been developed since Align Technology's patent expired. These alternative aligner systems differ from Invisalign in terms of construction material [10], production process, margin finishing and STL model precision, but perhaps the most influential difference is the professionals charged with executing treatment planning and setup (IT specialists, dental technicians or professional orthodontists) [11].

As regards treatment outcomes, Align Technology reports that roughly 20–30% of Invisalign patients require mid-course correction or post-alignment finishing in order to achieve the results prescribed on the setup [12]. This figure, however, contrasts with that reported by orthodontists, who indicate that the number of patients who require some unplanned correction or even recourse to fixed orthodontics, is closer to 70–80% [1, 13].

In fact, Kravitz [14] reported that Invisalign aligners had a mean accuracy of 41% in terms of achieving planned outcomes, with the most predictable movement being lingual contraction (47.1%), and the least predictable, extrusion (29.6%). In a systematic review of the literature, Rossini and Castroflorio confirmed that the most problematic movement for Invisalign was extrusion, followed by rotation [15].

However, these authors also emphasised the paucity of reliable literature on the subject, and the aim of this study was therefore to compare planned and achieved tipping and rotation in patients using F22 aligners (Sweden & Martina, Due Carrare, Italy) in order to provide data on their effective clinical predictability.

Methods

Sample selection

Sixteen adult Caucasian patients (6 males and 10 females, of mean age 28 years and 7 months) treated by means of F22 aligners at the University of Ferrara Postgraduate School of Orthodontics Clinic were retrospectively selected. Inclusion and exclusion criteria are reported in Table 1. Treatment staging, i.e. the maximum movement planned for each aligner, had been 2° rotation, 2.5° vestibulolingual and mesiodistal tip, and 0.2-mm linear displacement. No auxiliaries of any kind had been used (intermaxillary elastics, buttons, chains), although the use of F22 system Grip Points (attachments) and anterior and/or posterior stripping was allowed. Patients were instructed to wear their aligners for 22 h per day, excepting mealtimes and oral hygiene procedures. Aligners were replaced every 14 days.

Pre-treatment, ideal post-treatment (according to setup) and real post-treatment digital models of the upper and lower jaws of each patient were analysed. Pre-treatment and post-treatment models were acquired using a Trios intraoral scanner (3Shape, Copenhagen, Denmark), and setups were constructed using Orthoanalyzer software (3Shape, Copenhagen, Denmark).

Measurement of digital models

Digital models pertaining to each patient were analysed in .stl format by a single operator using VAM software (Vectra, Canfield Scientific, Fairfield, NJ, USA). This enabled the identification of anatomical reference points, planes and axes on the digital models, required, in turn, for calculation of the angulation, inclination and vestibular prominence of each tooth, as well as linear and angular measurements, for example, the intra-arch diameters [16]. Measurement was based on a method originally involving the identification of a total of 60 reference points per model (excluding second molars). However, in this case, we also included the second molars in the digital measurements, thereby expanding the number of reference points to 100 per model (Fig. 1).

Once the 100 reference points had been marked, their three-dimensional coordinates were extrapolated and exported, first into a .txt file, and then onto a dedicated spreadsheet provided with the software. This spreadsheet enabled extrapolation of the mesiodistal and vestibulolingual tip and rotation (Figs. 2, 3, and 4) of each tooth with respect to a 3D Cartesian grid based on the occlusal reference plane, which was obtained by means of the following points: (Fig. 5):

- Reference points at the mediovestibular cusps of teeth 16 in the maxilla and 46 in the mandible
- Reference points at the mediovestibular cusps of teeth 26 in the maxilla and 36 in the mandible
- The centroid of all occlusal points of the FACC (the facial axis of the clinical crown) of teeth 15, 14, 12, 11, 21, 22, 24 and 25 in the maxilla and 35, 34, 32, 31, 41, 42, 44 and 45 in the mandible; canines were excluded from this calculation as their occlusal

Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• Adult subjects > 18 years with permanent dentition • Complete dentition, or with 4 missing teeth at the most (third molars excluded) • No supernumerary teeth • No tooth shape anomalies • No dental rotation > 35° • No diastems > 5 mm • Crowding < 5 mm per arch	• Systemic pathologies • Ongoing pharmacological treatment able to influence orthodontic movement (e.g. prostaglandin inhibitors, biphosphonates) • Active periodontal disease • Treatments requiring extraction space closure