

A longitudinal comparison of body height growth of orthodontically treated Class I and Class III adolescents compared with the general population

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Introduction: The aim of this study was to evaluate the height growth of Class I and III orthodontic patients according to the Fishman skeletal maturation index (SMI) and to compare it with that of a general population.

Methods: The study sample included 81 Class I and 71 Class III adolescents who had height measurements and hand-wrist radiographs taken annually and categorized according to SMI. Height completion rate, residual height, height increase per sequential SMI stage, and height velocity were analyzed. Sex differences were evaluated and comparisons between Class I and Class III groups were made. In addition, the height of orthodontic patients was indirectly compared with that of the general population. **Results:** In boys and girls, height completion rate was >90% at SMI 6, residual height was fewer than 10 cm at SMI 7, and height increase per sequential SMI stage was greatest from SMI 6 to SMI 7. Height velocity was greatest from SMI 5 to SMI 6 in boys and from SMI 4 to SMI 5 in girls. **Conclusions:** There was no significant difference in body height parameters for all SMI stages between Class I and Class III adolescents. Adolescents who had orthodontic treatment were not shorter in stature at growth completion compared with the general population. (*Am J Orthod Dentofacial Orthop* 2019;156:383-90)

Growth changes are important when providing orthodontic treatment for adolescent patients because dentofacial orthopedic treatment of children involves maximizing the benefits of growth when modifying unbalanced growth tendencies between the maxilla and mandible. Orthodontic treatment in adolescents generally takes place close to the growth spurt, and it is not uncommon to encounter orthodontic patients experiencing significant pain and difficulty in eating foods, which would be a concern for parents of growing children.¹⁻³ Even in the

literature, there have been reports of altered dietary intake in patients having orthodontic treatment during critical stages of growth.^{4,5} Growth patterns and potentials are observed periodically throughout growth completion, even more so in skeletal Class III patients with excessive mandibular growth, and maintenance of early orthodontic treatment results is highly unpredictable.⁶⁻⁹

A widely used parameter for evaluation of growth that can be easily acquired in any clinical setting is body height measurement. Body height has been favored as a reflection of general skeletal maturation when discussing the timing of mandibular growth.¹⁰ However, several longitudinal studies have studied the relationship between body height and craniofacial dimensions, with controversial results.¹¹⁻¹⁴ Therefore, it is debatable whether height change may be used as an indirect indicator in recognizing the craniofacial growth stage of a child when deciding orthodontic treatment timing.

There are varying views of skeletal Class III adolescents exhibiting similar or different growth patterns and pubertal growth spurts compared with skeletal Class I adolescents.^{7,10,15-17} However, most growth studies

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Table I. Age (years) of boys and girls according to Fishman skeletal maturation stage in the Class I and III groups

SMI	Class I (age in years)					Class III (age in years)					Boys	Girls
	B (n=41)		G (n=40)		B vs G	B (n=28)		G (n=43)		B vs G	Class I vs III	Class I vs III
	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	P	P	P
1	10.6	0.94	8.5	0.96	*	10.2	0.84	8.0	0.59	*	0.093	0.162
2	11.2	0.88	8.9	0.99	*	10.8	0.88	8.6	0.58	*	0.232	0.457
3	11.9	0.89	9.6	1.01	*	11.6	0.94	9.3	0.57	*	0.444	0.534
4	12.5	0.90	10.2	1.06	*	12.2	0.93	10.0	0.60	*	0.394	0.638
5	12.9	0.83	10.7	1.09	*	12.8	0.9	10.4	0.68	*	0.693	0.312
6	13.4	0.83	11.1	1.13	*	13.2	0.96	10.9	0.72	*	0.535	0.382
7	14.0	0.87	11.9	1.03	*	14.0	0.93	11.7	0.85	*	0.799	0.409
8	14.7	0.93	12.8	1.05	*	14.3	0.91	12.6	0.92	*	0.229	0.470
9	15.2	0.89	13.3	1.12	*	15.2	1.00	13.2	0.94	*	0.911	0.590
10	15.6	0.89	13.7	1.14	*	15.6	1.08	13.6	0.91	*	0.826	0.608
11	18.6	0.83	17.1	1.15	*	18.1	0.90	17.0	0.94	*	0.107	0.787

SMI, skeletal maturation index; B, boys; G, girls.

*P<0.001.

Table II. Body height (cm) of boys and girls according to Fishman skeletal maturation stage in the Class I and III groups

SMI	Class I (height in cm)					Class III (height in cm)					Boys	Girls
	B (n=41)		G (n=40)		B vs G	B (n=28)		G (n=43)		B vs G	Class I vs III	Class I vs III
	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	P	P	P
1	140.8	5.90	128.9	4.35	*	140.4	5.71	128.6	4.50	*	0.955	0.473
2	143.8	5.91	132.3	4.76	*	144.5	5.40	132.8	4.50	*	0.711	0.951
3	147.8	5.64	136.1	4.89	*	149.5	5.83	136.1	4.69	*	0.278	0.902
4	152.3	6.14	140.4	5.23	*	153.9	6.46	140.6	5.06	*	0.239	0.681
5	156.4	5.22	143.9	5.65	*	158.6	6.13	143.7	5.00	*	0.101	0.860
6	160.5	5.69	146.6	4.95	*	162.2	6.36	146.6	4.90	*	0.217	0.926
7	165.7	5.59	153.0	4.77	*	167.9	6.07	152.9	5.63	*	0.094	0.884
8	169.0	5.53	157.7	5.03	*	171.0	6.34	157.5	5.90	*	0.070	0.833
9	170.8	5.32	159.4	5.18	*	172.7	6.10	159.4	5.75	*	0.164	0.916
10	171.6	5.16	160.1	5.07	*	173.5	6.24	160.2	5.68	*	0.200	0.884
11	174.4	5.60	162.7	5.07	*	176.0	5.82	162.9	5.43	*	0.232	0.888

SMI, skeletal maturation index; B, boys; G, girls.

*P<0.001.

have used chronological age, which does not include individual variations. Evaluating body height according to skeletal maturation with the use of the 11 Fishman stages of skeletal maturation and a hand-wrist radiograph would better illustrate the growth patterns of each adolescent.¹⁸

Therefore, the aim of the present longitudinal study was to evaluate and compare the height growth of skeletal Class I and Class III orthodontic patients according to the Fishman skeletal maturation index (SMI). In addition, the height growth of orthodontic patients were indirectly compared with that of the general population, which would be useful information for parents and clinicians regarding overall skeletal growth when a child is in need of orthodontic treatment.

MATERIAL AND METHODS

This retrospective study reviewed dental records of adolescent subjects that had visited Gangnam Severance Dental Hospital for orthodontic treatment and had consented to annual hand-wrist radiographs by enrolling in the growth and development longitudinal study. Subjects were considered for inclusion if they were categorized as skeletal Class I ($0^\circ < ANB < 4^\circ$) or skeletal Class III ($ANB < 0^\circ$) from the initial cephalometric radiograph and had hand-wrist radiographs as well as height measurements taken at least once every year from initial visit to growth completion. The average age range was ~7-9 years for girls and ~9-11 years for boys when the initial cephalometric and hand-wrist radiographs

Table III. Height completion rate (%) of boys and girls according to Fishman skeletal maturation stage in the Class I and III groups

SMI	Class I (height completion rate, %)					Class III (height completion rate, %)					Boys		Girls	
	B (n=41)		G (n=40)		B vs G	B (n=28)		G (n=43)		B vs G	Class I vs III	Class I vs III		
	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	P	P	P		
1	80.7	2.22	79.6	1.94		79.9	2.29	79.1	2.04		0.480	0.612		
2	82.5	2.19	81.3	2.14		82.2	1.88	81.3	1.62		0.744	0.962		
3	84.8	2.16	83.7	2.18		84.9	2.21	83.7	1.45		0.959	0.990		
4	87.4	2.40	86.3	2.21		87.5	2.24	86.5	1.64		0.978	0.815		
5	89.7	1.99	88.4	2.31		90.1	1.85	88.3	1.66		0.688	0.839		
6	92.0	1.80	90.0	2.10	*	92.2	1.93	90.0	1.62	*	0.732	0.973		
7	94.9	1.20	94.0	1.24		95.4	1.11	93.9	1.72		0.663	0.856		
8	96.8	0.80	96.9	0.84		97.4	1.06	96.7	1.00		0.585	0.809		
9	97.9	0.69	97.9	0.82		98.1	0.76	97.9	0.85		0.831	0.982		
10	98.5	0.54	98.4	0.67		98.6	0.80	98.3	0.67		0.897	0.973		
11	100.0	0.00	100.0	0.00		100.0	0.00	100.0	0.00		>0.999	>0.999		

SMI, skeletal maturation index; B, boys; G, girls.
*P<0.05.

Table IV. Residual height (cm) of boys and girls according to Fishman skeletal maturation stage in the Class I and III groups

SMI	Class I (residual height in cm)					Class III (residual height in cm)					Boys		Girls	
	B (n=41)		G (n=40)		B vs G	B (n=28)		G (n=43)		B vs G	Class I vs III	Class I vs III		
	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	P	P	P		
1	33.8	3.99	33.0	3.47		35.4	4.54	34.1	3.77		0.194	0.408		
2	30.6	3.90	30.4	3.77		31.4	3.74	30.6	2.97		0.432	0.866		
3	26.5	3.92	26.6	3.79		26.6	4.21	26.6	2.60		0.883	0.981		
4	21.9	4.29	22.3	3.74		22.0	4.03	21.9	2.85		0.904	0.735		
5	18.0	3.68	18.8	3.78		17.4	3.32	19.1	2.91		0.612	0.743		
6	13.9	3.20	16.3	3.58	*	13.8	3.41	16.3	2.80	*	0.758	0.978		
7	8.8	2.11	9.7	2.10		8.1	1.93	10.0	2.83		0.541	0.780		
8	5.6	1.39	5.1	1.39		4.6	1.78	5.4	1.60		0.426	0.725		
9	3.7	1.23	3.5	1.34		3.3	1.32	3.4	1.38		0.766	0.987		
10	2.7	0.96	2.6	1.10		2.4	1.37	2.7	1.07		0.864	0.975		
11	0.0	0.00	0.0	0.00		0.0	0.00	0.0	0.00		>0.999	>0.999		

SMI, skeletal maturation index; B, boys; G, girls.
*P<0.05.

were taken (Table I). The average ANB values of the adolescents are as follows: Class I boys $2.84^\circ \pm 1.01^\circ$, Class I girls $3.03^\circ \pm 0.85^\circ$, Class III boys $-1.27^\circ \pm 1.14^\circ$, and Class III girls $-0.93^\circ \pm 1.56^\circ$. The mean durations of primary orthodontic treatment in the Class I and III groups were 1.2 years and 1.3 years, respectively. Primary orthodontic treatment included removable appliances with median screws or facemasks. The mean durations of fixed orthodontic treatment in the Class I and III groups were 1.8 years and 1.7 years, respectively. Subjects were excluded if any they had any medical history of developmental abnormalities, treatment for growth disorders, hand-wrist radiographs of poor

diagnostic quality, or incomplete or missing dental records for any time period during growth. This study was approved by the Institutional Review Board of Gangnam Severance Hospital (3-2017-0360).

According to a power analysis of a previous study,¹⁰ using the mean and standard deviation between the height of Class III and non-Class III groups at peak height velocity of 3 cm/y as the desired effect size, 28 subjects were needed per each group to achieve a power level of 80% with an α significance level of 0.05. A total of 69 boys and 83 girls were included in the final sample (Table I). All hand-wrist radiographs were taken on the same cephalostat (Planmeca Promax, Planmeca Inc.,

Table V. Height increase (cm) of boys and girls between sequential Fishman skeletal maturation stages in the Class I and III groups

SMI	Class I (height increase in cm)					Class III (height increase in cm)					Boy	Girl
	B (n=41)		G (n=40)		B vs G	B (n=28)		G (n=43)		B vs G	Class I vs III	Class I vs III
	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	P	P	P
1 to 2	3.4	1.57	3.2	1.09		3.5	1.88	3.4	1.65		0.860	0.488
2 to 3	4.1	1.90	3.8	1.42		4.6	2.27	3.9	1.38		0.270	0.877
3 to 4	4.6	2.57	4.3	1.86		4.7	1.96	4.4	1.87		0.755	0.738
4 to 5	4.7	2.53	4.0	2.06		4.7	2.32	3.8	1.06		0.987	0.622
5 to 6	4.2	2.37	3.7	1.51		3.6	2.54	3.6	1.38		0.198	0.944
6 to 7	5.1	2.34	6.6	2.37	**	5.7	2.56	6.2	1.95		0.173	0.328
7 to 8	3.3	1.20	4.7	1.99	*	3.5	1.76	4.8	2.27	*	0.630	0.707
8 to 9	1.9	0.97	1.7	0.83		1.3	1.29	2.1	1.01		0.197	0.373
9 to 10	0.9	0.94	1.2	0.72		0.9	0.92	1.2	0.66		0.865	0.922
10 to 11	2.7	0.96	2.6	1.10		2.4	1.37	2.7	1.07		0.541	0.874

SMI, skeletal maturation index; B, boys; G, girls.

* $P < 0.01$, ** $P < 0.001$.

Table VI. Height velocity (cm/y) of boys and girls between sequential Fishman skeletal maturation stages in the Class I and III groups

SMI	Class I (height velocity in cm/y)					Class III (height velocity in cm/y)					Boys	Girls
	B (n=41)		G (n=40)		B vs G	B (n=28)		G (n=43)		B vs G	Class I vs III	Class I vs III
	Mean	SD	Mean	SD	P	Mean	SD	Mean	SD	P	P	P
1 to 2	4.5	2.68	5.6	1.18	*	4.4	2.78	5.7	1.30	*	0.854	0.816
2 to 3	5.9	2.22	6.4	1.90		6.1	3.63	6.0	2.06		0.627	0.351
3 to 4	7.0	3.16	6.5	1.66		6.7	3.96	6.6	1.94		0.609	0.866
4 to 5	8.5	3.35	7.5	2.63		8.6	3.16	7.4	1.83	*	0.697	0.919
5 to 6	8.6	2.33	6.7	2.31	***	9.0	1.84	6.8	1.94	***	0.552	0.892
6 to 7	7.7	2.29	8.1	1.47		7.5	1.54	7.7	1.39		0.708	0.423
7 to 8	5.1	1.92	6.1	3.32	*	4.7	2.05	5.4	1.51		0.502	0.130
8 to 9	3.7	1.31	3.2	1.42		2.6	1.41	3.5	1.66		0.051	0.553
9 to 10	2.1	1.31	2.5	1.26		2.2	1.11	2.1	1.25		0.828	0.390
10 to 11	0.8	0.47	0.8	0.29		0.9	0.57	0.8	0.27		0.837	0.975

SMI, skeletal maturation index; B, boys; G, girls.

* $P < 0.05$; *** $P < 0.001$.

Helsinki, Finland) and height measurements were taken with a stadiometer (Jenix, Dongsan, Korea). The hand-wrist radiographs were reviewed twice with a 2-week interval by 1 clinician (K.H.K) with more than 20 years of experience in diagnosing skeletal growth stages. The intra-examiner correlation coefficient showed high reliability ($r = 0.95-0.97$). All subjects were categorized into the 11 stages of the Fishman SMI and height measurements for each stage were recorded (Table II).

Height completion rate (%) was assessed by the height at a certain SMI stage divided by the height at growth completion and multiplying this ratio by 100. Residual height (cm) was calculated by subtracting the height at a certain SMI stage from the height at growth completion. Height increase per sequential SMI stage

(cm) was evaluated and height velocity (cm/y) was assessed by dividing the increase in height by the period in years for each sequential SMI stage. All parameters were evaluated for sex differences and comparisons were made between Class I and III groups. The body height and height velocity of Class I and III groups were also indirectly compared with those of the general adolescent population reported in 2017 by the Korea Centers for Disease Control and Prevention.

All data were analyzed with the use of the SPSS software program, version 22.0 (SPSS, Chicago, Ill). Mean and standard deviations for height values were acquired and sex differences as well as comparisons between Class I and III groups were evaluated by means of independent t tests. Height values were indirectly compared with

Table VII. Height and height velocity of orthodontic patients and general population according to Fishman skeletal maturation stages in the Class I and III groups

SMI	Class I (mean height in cm)						Class III (mean height in cm)						Class I (mean height velocity in cm/y)						Class III (mean height velocity in cm/y)							
	Boys			Girls			Boys			Girls			Boys			Girls			Boys			Girls				
	Orthod	General	P	Orthod	General	P	Orthod	General	P	Orthod	General	P	Orthod	General	P	Orthod	General	P	Orthod	General	P	Orthod	General	P		
1	140.8	142.2	128.9	129.6	140.4	139.8	128.6	126.7	**	4.5	6.1	***	5.6	6.0	*	4.4	5.8	*	5.7	5.9		4.4	5.8	*	5.7	5.9
2	143.8	145.8	132.3	132.1	144.5	143.7	132.8	130.1	***	5.9	6.7	*	6.4	6.4		6.1	6.4		6.0	6.2		6.1	6.4		6.0	6.2
3	147.8	150.8	136.1	136.4	149.5	148.5	136.1	134.7		7.0	7.2		6.5	6.6		6.7	7.1		6.6	6.6		6.7	7.1		6.6	6.6
4	152.3	155.0	140.4	140.2	153.9	152.6	140.6	139.1		8.5	7.2	*	7.5	6.7		8.6	7.2	*	7.4	6.7	*	8.6	7.2	*	7.4	6.7
5	156.4	158.1	143.9	143.6	158.6	157.4	143.7	141.9	*	8.6	6.9	***	6.7	6.5		9.0	7.0	***	6.8	6.6		9.0	7.0	***	6.8	6.6
6	160.5	161.5	146.6	146.3	162.2	159.8	146.6	145.2		7.7	5.9	***	8.1	6.0	***	7.5	6.2	***	7.7	6.1	***	7.5	6.2	***	7.7	6.1
7	165.7	165.0	153.0	151.3	167.9	165.0	152.9	149.8	***	5.1	4.6		6.1	4.5	**	4.7	5.0	**	5.4	4.9	*	4.7	5.0	**	5.4	4.9
8	169.0	168.0	157.7	155.3	171.0	166.6	157.5	154.3	**	3.7	3.5		3.2	3.1		2.6	3.6	**	3.5	3.5		2.6	3.6	**	3.5	3.5
9	170.8	169.2	159.4	156.9	172.7	169.6	159.4	156.4	**	2.1	2.5		2.5	2.3		2.2	2.4		2.1	2.6	*	2.2	2.4		2.1	2.6
10	171.6	170.6	160.1	157.7	173.5	170.6	160.2	157.5	**	0.8	1.2	***	0.8	0.8		0.9	1.2	**	0.8	0.8		0.9	1.2	**	0.8	0.8
11	174.4	174.2	162.7	160.3	176.0	173.7	162.9	160.2	**																	

SMI, skeletal maturation index; Orth, orthodontic patients; Gen, general population.
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

those of the general adolescent population by means of the 1-sample *t* test. The level of significance was determined as $P < 0.05$.

RESULTS

The average age per SMI stage was not significantly different between Class I and III groups for both sexes (Table I). There was no significant difference in body height, height completion rate, residual height, height increase between sequential SMI stages, and height velocity between Class I and III adolescents for both sexes in all SMI stages (Tables II–VI).

In Class I boys, the average height was 140.8 cm at SMI 1, which increased to 174.4 cm at SMI 11. The average height of skeletal Class III boys was 140.4 cm at SMI 1, which increased to 176.0 cm at growth completion. Boys showed significantly greater height compared with girls during all SMI stages (Table II). The height completion rate in boys was close to 80% at SMI 1, which increased to above 90% at SMI 6, with about a 2% higher rate in boys compared with girls for both Class I and III groups (Table III). The residual heights in the Class I and III groups for boys at SMI stage 1 were 33.8 cm and 35.4 cm, respectively, which decreased to 8.8 cm and 8.1 cm by SMI stage 7 (Table IV). The height increase per sequential SMI stage in boys was greatest, >5 cm, from SMI stages 6 to 7, and it was the smallest, ~1 cm, from SMI stages 9 to 10 for both Class I and III groups (Table V). Height velocity in boys was greatest from SMI stages 5 to 6, with a value close to 9 cm/y for both Class I and III groups. In both Class I and III groups, boys showed greater height velocity than girls from SMI stages 5 to 6 (Table VI).

In Class I girls, the average height was 128.9 cm at SMI 1, which increased to 162.7 cm at SMI 11. The average height of skeletal Class III girls was 128.6 cm at SMI 1, which increased to 162.9 cm at growth completion (Table II). The height completion rate in girls was close to 80% at SMI 1, which increased to 90% at SMI 6 (Table III). The residual height at SMI stage 1 was 33.0 cm and 34.1 cm for girls in the Class I and III groups, respectively. At SMI stage 6, the residual height in girls was 16.3 cm, which was significantly greater than that of boys by about 2.5 cm. At SMI stage 7, there was <10 cm of growth remaining in both Class I and III girls (Table IV). The height increase per sequential SMI stage in girls was greatest, >6 cm, from SMI stages 6 to 7 and smallest, ~1 cm, from SMI stages 9 to 10 in both Class I and III groups (Table V). In girls, height velocity was greatest from SMI stages 4 to 5, ~7.5 cm/y. In both Class I and

III groups, girls had greater height velocity than boys from SMI stages 1 to 2 (Table VI).

Height values of adolescents included in this study and the general population were matched by average age according to each SMI stage. All Class III adolescents and Class I girls who had received orthodontic treatment showed greater body height from SMI 7 to growth completion compared with the general population (Table VII). The height velocity of boys who had received orthodontic treatment was greater than that of the general population from SMI stages 4 to 7. The same tendency was observed from SMI stages 6 to 8 for girls. The height growth characteristics of orthodontically treated Class I and III adolescents and that of the general population according to SMI stages are illustrated in Figure.

DISCUSSION

When an adolescent is diagnosed with skeletal malocclusion, facial growth is carefully monitored for optimal treatment timing. Dentofacial orthopedic treatment is generally started close to the growth spurt to maximize the benefits of growth. However, adolescents receiving orthodontic treatment experience pain due to rather uncomfortable intraoral appliances, which is reported to affect their dietary intake.^{4,5} This may be a concern for parents in terms of overall skeletal growth. Previous reports have studied growth patterns of the dentofacial region and its relation to general skeletal growth with varying results.^{12,14,19,20} Body height has been used in studies as a representation of overall skeletal growth owing to its close relationship to facial growth and its simplicity in a clinical setting.^{13,21,22} Although it is debatable as to whether body height growth patterns may be used as a practical method to estimate the dentofacial growth stages of an adolescent, it is meaningful to compare stature growth in Class I and III adolescents as well as the general population to help clarify whether orthodontically treated Class I and III children showed differences in general skeletal growth patterns.

Girls were younger than boys in every SMI stage. The average age per each SMI stage was greater by ~2 years in boys compared with girls, and this difference decreased to ~1 year at SMI 11 for both Class I and III groups (Table I). According to a study by Hägg and Tanager,²³ girls were ~2.4 years ahead in age compared with boys during the pubertal growth period, and the age difference gradually decreased to ~1.3 years at growth completion, which was mostly due to advanced growth stages in girls before puberty although in boys acceleration occurred after puberty. A previous study

also supported this finding in that once boys reach puberty, an increase in testosterone enhanced bone maturity.^{24,25}

During SMI stages 4-6, boys had a height velocity of >8.5 cm/y, which was significantly greater by ~1-2.2 cm/y than that of girls. This coincides with a steeper increase in growth rates during puberty that contributes to greater stature in boys until growth completion.²⁶ It is interesting to note that the time period between SMI stages 7-11 was longer in girls by ~1 year and height increase was greater by ~1-2 cm in girls compared with boys during this time in both Class I and III groups. However, greater height increase of girls during the postpubertal period was not enough to exceed the height of boys. Consequently, boys were taller than girls at every SMI stage, starting with a difference of ~11 cm at SMI 1 which increased to ~11.7 cm in the Class I group and 13.1 cm in the Class III group at growth completion (Tables II and VI).

There have been controversial reports of Class III adolescents having longer pubertal growth spurts compared with those with normal skeletal relationships, which may contribute to a larger mandibular size.^{7,10,17,27,28} However, the present study showed similar pubertal growth periods between the Class I and III groups; the time period between SMI stages 4-7 was ~1.5-1.8 years for boys and 1.7 years for girls in the Class I and III groups (Table I). The height velocity per each SMI stage also did not show significant difference between the Class I and III groups (Table VI). Accordingly, there was no significant difference in height between the Class I and III groups in all SMI stages for both boys and girls (Table II).

A small amount of difference in stature, if any, may be observed 1-2 years after fusion of the radius, which has been used as a time point for growth completion in many studies.^{23,29} Accordingly, this study calculated the height completion rate and the residual height by comparing the height value of each corresponding growth stage with that of SMI stage 11. In both Class I and III groups, both boys and girls had height completion rates of >90% at SMI stage 6. At this stage, boys had a 2% higher growth completion rate, which resulted in girls in both Class I and III groups having a greater amount of remaining growth, ~2.5 cm, compared with boys. Thereafter, when the adolescents reached SMI stage 7, there was <10 cm of growth remaining for both Class I and III groups without any significant sex difference. When comparing the Class I and III groups, there was no significant difference in the height completion rate or residual height values in all skeletal maturation stages for both genders (Tables III and IV).

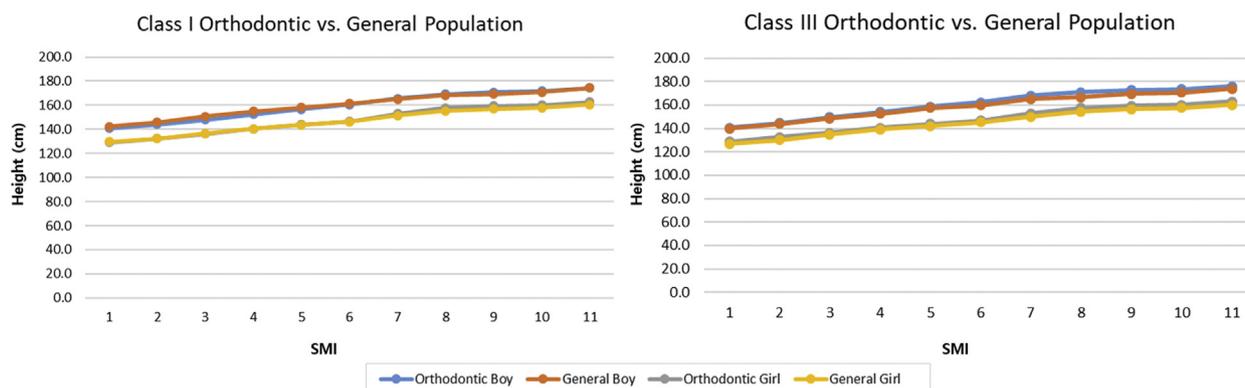


Fig. Height growth of orthodontically treated Class I and III adolescents and the general population. SMI, skeletal maturation index. Orthodontic Boy: body height of adolescent boys that had received orthodontic treatment; General Boy: body height of adolescent boys in the general population; Orthodontic Girl: body height of adolescent girls that had received orthodontic treatment; General Girl: body height of adolescent girls in the general population.

When considering the amount of height growth per sequential SMI stage increase, girls showed greater amount of height increase than boys during SMI stages 6–8 in the Class I group and the same tendency was observed in SMI stages 7–8 in the Class III group. However, this parameter did not consider the time period between each sequential SMI stage and does not adequately represent the velocity of growth. Nonetheless, it is noteworthy to recognize that the greatest amount of increase in body height, >5 cm, occurred from SMI stages 6 to 7 for both sexes in the Class I and III groups (Table V). Also, there was no significant difference in height growth per sequential SMI stage increase between Class I and III groups. In other words, Class III adolescents do not necessarily grow to a greater degree during pubertal growth periods compared with Class I adolescents.

In the Class I and III groups, boys showed significantly greater height velocity, 8.6 cm/y and 9.0 cm/y, respectively, from SMI stages 5 to 6 compared with girls. For Class I and III girls, the greatest height velocity was seen from SMI stages 6 to 7, with values of 8.1 cm/y and 7.7 cm/y, respectively. However, when comparing the Class I and III groups, there was no significant difference in velocity for all sequential SMI stages in boys as well as girls (Table VI). Again, the findings of this study are that Class III adolescents showed pubertal growth rates similar to those of Class I adolescents.

The longitudinal height values of this study were of adolescents who received orthodontic treatment, and the data were compared with that reported for the general population by the Korea Centers for Disease Control and Prevention. Contrary to the popular misconception that adolescents receiving orthodontic treatment during

puberty may have a reduced nutritional intake which might affect skeletal growth, boys who received orthodontic treatment showed greater height velocities from SMI stages 4 to 7 in the Class I and III groups compared with the general population. For Class I and III girls who had orthodontic treatment, greater growth velocities were seen from SMI stages 6 to 7 compared with the general population. Although boys with orthodontic treatment had shorter stature during SMI stages 2–5, height measurements of this group was not significantly different from that of the general population at growth completion. Class I girls as well as Class III boys and girls that had received orthodontic treatment showed even significantly greater heights from SMI stage 7 to growth completion compared with the general population (Table VII). Within the limitations of the indirect comparison made in this study, we thus found that orthodontic treatment does not negatively affect growth rates during puberty nor the body height at growth completion. Future studies allowing direct comparisons of body height growth of adolescents who have received orthodontic treatment and those who were periodically observed without any treatment would further support the findings of this study.

CONCLUSIONS

1. Boys were taller than girls at every SMI stage, with a difference of ~11 cm at SMI stage 1 which increased to ~11.7 cm in the Class I group and ~13.1 cm in the Class III group at growth completion.
2. There was no significant difference in body height, height completion rate, residual height, and height

velocity for all SMI stages between the Class I and III adolescents for both sexes.

3. Within the limitations of an indirect comparison made in this study, the pubertal height velocity from SMI stages 4 to 7, were greater in boys who had received orthodontic treatment compared with the general population, with a similar trend in girls. Class I and III adolescents who had orthodontic treatment were not shorter in stature at growth completion compared with the general population.

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