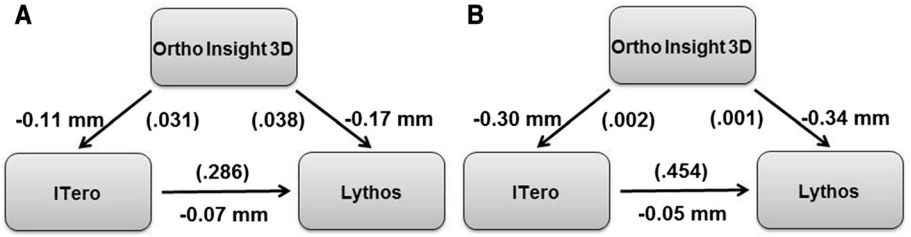


**Fig. 2** **a** Arch_length and **b** Canine_height comparisons among the scanners, with *arrows* pointing to the larger measure and probabilities in *parentheses*

ICCs ranging between 0.913 and 0.999 [24]. Considering that reliability coefficients above 0.75 have been considered to be excellent [25], the substantially higher ICCs obtained in the present study indicate excellent reproducibility.

While they were all reliable, Ortho Insight 3D produced larger random errors than the two intraoral scanners. Arch_length measured with Ortho Insight 3D showed the greatest method error, with differences between replicate measurements differing by ±0.48 mm 95 % of the time. In contrast, the same measurement made from the ITero scanner varied by ±0.17 mm 95 % of the time. Ortho Insight 3D produced larger random measurement errors than the intraoral scanners because the image resolution was not as sharp, making landmark identification more difficult (Fig. 3). The method errors for premolar diameter in the present study were similar to or smaller than the length estimates obtained from OrthoCAD™ (Cadent Inc, Fairview, NJ) [26]. Method errors for intercanine width were also smaller than previously reported for measurements taken from O3DM™ (OrtoLab, Czestochowa, Poland) [27] and 3Shape (D-250; 3Shape, Copenhagen, Denmark) [13] scans.

Measurements taken from the mandibles scanned with ITero and Lythos compared closely to the same measurements taken directly from the dry mandibles. Most of measurements were comparable, with average differences ranging between .002 and .066 mm. While the Lythos scans have not been previously evaluated, ITero scans have been previously shown to be highly accurate [17]. The results indicate that both scanners produce valid presentations of the mandible.

Two of the measurements taken from the Ortho Insight 3D scan reconstructions were slightly smaller than the corresponding measures taken on the dry mandibles. Comparing plaster models and emodels, Mullen and coworkers [28] also found significant differences, with arch lengths measured on plaster models being approximately 1.5 mm larger than arch lengths measure on emodels. Using an extraoral scanner (Optimet 3D scanner), Redlich and coworkers [29] also reported statistically significant differences in mandibular arch length measurements obtained from plaster and digital models. Another study comparing plaster models and emodels found significant differences in anterior mandibular arch perimeter (plaster model measurements were 0.40 mm larger), but no differences when perimeter included all of the teeth between the first mandibular molars [10]. Schirmer and Wiltsire [22] attributed the differences between digital and actual models to the difficulty of measuring a 3D object in two dimensions, i.e., on a computer monitor.

The results of this study were probably limited by the use of dry mandibles. Because measurements on dry mandibles can be more easily standardized, they

**Table 3** Systematic differences (mm) between the measures made directly on the dry mandibles and corresponding measures made on the 3D digital reconstructions for each of the three scanning protocols, with positive values indicating digital underestimation

| | Ortho Insight 3D | | ITero | | Lythos | |
|---|---|---|---|---|---|---|
| Variable | Difference (SD) | Sig | Difference (SD) | Sig | Difference (SD) | Sig |
| Molar_width | −0.067 (0.314) | 0.420 | −0.012 (0.090) | 0.613 | 0.016 (0.049) | 0.230 |
| Canine_width | −0.006 (0.164) | 0.887 | −0.035 (0.085) | 0.132 | −0.002 (0.045) | 0.864 |
| Arch_length | 0.159 (0.275) | *0.042* | 0.054 (0.219) | 0.357 | −0.012 (0.092) | 0.613 |
| Premolar_diameter | −0.064 (0.156) | 0.136 | −0.032 (0.077) | 0.134 | −0.005 (0.024) | 0.424 |
| Canine_height | 0.363 (0.331) | *0.001* | 0.066 (0.290) | 0.391 | 0.018 (0.058) | 0.252 |

Italic indicates statistically significant differences between replicates ($p < .05$)