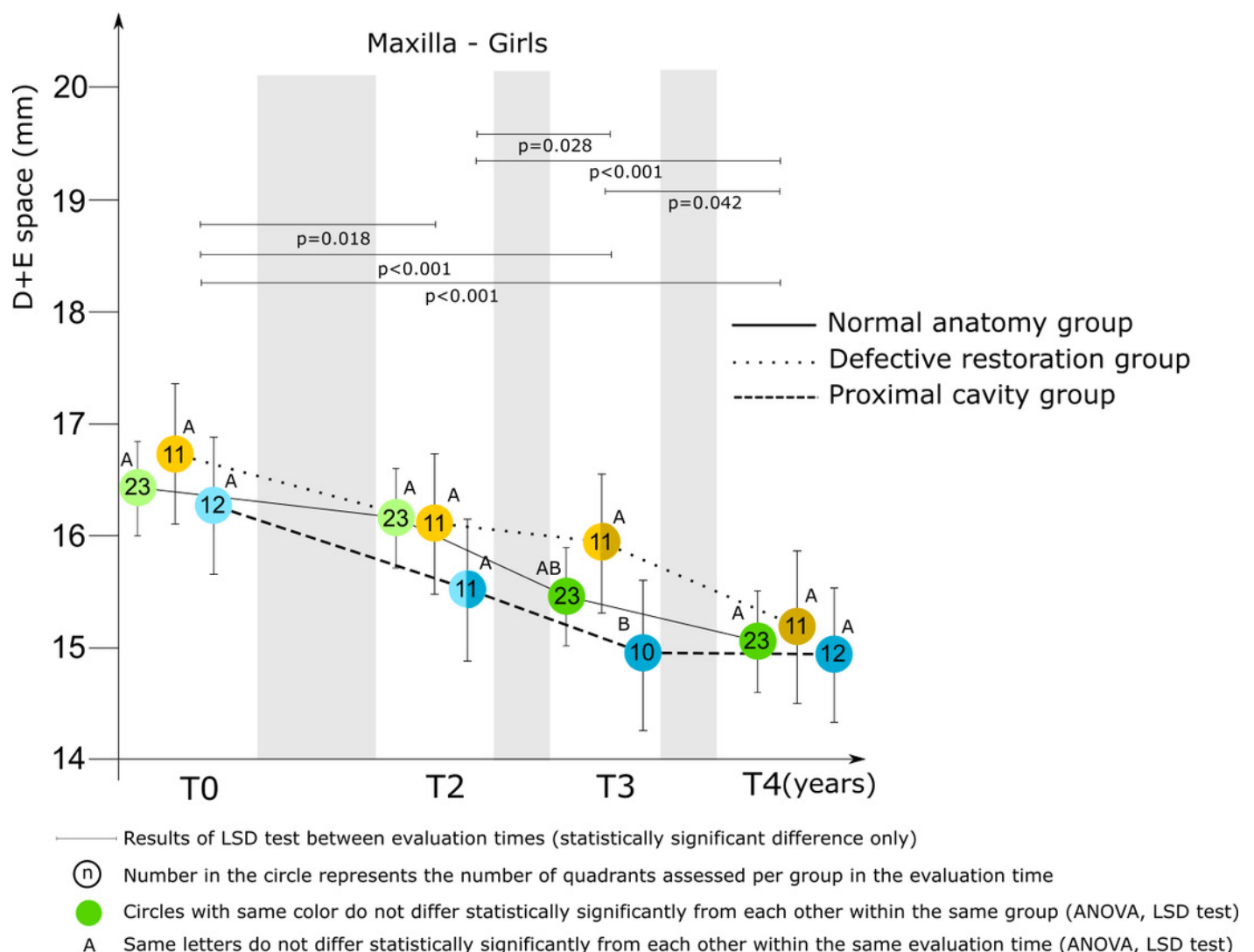
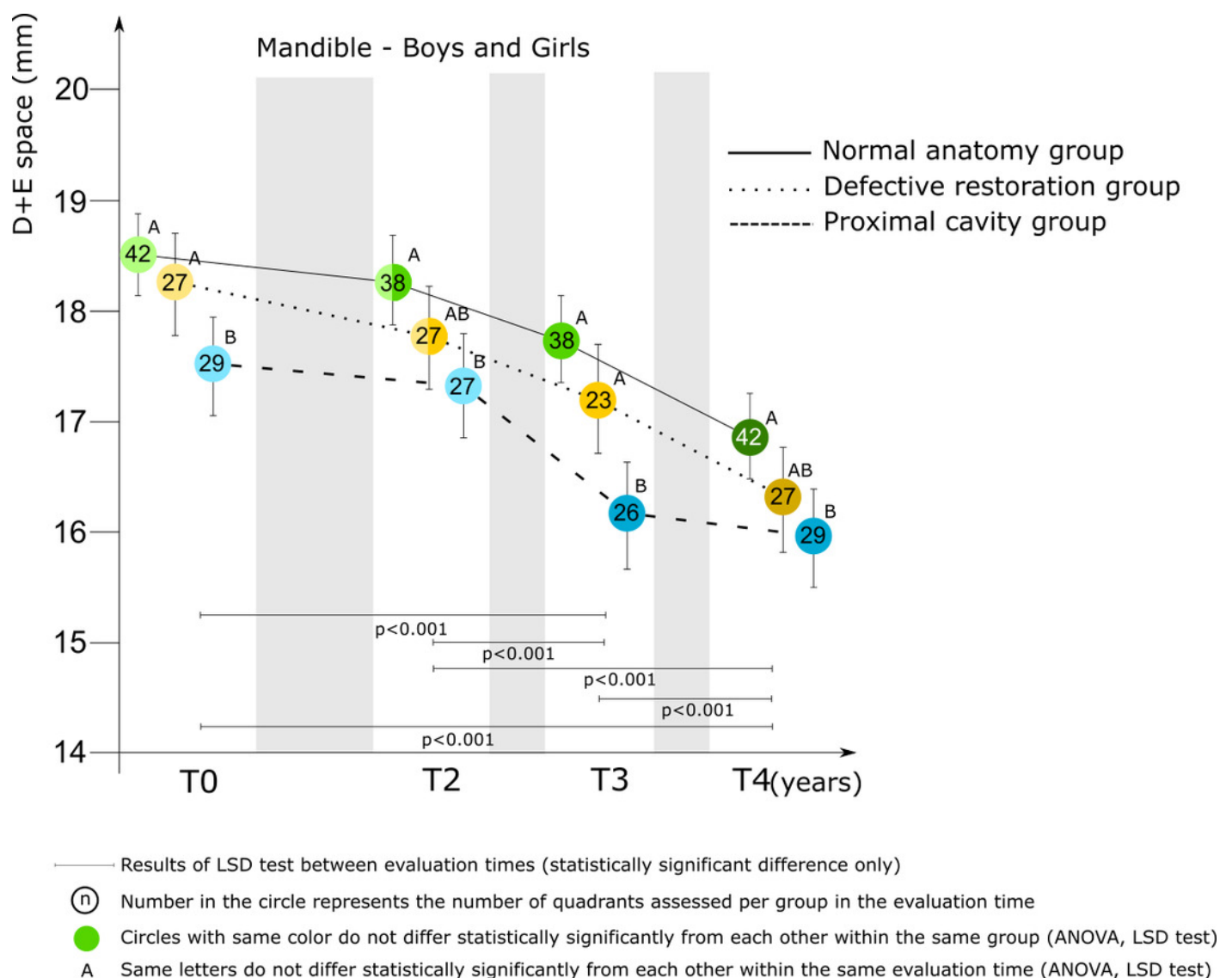



Figure 5

Mixed model ANCOVA results of the D+E space (mean score and 95% C.I.) for the 3 groups by evaluation time for boys and girls combined in the mandible. Significant difference between groups at each evaluation time are denoted by different letters (A to C).

Intra-observer agreement (Pearson's correlation coefficient, mean difference, 95% confidence interval and p value) of the D+E space in the maxilla and the mandible, and displacement of the premolars (in mm).

Paired sample correlation test

Variable	Correlation	Mean difference	95% CI of mean dif	*p*
D+E space in the maxilla	0.997	0.01	[-0.04…0.05]	0.703
D+E space in the mandible	0.994	0.01	[-0.04…0.05]	0.993
Displacement of the premolar	0.672	0.14	[-0.06…0.34]	<0.001

Descriptive statistics (mean, 95% CI, and p) of displacement in mms of the premolars in quadrants with normal anatomy, defective restoration and proximal cavity in both arches.

n- Number of quadrants assessed

Maxilla					Mandible			
Group	**Mean**	**95% C.I**	**n**	***p***	**Mean**	**95% C.I**	**n**	***p***
Normal anatomy	1.78	(1.54…2.02)	69		1.66	(1.40…1.92)	42	
Defective restoration	1.70	(1.28…2.11)	21	0.948	1.24	(0.90…1.59)	27	0.057
Proximal Cavity	1.76	(1.40…2.11)	28		1.22	(0.90…1.53)	29	

Influence of group, age, and sex on the displacement of the premolars in the maxilla and mandible (mixed model ANCOVA).

	Maxilla			Mandible		
Variable	F	df	*p*	F	df	*p*
Group	0.053	2	0.948	2.965	2	0.057
Age	0.101	1	0.751	0.604	1	0.439
Sex	13.726	1	**<0.001**	0.037	1	0.847
Group * Sex	0.929	2	0.398	0.172	2	0.842

Impaction of the premolars. Cross-tabulation associating groups (normal anatomy, defective restoration, and proximal cavity group) and number of quadrants with premolar impaction

	Maxilla			Mandible		
Group	Impacted	No impaction	p	Impacted	No impaction	p
Normal anatomy	5	64		1	41	
Defective restoration	1	20	0.921	1	26	0.302
Proximal cavity	2	26		3	26	