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ORIGINAL ARTICLE

Crown heights in the permanent teeth of 45,X and 45,X/46,XX females

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Abstract

Objective. Previous results regarding human sex chromosome aneuploidies have shown that the X and Y chromosomes affect tooth size and morphology. This study looked for the effect of sex chromosome deficiency on permanent tooth crown heights. ***Materials and methods.*** The material, from the Finnish KVANTTI Research Project, consisted of 97 45,X females and 15 45,X/46,XX females. The controls were 32 sisters and 28 mothers of the 45,X females, eight sisters and two mothers of the 45, X/46,XX females and 35 female population controls. Crown heights of all the available teeth except third molars on both sides of the jaws were measured from panoramic radiographs with a digital calliper according to the defined procedure. ***Results.*** The tooth crown heights were significantly smaller in the 45,X females than in the female population controls, except for the incisors and one canine in the maxilla, whereas the tooth crown heights of the 45,X/46,XX females were close to those of the normal control females. The differences between the 45,X and 45,X/46,XX females were statistically significant, excluding the upper incisor area and a few teeth in the mandible. ***Conclusions.*** The effect of the sex chromosome deficiency on permanent tooth crown height is due to the magnitude of lacking sex chromosome material. The present results regarding the 45,X females are parallel to previous findings in Turner patients regarding reduced mesiodistal and labiolingual dimensions and tooth crown heights in the permanent dentition.

Key Words: *sex chromosomes, tooth crown, tooth size, Turner syndrome, X chromosome*

Introduction

Human dental development begins at ~4 weeks *in utero* and both the deciduous and the permanent tooth crowns, apart from those of the third permanent molars, have reached their final size and shape between the ages of 2 months and 8 years. The formation of dental structures is a complex and delicate process guided by specific genetic programmes during which each tooth passes through a series of well-defined developmental stages [1,2]. After the formation of the cusp pattern during the bell stage, the tooth grows to its final size and mesenchymal odontoblasts and epithelial ameloblasts differentiate at the epithelial–mesenchymal interface to form dentin and enamel, respectively. Tooth crown development starts in a pre-determined order from the cusp tips and proceeds to the base of the crown, from which point the roots start to develop.

Previous results have shown that a deficiency in the normal sex chromosome constitution (46,XX in females and 46,XY in males) leads to marked changes in the craniofacial areas, including changes in tooth size, structure and morphology [3]. One example of sex chromosomal disorders characterized by the absence of all or part of the normal second sex chromosome is Turner syndrome, where the general physical findings often include growth deficiency, sexual infantilism and various somatic abnormalities [4]. Turner patients, especially 45,X females, have significantly retarded skeletal maturity, while dental maturity and tooth eruption are advanced [5–7]. There is also a marked reduction in the mesiodistal and labiolingual dimensions of the permanent and deciduous tooth crowns [5,8–14] and there have also been reports of decreased crown heights in the permanent incisors and canines in this syndrome [15]. Varrela et al. [11] found that the tooth crowns of 45,X and 45,X/46,XX females (a female with one X cell

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line and one normal XX line) were almost the same in the mesiodistal direction, while the 45,X/46,XX females had larger crowns in the labiolingual direction. The reduction in tooth crown size in the mesiodistal and labiolingual dimensions in Turner patients has been shown to be primarily caused by a thinner layer of enamel [16,17], although the crown dimensions may also be affected by the changed crown morphology [12,13,18,19]. Measurements performed on dental casts from individuals with various sex chromosome constitutions [3,19] and on the natural teeth of normal females and males [20] have demonstrated sexual dimorphism in average tooth crown sizes, the Y chromosome having been shown to increase both tooth crown enamel and dentin growth, whereas the effect of the X chromosome seems to be restricted to enamel formation [16,17,19–24].

The aim of the present work with a large group of patients of the 45,X karyotype was to obtain information on the effect of the sex chromosomes on total crown height in the various teeth making up the human dentition. The groups studied were the two most common karyotypes of Turner patients: 45,X females (~45% of all Turner patients) and 45,X/46,XX females (~13%) [4].

Materials and methods

All the participants with sex chromosome aneuploidy and their first-degree relatives were from the KVANTTI research project conducted by Professor Lassi Alvesalo. They were all of Finnish ancestry. The material consisted of 97 45,X females and 15 45,X/46,XX females (Table I). The population controls were 35 first-degree females other than relatives of the 45,X or 45,X/46,XX females, while the relative controls were 32 sisters and 28 mothers of the 45,X females and eight sisters and two mothers of the 45,X/46,XX females. The protocol for the research had been reviewed and approved by the Ethical Committee of the Faculty of Medicine at the University of Turku, Finland, which established that the patients and their relatives had received appropriate information on the research. The present groups of 45,X females, female relatives and 45,X/46,XX females were the same as in the earlier study performed by Pentinpuro et al. [25]. Some of the present females with a 45,X or 45,X/46,XX chromosome constitution had received therapy with oestrogen or growth hormone substitute after the age of 15, but taking into account the timing of deciduous and permanent tooth crown formation (from 2 months to 8 years) the possibility of any impact of this hormone therapy on tooth crown development can be ignored.

Measurements

The measurement procedures were as detailed in Lähdesmäki's [26] doctoral thesis. In the present research the orthopantomograms were taken following a standardized procedure and by one person at the Institute of Dentistry, University of Turku, with the same machine, an Orthopantomograph 3, Palomex Corporation, Helsinki, Finland. The radiograph was placed on a light table and observed in a dark room, using a magnifying lens (2×) to determine the outlines of the teeth. The outlines were marked with a special sharp pencil designed for use on plaster (Schwan All Stabilo 8008). The measurement was taken from the outer edges of the pencil traces on the radiograph. All the measurements were made in the same manner, with a sliding digital calliper (Mitutoyo, digimatic 500-123U, CD-15B, Andover, England) to an accuracy of 0.01 mm, and without any knowledge of the group to which the patient belonged. The tooth root lengths and cusp heights were measured at the same time (Figure 1), the tooth root length results for the 45,X and 45,X/46,XX females having been reported earlier [25,27]. The cusp heights of the upper molars were determined from the highest mesial cusp, those of the lower molars from the highest distal cusp and those of the premolars from the highest cusp seen in the orthopantomogram (OPTG). In the canines and incisors the measurements were taken from the highest point of the incisor edge or the

Table I. Age distributions in the patient and control groups.

Study group	Mean age (years)	SD	Age range (years)	Median	*n*
45,X females	18.9	7.4	6.2–46.4	18.4	97
45,X/46,XX females	23.4	8.4	7.1–41.0	20.8	15
Population control females	34.4	11.4	9.7–59.1	35.5	35
45,X females with a female relative	17.1	6.3	6.2–37.8	17.0	60
Sisters of the 45,X females	21.0	7.2	10.9–39.6	19.2	32
Mothers of the 45,X females	36.9	8.6	23.7–53.6	35.1	28
45,X/46,XX females with a female relative	20.1	6.4	7.1–28.6	19.5	10
Sisters of the 45,X/46,XX females	21.2	5.9	15.1–30.5	20.0	8
Mothers of the 45,X/46,XX females	33.6	5.3	29.9–37.4	33.6	2

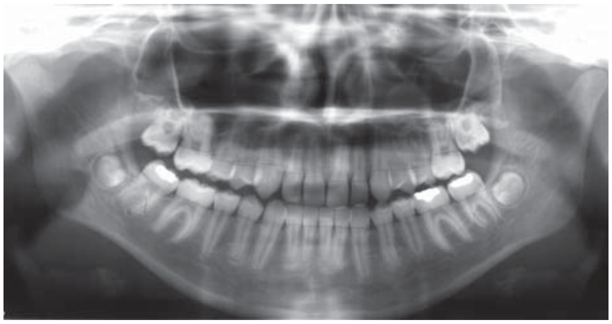

Figure 1. The dentition of a 45,X female at the age of 12 years. The markings for measurement purposes were made on the orthopantomograms.

middle of the incisor edge with rotated teeth. The crown height was the perpendicular distance between two parallel lines, one tangential to the outer edge of the cusp or incisor edge and the other running between the mesial and distal cemento-enamel junctions, as shown in Figure 2. All the applicable permanent teeth, except for third molars, were measured. There was no evidence of extensive tooth wear on the orthopantomograms, although it was not possible to discern smaller amounts of wear from these records.

The measurements were made by Raija Lähdesmäki (RL) and Raija Pentinpuro (RP). In order to check the reliability of the measurements they performed double determinations of the tooth crown heights on a sample of 45 patients from the KVANTTI material (15 45,X females, 15 first-degree female relatives and 15 first-degree male relatives). In the second measurement the line joining the mesial and distal cemento-enamel junctions was erased and a new line drawn in its place, whereas the outlines of the tooth cusp tips and incisor edges as marked on the first occasion were retained. Estimates of both intra-examiner and inter-examiner accuracy were made to enable comparison of the tooth crown heights in the 45,X females and their first-degree relatives, as measured by RP, with the previous measurements for 45,X/46,XX females, their female relatives and population control females made by RL.

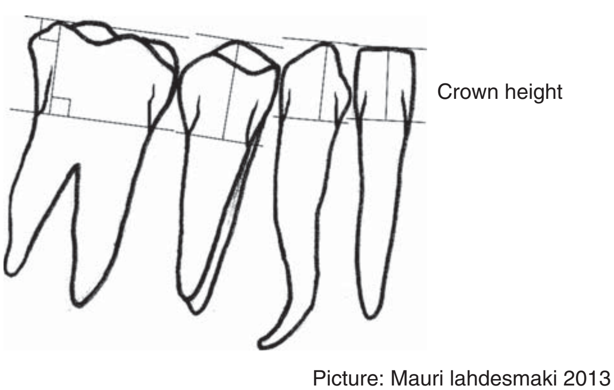

Figure 2. The permanent tooth crown height was taken here to be the perpendicular distance between two parallel lines, one tangential to the outer edge of the cusp or incisor edge and the other running between the mesial and distal cemento-enamel junctions.

Statistical methods

The SPSS program (version 20.0, SPSS, Inc., Chicago, IL) and SAS Enterprise Guide 4.3 were used in the statistical analyses. Results were considered statistically significant at $p < 0.05$. In order to check the reliability of the measurements, coefficients of intra-class correlation (ICC) for the double determinations and the average of the differences in tooth crown heights between the second measurements performed by RP and RL were calculated. A further statistical evaluation of intra-examiner accuracy was performed by comparing the two measurements made by RL or RP using the paired samples *t*-test. Statistically significant differences between these double determinations were found only in four incisors in the mandible in the measurements performed by RL. The comparison between the second measurements made by RL and RP was performed by the Bland-Altman method [28]. The standard deviation of the differences between the double determinations was calculated and 95% of the differences were expected to lie within the limits of ±2 SD. Scatter plot graphics were used to determine the limits of agreement. According to these calculations the crown height measurements lay within the assumed limits.

Mean tooth crown heights were calculated and tested using ANOVA to compare the 45,X females with the population control females and with the 45,X/46,XX females and the paired samples *t*-test to compare these two Turner groups with their sisters and mothers. The relative reduction (RR) in crown height was determined for each tooth in the 45,X females using the formula RR = (PCH-TCH):PCH × 100% (where RR = relative reduction in a crown height, PCH = mean crown height in the population control females and TCH = mean crown height in the Turner females (here the 45,X females). The mean relative reduction was calculated from the RR values for each group of teeth. We assumed that tooth crown height would also be influenced by differential amounts of tooth wear, possibly associated with age. Consequently, the tooth crown heights in different age groups were studied with the *t*-test in the 45,X and 45,X/46,XX females and female population controls. Mean ages were calculated for these three groups and each group was divided into two age classes, those below the mean age for the group and those at or above the mean age.

The paired samples *t*-test was used to analyse the differences in tooth crown height between the right and left sides of the jaws in the 45,X group, the 45,X/46,XX group and the population controls in order to look for directional asymmetry (cases in which the two sides of the jaw are modified in different directions), so that the total count of significant differences between the patients and controls differs between the two sides. A value for the fluctuating asymmetry (FA), the deviation from perfect bilateral symmetry, in which the larger and smaller sides are determined at random [29], was obtained by dividing the absolute difference between the sides by the absolute mean sizes of the left and right teeth [30], FA = abs (R – L)/((R + L)/2), where R = measurements taken on the right sides and L = measurements taken on the left sides. The FA values were calculated for each subject by dividing the absolute crown height difference by the absolute mean crown height of the left and right sides separately. A mean FA was then calculated from the FA values for each tooth and the statistical evaluation was performed using ANOVA to compare FA in the 45,X females with that in the population controls and 45,X/46,XX females.

Results

When RP performed double determinations of tooth crown heights on a total of 45 dental radiograms she achieved coefficients of intra-class correlation (ICC) ranging from 0.500– 0.939 (see Appendix, Table AI), whereas the ICCs for RL had ranged from 0.657–

Table II. Mean permanent tooth crown heights (mm) in the population control, 45,X and 45,X/46,XX females.

	45,X females		Population control females			45,X/46,XX females		
Tooth	Mean (SD)	*n*	Mean (SD)	*n*	p^a	Mean (SD)	*n*	p^b
Maxillary								
Right second molar	8.8 (0.8)	65	10.0 (0.9)	22	0.000***	9.5 (0.7)	12	0.012**
First molar	9.0 (0.8)	80	10.3 (0.9)	19	0.000***	9.9 (0.8)	14	0.001***
Second premolar	8.3 (0.8)	76	10.2 (0.9)	19	0.000***	9.9 (0.9)	13	0.000***
First premolar	8.9 (1.1)	76	10.3 (1.1)	19	0.000***	10.5 (0.8)	12	0.000***
Canine	10.5 (1.1)	87	11.2 (1.1)	27	0.008**	11.4 (1.3)	13	0.023**
Lateral incisor	9.7 (1.1)	85	9.7 (1.0)	24	0.988	10.0 (0.8)	14	0.627
Central incisor	10.3 (0.8)	87	10.5 (1.1)	26	0.440	10.4 (0.9)	15	0.883
Left central incisor	10.2 (0.9)	86	10.5 (1.0)	26	0.291	10.2 (0.9)	14	0.990
Lateral incisor	9.7 (0.9)	87	9.4 (0.8)	23	0.283	9.5 (1.0)	15	0.574
Canine	10.7 (1.0)	87	11.0 (1.0)	24	0.312	11.3 (1.2)	14	0.079*
First premolar	9.0 (0.9)	78	10.9 (1.0)	18	0.000***	10.6 (0.9)	12	0.000***
Second premolar	8.3 (0.8)	72	10.0 (0.9)	18	0.000***	9.8 (0.9)	12	0.000***
First molar	8.8 (0.8)	76	10.4 (1.0)	20	0.000***	10.1 (0.9)	11	0.000***
Second molar	8.6 (0.8)	67	10.1 (0.8)	18	0.000***	9.5 (0.8)	13	0.001***
Mandibular								
Right second molar	9.0 (0.9)	68	9.9 (0.8)	16	0.001***	9.6 (0.7)	10	0.117
First molar	8.6 (0.7)	68	9.8 (0.9)	10	0.000***	9.7 (0.9)	9	0.000***
Second premolar	8.5 (0.7)	80	9.4 (1.1)	18	0.000***	9.2 (0.7)	11	0.018**
First premolar	8.8 (0.9)	84	9.9 (1.1)	29	0.000***	9.3 (1.0)	12	0.177
Canine	9.2 (1.0)	88	10.3 (1.2)	30	0.000***	10.1 (1.3)	13	0.018**
Lateral incisor	7.8 (0.8)	89	8.7 (1.0)	34	0.000***	8.6 (1.1)	14	0.010**
Central incisor	7.5 (0.8)	89	8.1 (0.8)	35	0.002**	8.0 (1.0)	15	0.085*
Left central incisor	7.4 (0.8)	90	8.0 (0.9)	34	0.001***	8.4 (0.8)	14	0.001***
Lateral incisor	7.6 (0.8)	90	8.4 (0.8)	35	0.000***	8.3 (0.7)	15	0.001***
Canine	9.0 (1.1)	87	10.1 (1.1)	32	0.000***	9.9 (1.0)	13	0.012**
First premolar	8.7 (0.8)	84	9.6 (0.9)	29	0.000***	9.3 (0.9)	13	0.064*
Second premolar	8.3 (0.6)	80	9.4 (0.8)	21	0.000***	8.9 (0.7)	12	0.013**
First molar	8.6 (0.7)	68	9.7 (0.8)	9	0.000***	9.5 (1.1)	9	0.003**
Second molar	8.9 (0.8)	63	9.7 (1.0)	16	0.005**	9.2 (0.9)	13	0.578

Results were not considered statistically significant, when $p \geq 0.05$. * = $p < 0.05$; ** = $p < 0.01$; *** = $p \leq 0.001$.
[a]45,X females vs population control females.
[b]45,X females vs 45,X/46,XX females.

0.899. ICC values for the second measurements of the double determinations performed by RP and RL ranged from 0.424–0.864 and average of the differences in tooth crown heights in these determinations was 0.49 mm (range from 0.02–0.86 mm) in the upper jaw and 0.26 mm (range from 0.01–0.73 mm) in the lower jaw. The largest difference between these measurements made by both RL and RP were in the first molar on the right in the upper jaw and the first incisor on the left in the lower jaw, whereas the smallest differences were in the second upper molar on the right and the second lower molar on the right.

Apart from two incisors in the maxilla, the crown heights of all the permanent teeth were smaller in the 45,X females than in the female population controls. The differences between these groups were statistically highly significant ($p < 0.001$), except for the incisors and one canine in the maxilla (Table II). The mean relative reduction in the 45,X females varied from 0.4% for the incisors to 17.4% for the premolars in the maxilla and between 8.7% (incisors) and 10.8% (canines) in the mandible. Almost all the tooth crown heights in the 45,X females were significantly smaller than those of their sisters (Table III), while the differences between the 45,X females and their mothers were not

Table III. Mean permanent tooth crown heights (mm) in the 45,X females, their sisters and their mothers.

	45,X females		Sisters			45,X females		Mothers		
Tooth	Mean (SD)	*n*	Mean (SD)	*n*	p^a	Mean (SD)	*n*	Mean (SD)	*n*	p^b
Maxilla										
Right second molar	8.6 (0.8)	19	10.0 (0.7)	19	0.000***	8.8 (0.4)	5	9.4 (0.8)	5	0.285
First molar	9.0 (0.9)	22	10.3 (0.7)	22	0.000***	9.1 (0.7)	12	10.1 (0.7)	12	0.008**
Second premolar	8.4 (0.7)	18	9.5 (0.7)	18	0.000***	8.8 (1.4)	3	9.9 (0.0)	3	0.321
First premolar	8.9 (0.9)	23	9.6 (0.7)	23	0.015*	9.0 (0.6)	4	10.4 (0.8)	4	0.058
Canine	10.5 (1.0)	28	11.0 (1.0)	28	0.066	10.9 (1.4)	10	10.8 (1.0)	10	0.743
Lateral incisor	9.8 (1.1)	27	10.2 (0.9)	27	0.151	10.5 (1.2)	10	9.9 (0.9)	10	0.330
Central incisor	10.3 (0.7)	28	11.2 (0.8)	28	0.000***	10.5 (0.9)	15	10.1 (1.0)	15	0.289
Left central incisor	10.3 (1.0)	28	11.2 (0.9)	28	0.003**	10.3 (0.8)	14	10.3 (1.1)	14	0.881
Lateral incisor	9.8 (1.0)	27	10.1 (1.1)	27	0.307	10.3 (1.3)	10	10.1 (1.2)	10	0.794
Canine	10.7 (0.9)	24	11.2 (1.2)	24	0.161	11.0 (1.3)	8	10.6 (1.2)	8	0.517
First premolar	8.9 (0.8)	21	9.9 (1.0)	21	0.007**	9.2 (1.3)	8	9.6 (0.7)	8	0.563
Second premolar	8.3 (1.0)	12	9.2 (0.6)	12	0.005**	8.6 (0.5)	3	9.5 (0.3)	3	0.036*
First molar	8.9 (0.8)	17	10.3 (1.0)	17	0.000***	9.0 (1.0)	9	10.4 (0.8)	9	0.009**
Second molar	8.5 (0.9)	18	10.0 (0.9)	18	0.000***	9.2 (0.7)	4	9.7 (0.9)	4	0.539
Mandibular										
Right second molar	8.9 (1.0)	16	10.1 (0.5)	16	0.001***	9.1 (0.6)	5	9.8 (1.0)	5	0.204
First molar	8.7 (0.6)	15	9.6 (0.5)	15	0.002**	8.7 (0.9)	6	9.4 (0.7)	6	0.178
Second premolar	8.3 (0.7)	18	9.2 (0.5)	18	0.000***	9.0 (0.8)	13	8.5 (0.8)	13	0.072
First premolar	8.7 (0.8)	25	9.5 (0.8)	25	0.000***	9.3 (1.0)	15	9.0 (0.7)	15	0.360
Canine	9.1 (1.0)	29	9.9 (1.2)	29	0.002**	9.6 (0.8)	19	9.2 (1.3)	19	0.262
Lateral incisor	7.5 (0.8)	31	8.2 (0.7)	31	0.000***	8.1 (0.8)	23	7.5 (1.0)	23	0.055
Central incisor	7.2 (0.8)	31	7.7 (1.0)	31	0.014*	8.0 (0.9)	23	7.1 (1.3)	23	0.009**
Left central incisor	7.2 (0.7)	30	7.8 (0.9)	30	0.009**	7.8 (0.9)	25	6.7 (1.0)	25	0.001***
Lateral incisor	7.4 (0.7)	30	8.0 (0.9)	30	0.003**	7.9 (0.7)	23	7.2 (1.0)	23	0.020*
Canine	8.8 (1.0)	30	9.6 (1.1)	30	0.008**	9.7 (1.2)	18	8.6 (1.0)	18	0.003**
First premolar	8.7 (0.8)	27	9.3 (1.1)	27	0.048*	9.2 (1.0)	13	8.8 (0.8)	13	0.277
Second premolar	8.4 (0.6)	22	9.2 (0.6)	22	0.001***	8.3 (0.5)	5	9.0 (0.9)	5	0.112
First molar	8.6 (0.7)	15	10.0 (0.7)	15	0.000***	9.0 (1.0)	6	9.6 (0.5)	6	0.258
Second molar	9.1 (0.6)	15	10.0 (0.7)	15	0.003**	8.5 (0.4)	3	10.2 (1.1)	3	0.141

Results were not considered statistically significant, when $p \geq 0.05$. * = $p < 0.05$; ** = $p < 0.01$; *** = $p \leq 0.001$.
[a]The 45,X females vs their sisters.
[b]The 45,X females vs their mothers.

significant, apart from a few teeth in the maxilla or mandible. The differences between the sisters and mothers of the 45,X females were significant in two incisors in the maxilla and in the incisors, canines and one premolar in the mandible.

The average of the differences in tooth crown heights between the two sides of the jaw was statistically significant in the 1st maxillary molars, the lateral mandibular incisors and the 2nd premolars in the 45,X females (see Appendix, Table AII), whereas significant differences in the 45,X/46,XX females were noted in the lateral and central incisors in the maxilla and the central incisors in the mandible and those in the female population controls were found in the lateral incisors in the mandible. The only significant difference between the FA values for the 45,X females and the population controls was in the central incisors in the mandible, whereas there were no statistically significant differences between the FA values of the 45,X and 45,X/46,XX females (see Appendix, Table AIII).

The 45,X/46,XX females had significantly larger tooth crowns than the 45,X females, excluding the incisor area of the maxilla and a few teeth in the mandible (see Appendix, Figure A1). The tooth crown heights of the 45,X/46,XX females were close to those of the normal control females, but significantly smaller than those observed in their female relatives (sisters and mothers) in five teeth in the maxilla and six teeth in the mandible (Table IV).

Table IV. Mean permanent tooth crown heights (mm) in the 45,X/46,XX females and their female relatives (mothers and sisters).

	45,X/46,XX females		Female relatives		
Tooth	Mean (SD)	*n*	Mean (SD)	*n*	*p*
Maxillary					
Right second molar	9.6 (0.7)	8	10.4 (0.5)	8	0.049*
First molar	10.3 (0.7)	7	10.6 (0.9)	7	0.087
Second premolar	10.0 (1.0)	8	10.7 (1.1)	8	0.066
First premolar	10.4 (0.8)	7	10.8 (1.0)	7	0.473
Canine	11.5 (1.2)	8	11.4 (0.8)	8	0.805
Lateral incisor	9.9 (0.7)	9	9.7 (0.7)	9	0.401
Central incisor	10.3 (0.7)	10	10.7 (0.6)	10	0.102
Left central incisor	10.1 (0.8)	9	10.7 (0.5)	9	0.017*
Lateral incisor	9.4 (0.9)	10	9.9 (0.6)	10	0.064
Canine	11.2 (1.2)	9	11.4 (1.0)	9	0.426
First premolar	10.5 (0.9)	8	11.1 (1.2)	8	0.021*
Second premolar	10.0 (1.0)	7	10.3 (1.1)	7	0.311
First molar	10.4 (0.9)	7	11.1 (0.7)	7	0.008**
Second molar	9.8 (0.5)	6	10.9 (1.1)	6	0.024*
Mandibular					
Right second molar	9.7 (0.7)	6	10.7 (0.5)	6	0.004**
First molar	9.8 (0.8)	6	10.2 (0.6)	6	0.426
Second premolar	9.4 (0.8)	6	10.2 (0.7)	6	0.173
First premolar	9.5 (0.9)	8	10.1 (0.8)	8	0.272
Canine	10.3 (1.0)	9	10.8 (1.1)	9	0.323
Lateral incisor	8.7 (1.0)	9	9.3 (0.8)	9	0.084
Central incisor	7.8 (0.7)	8	8.5 (0.5)	8	0.033*
Left central incisor	8.3 (0.8)	8	8.5 (0.4)	8	0.372
Lateral incisor	8.3 (0.6)	9	8.9 (0.3)	9	0.011*
Canine	10.0 (0.8)	7	10.3 (0.4)	7	0.477
First premolar	8.9 (0.5)	6	9.7 (0.2)	6	0.017*
Second premolar	8.8 (0.5)	6	9.7 (0.4)	6	0.009**
First molar	9.3 (1.2)	6	9.9 (0.7)	6	0.147
Second molar	9.4 (1.1)	7	10.4 (1.1)	7	0.002**

Results were not considered statistically significant, when $p \geq 0.05$. * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

Discussion

Turner patients such as 45,X and 45,X/46,XX females have an increase in class II malocclusion, lateral crossbites and anterior open bite [31–33]. The most significant differences were found between the 45,X patients and the controls, the mosaic karyotypes showing the same pattern of malocclusion but with greater variation [33]. Subjects with a normal occlusion and class II malocclusions have different tooth wear patterns [34] and the same is also assumed to apply to lateral crossbites and anterior open bite. The possible effect of age on the tooth crown heights of the three groups studied here was assessed with the *t*-test and when the mean ages of the 45,X and 45,X/46,XX females and the population controls were calculated (see Appendix, Table AIV) and the subjects were grouped into those younger than the calculated mean age or equal to/older than the mean age. We found statistically significant age differences in crown heights in two teeth in the maxilla and eight teeth in the mandible in the 45,X females (see Appendix, Table AV), in only one tooth in the maxilla and three teeth in the mandible in the 45,X/46,XX females and in three teeth in the maxilla in the female controls. In all these statistically significant cases the older females had lower tooth crowns than the younger ones. The mean of the differences in tooth crown heights between the age groups ranged between 0.3 (the second incisor) and 0.8 mm (d. 33) in the 45,X females, between 1.1 (d. 33) and 1.2 mm (d. 44) in the 45,X/46,XX females and between 0.8 (d. 13) and 1.0 mm (d. 11) in the population controls.

To detect the percentage reduction in tooth crown height in a group relative to that for the younger females, the relative tooth crown reduction, RCR, was determined: $RCR = (MDC : MCY) \times 100\%$ (where RCR = relative tooth reduction, MDC = mean of the differences in crown heights between the younger and older age groups and MCY = mean crown height in the younger age group). Van't Spijker et al. [35] have observed previously that increasing levels of tooth wear are significantly associated with age, so that the predicted percentage of adults presenting with severe tooth wear increases from 3% at the age of 20 years to 17% at the age of 70 years. We observed that the percentage size reductions in tooth crown heights in the statistically significant cases were of the same magnitude as those indicated previously for a normal population. It was a complicated matter in the present research to compare the amount of wear between the groups, due to their varying occlusion status, but the population controls were considerably older than the 45,X or 45,X/46,XX females, so that we could assume that their tooth crowns had suffered greater wear. On the other hand, we found that the mean tooth crown heights of the controls, except for the incisors and one canine in the maxilla, were significantly greater than those of the 45,X females and that the number of tooth crowns that showed a significant reduction between the younger and older 45,X females was larger than in the other two groups, although the mean age in this group was the lowest of all.

The means of the differences in tooth crown heights between the two age groups were negative in the first molars of the mandible in the 45,X females (range from −0.13 to −0.21 mm), in the first upper premolar in the 45,X/46,XX females (0.12 mm) and in six teeth in the maxilla and six teeth in the mandible in the control females (range from −0.01 to −0.92 mm). These negative values show that the differences in tooth crown heights are not entirely due to wear, but are also influenced by the normal size variation in tooth crowns. It has been shown that subjects with malocclusions have different tooth wear patterns from those with a normal occlusion [34] and it is also possible that wear is not the same on both sides of the jaw, which will tend to alter the differences between crowns sizes on the two sides and, thereby, also the directional and fluctuating asymmetry caused by variations in growth. The differences between the age groups were largest in the 45,X/46,XX females, which could conceivably originate at least in part from the lacking chromosome material. The differences between the sisters and mothers of the 45,X females must be at least partially due to wear in the case of the mothers, and we can suppose that the differences in crown heights between the 45,X females and the controls might have been larger if we could have taken the greater wear on the tooth crowns of the older control females into account. It should be kept in mind that the rise in standard of living increases body height (a secular trend) and also tooth size. It is possible that this trend may be at least partly responsible for the fact that the decreased tooth crown heights in the 45,X females were generally closer to those in their mothers than those in their sisters.

Investigations based on individuals with various sex chromosome anomalies have shown that the effects of sex chromosomes on tooth growth are dependent on the magnitude of the sex chromosome material that is lacking or additionally present. Lähdesmäki and Alvesalo [27] reported significantly shorter tooth root lengths in 45,X/46,XX females than in normal females and Pentinpuro et al. [25] found that, apart from one tooth in the mandible, there were no significant differences in tooth root lengths between 45,X and 45,X/46,XX females. This latter finding differs from the present results as we now found significant differences in tooth crown height between the 45,X and 45,X/46,XX females, but not between the 45,X/46,XX and control females. Taken together, the previous reports and the present work demonstrate a direct effect of sex chromosome genes on the growth of certain tooth groups [25,27,36], tooth roots and crowns [13,15,25] and the different parts of the tooth crown [12,17,19,37].

Midtbo and Halse [13] have reported a significant difference between Turner and control patients in the number of teeth with morphological irregularities in the permanent dentition, traits which were observed with equal frequency on both the right and left side. Pirttiniemi et al. [29] found that 45,X/46,XX females have an apparent increase in the asymmetry of the occlusal morphology between the first permanent molars on opposite sides of the jaw, while Townsend et al. [10] observed no noticeable asymmetry in mesiodistal or labiolingual widths in either the deciduous or permanent dentition of 45,X females. In the present work the number of cases in which the means of the differences in tooth crown heights between the jaw sides were statistically significant was slightly increased in the 45,X and 45,X/46,XX females compared with the female controls.

In conclusion, the reduction in tooth crown heights observed here is apparently due to the degree of sex chromosome deficiency. The effect of the lacking sex chromosome material in reducing the tooth crown sizes of Turner patients, as observed in the mesiodistal and labiolingual dimensions of both the deciduous and permanent dentition in previous investigations, was also expressed here in the form of reduced permanent tooth crown heights in the 45,X females by comparison with their sisters and with the females from the normal population and in the fact that this effect was more pronounced than in the 45,X/46,XX females.

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Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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Notice of correction

The Early Online version of the appendix for this article published online ahead of print on 2 Jun 2014 contained some errors. The corrected version is shown in this issue.

Supplementary materials available online.

Tables AI-AV.
Figure A1.