Table 4 Differences between T2 (end of therapy) and T1 (begin of therapy) in the two subgroups. Between-groups differences

	Subgroup 1 T2–T1	Subgroup 2 T2–T1	*p* value
SNA (degrees)	−0.9 ± 1.6	−0.8 ± 2.5	0.88
SNB (degrees)	1.3 ± 1.7	0.8 ± 1.7	0.36
ANB (degrees)	−2.3 ± 1.1	−1.6 ± 2	0.18
SN-GoMe (degrees)	−1 ± 2.5	0.5 ± 2.2	0.05
A/Olp (mm)	−0.8 ± 2.2	0.1 ± 1.8	0.17
Pg/Olp (mm)	2.3 ± 3.3	1 ± 1.9	0.13
AD1 (mm)	1.1 ± 3.5	0.9 ± 1.9	0.74
AD2 (mm)	2.4 ± 1	0.9 ± 1.4	0.00*
AD-PtV (mm)	1.7 ± 1.4	0.9 ± 1.4	0.07
OA (mm)	1.7 ± 1.2	0.9 ± 0.6	0.01*
LA (mm)	1.65 ± 3.6	1 ± 2.2	0.49

*$p < 0.05$

Furthermore, it appears that, in addition to mandibular growth, there is a slight increase in anterior mandibular rotation in subgroup 1 treated with the Herbst appliance and skeletal anchorage.

The oropharyngeal and laryngopharyngeal airways, in the subgroup 1, showed an increase in size in the sagittal direction that could be related to orthopedic changes caused by the Herbst appliance and in part to the forward shift of the jaw. The subgroup 1 showed a higher increase of OA, at the end of the therapy, which is probably related to the skeletal anchorage, which maintains the lower incisor anteroposterior position and facilitates a forward displacement of the lower jaw.

Indeed, it has been observed that the air volume is directly related to the position of the jaw, as discussed by Kikuchi [21]. Therefore, orthodontic treatment of class II with correction of the position of the mandible could be particularly beneficial for those patients with respiratory problems, such as prevention of obstructive sleep apnea syndrome [22].

By analyzing the airway, it was found that there is a slight greater increase in parameter AD2 and for the sum of upper airways parameters in subgroup 1. This could be related to the slight greater palatal expansion that was performed in subgroup 1 in comparison to subgroup 2. Moreover, the increase of nasopharyngeal dimension after rapid palatal expansion, observed in the present study, is similar to the findings of [9].

The forward displacement of the jaw, particularly after surgical procedures, has been highlighted in the literature for improving the upper airways [5]. However, few studies have analyzed the effects of the Herbst appliance on airways, and, to our knowledge, no study to date has analyzed the airways of patients treated with the Herbst appliance with skeletal anchorage. Battagel et al. analyzed the pharyngeal space of patients with obstructive sleep apnea syndrome at rest and in maximum comfortable protrusion, and found some airway improvements related to mandibular protrusion [7].

Iwasaki et al, using measurements from three-dimensional cone-beam computed tomography images of the pharyngeal airway, observed that Herbst appliance increases both the oropharyngeal and the laryngopharyngeal dimensions with similar results [23]. Furthermore, also in a recent study of Koay et al. it was found, from lateral cephalograms, that the Herbst appliance increased the oropharyngeal and hypopharyngeal airway dimensions among patients with class II malocclusion [24].

An ideal study design to evaluate airway dimension after orthodontic treatment would also include a control group of untreated patients in order to observe purely growth changes. However, lateral cephalogram of patients without any orthodontic treatment were not available for this study and could not be taken for ethical reasons.

Mislik et al. measured the pharyngeal space and the physiological modifications based on a large sample size of lateral cephalograms of untreated patients and stated that the airway measurements are being established in early childhood; only a slight continuous increase of about 1 mm was detected between 6 and 17 years of age [25].

So, we can hypothesize that the changes in airway dimension related purely to growth, in our study, were limited due to the short treatment time.

Furthermore, a limitation of the current study, in addition to the small number of patients, is the cephalometric analysis of lateral cephalogram method, which only allows a two-dimensional evaluation of the airway and cannot be used to determine the thickness and volume of the pharyngeal airway space [26, 27]. Currently, the cone-bean computed tomography (CBCT) method provides an accurate three-dimensional analysis of the airways, and on the other hand, CBCT cannot be performed in all patients for legal and ethical reasons, while lateral cephalogram is a legal and ethical accepted method utilized routinely in all orthodontic patients. Moreover, Kaur et al. have observed that the cephalometric analysis of the lateral cephalogram is a reliable and reproducible method for evaluating the pharyngeal space [2].

In the present study, lateral cephalogram was taken fixing the hyoid in a consistent position in order to obtain a reliable analysis for each patient [18].

Therefore, further studies evaluating a larger number of patients and, possibly, the three-dimensional evaluation of the airways using CBCT, where legally and ethically acceptable, could be useful to assess more precisely the possible correlations between orthodontic treatments and airway space.