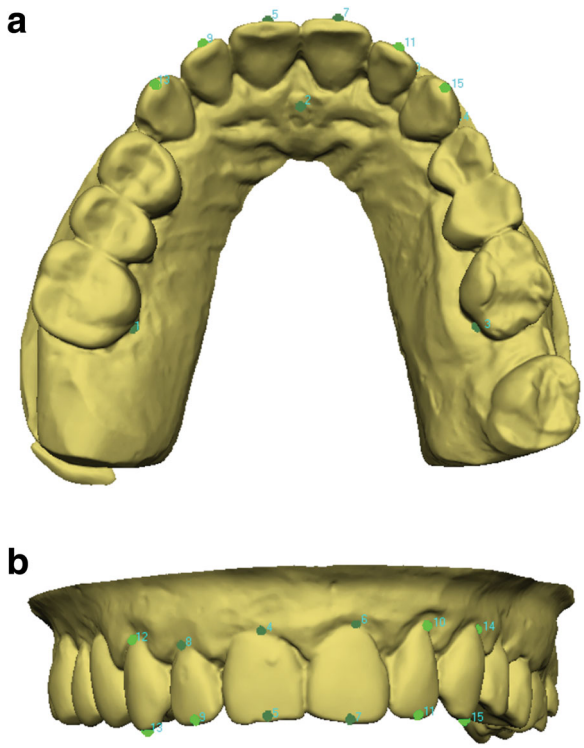

Fig. 1 Torque measurement using VAM software. Reference landmarks and points defining the labial FACC of the anterior teeth were localised on every digital model. **a** Occlusal view and **b** frontal view

according to this reference plane. Torque was measured as the labiolingual inclination of the FACCs relative to the reference plane [21]. The torque angles were then calculated using trigonometry.

Error of the method

Thirty dental arches were randomly selected using online software (https://www.randomizer.org/), and landmark selection and torque measurements were repeated by the same operator after 2 weeks. For all measurements, Dahlberg's formula ($s = \sqrt{(Sd \wedge 2)}/2n$, where d = difference between the first and second measurements) was used to calculate the standard error on the repeated sets of measurements. Bland–Altman plots were used to check for the intra-observer reliability between the two sets of measurements [22].

Statistical analysis

A Shapiro–Wilk normality test was used to analyse the type of data distribution for all the variables. A paired sample t test or a Wilcoxon signed-rank test was used to evaluate if any statistically significant difference was present between the predicted movements (TS) and the clinically achieved torque (T1). First-type error was set as 0.008 after applying Bonferroni correction for multiple testing. Descriptive statistics including mean and standard deviation were also computed for all the variables.

Results

Regarding the error of the method, the standard error was 1.2° for central incisor's torque, 1.3° for lateral incisor's torque, and 1.3° for canine's torque. Bland–Altman plots revealed no systematic errors, confirming the intra-observer reliability of the measurements (Figs. 2, 3, and 4).

Descriptive statistics are reported in Table 2. The mean predicted torque movement (predicted = TS−T0) was 2.3° ± 2.5 for left central incisor, 2.3° ± 2.4 for left lateral incisor, 2.6° ± 2.6 for left canine, 2.4° ± 2.4 for right central incisor, 3.1° ± 2.9 for right lateral incisor, and 2.8° ± 2.8 for right canine in the upper arch; in the lower arch, the mean predicted torque movement was 2.3° ± 1.7 for left central incisor, 3.1° ± 2.7 for left lateral incisor, 3.2° ± 3.1 for left canine, 1.7° ± 1.7 for right central incisor, 3.2° ± 3.6 for right lateral incisor, and 2.2° ± 4.0 for right canine. Increasing angular values means that the tooth's crown was moved labially, while decreasing values were measured when the crown moved lingually.

The paired sample t test and Wilcoxon signed-rank test revealed that no statistically significant difference was present between the torque measurements at TS and T1; therefore, the null hypothesis was accepted, confirming that the predicted movements were generally achieved (Table 3). The dataset containing all the collected measurements is attached as Additional file 1.

Discussion

The aim of the present study was to evaluate the predictability of the Nuvola® aligner system in performing torque movements on the anterior teeth, and the results showed that the movements predicted from the digital setup were generally achieved.

It was decided to include only adult patients in the study group because they represent most of the patients who require orthodontic treatment with invisible techniques, and because those patients generally show a better compliance, compared to adolescents [3, 23], thus reducing a possible source of bias. In addition, only patients with mild crowding were included because clear aligner treatment is not yet recommended for complex malocclusions [8].

Regarding overall treatment efficiency, some studies evaluated the outcomes of clear aligner treatment versus fixed appliance treatment using the discrepancy index of the American Board of Orthodontics or the Peer Assessment Rating (PAR) index [24]. Some authors showed that Invisalign® produced significantly lower scores than fixed appliances and was unable to correct buccolingual inclination, occlusal contacts, occlusal relationships, and overjet [25], while other