Cervical Skeletal Maturity Index (CSMI):

A predictor for % remaining mandibular growth

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Introduction

Understanding and being able to predict future growth is of great importance in the practice of clinical orthodontics. The percent of growth remaining can have a large influence on diagnosis, treatment goals, treatment planning, and the eventual treatment outcome. Clinical decisions such as the use of functional appliances, headgear, non-extraction versus extraction, and orthognathic surgery are very often based on growth considerations.[1] It would therefore be quite useful for orthodontists to have a quick and easy way to predict the percentage of growth remaining.

Skeletal age has proven to be a more reliable indicator than chronological age when predicting skeletal maturation. Skeletal maturation refers to the degree of development of ossification in bone.[8] Physiologic parameters such as peak growth velocity in standing height, voice changes in boys, menarche in girls, dental development, and skeletal ossification have been used to assess developmental status and facial growth.[2] Peak velocity in maxillary and mandibular size occurs either concurrently with growth peak[5] or slightly after.[6] While the Skeletal Maturity Index developed by Fishman[3] is a good predictor to evaluate maturational status, it requires a supplemental hand-wrist radiograph. An index based on maturational changes of the cervical vertebrae morphology has the advantage that an additional radiograph need not be taken.

In a previous study performed by Kim,[4] a ratio of the inter-vertebral disc space of C2-3 to the vertebral height of C3 was compared to chronological age and other skeletal indices in its ability to predict the amount of facial bone growth remaining. This ratio is named CSMI, or cervical skeletal maturity index. The purpose of this study is to test the efficacy of the CSMI in its ability to predict the percent of remaining mandibular growth.

Literature Review

Growth and Development of the Cervical Spine

The cervical vertebrae are comprised of the first 7 vertebrae in the spinal column. They are also the smallest vertebrae. The body is small and the superior surface is concave transversely. The inferior surface is concave anteroposteriorly. The second cervical vertebra (axis or C2) has a much different form than the remaining cervical vertebrae. C1 and C2 are both modified where the body of C1 is essentially incorporated into C2. In the axis, the bony addition forms the dens, which rises perpendicularly from the upper surface of the body. This is the pivot on which the atlas rotates.[7]

The articulations of the vertebral column are cartilaginous joints between the vertebral bodies, the synovial joints between the vertebral arches, the articulations between the axis and atlas, and the articulation of of the atlas with the skull. The vertebral bodies are joined by intervertebral disks and the anterior and posterior longitudinal ligaments. The intervertebral disks of fibrocartilage are situated between the vertebral bodies. In the cervical region intervertebral disks are thicker anteriorly than posteriorly, which accounts for the cervical curvature. Each disk is composed of an outer fibrous ring surrounding a nucleus pulposus. The fibrous ring consists of fiber bundles and fibrocartilage.

Maturational changes in the vertebral column can be measured from birth to maturity. [7] Growth occurs from the cartilaginous layer on the superior and inferior surfaces of the vertebrae. Secondary ossification nuclei on the transverse processes and the bifid spinous process appear during puberty. These nuclei unite with the spinous processes when vertebral growth is complete. [9] Once endochondral ossification is complete, periosteal apposition occurs only at the front and sides of the vertebral body. [7]

Predictors of Facial Bone Growth

Typically, a child's growth rate decreases from birth, with minor growth spurt at approximately 6 to 8 years or age, or the prepubertal minimum, and a pubertal growth spurt. [17] While the fact that this pattern occurs is fairly predictable, the timing between individuals is quite variable. Therefore chronological age is not a good predictor of a child's developmental status.

There is general agreement that after the pubertal growth spurt, growth slows down and ceases and that menarche is a good indicator that growth is decelerating. [10] The circumpubertal growth spurt of the face occurs just after the peak growth velocity in height. Bambha[11] found that the facial bones follow the same growth curve of height. Additionally, Hunter[12] reported that of all of the facial dimensions studied, mandibular length exhibited the most consistent relationship with growth in height.

Tofani[13] investigated whether growth of the mandible continues after menarche. His findings indicate that growth does continue past menarche. The average amount of growth was usually greater before menarche. Tofani also found that menarche occurred most often after maximum growth velocity in the mandible for early and average maturing girls but before maximum growth velocity in late maturers.

Bjork[5] studied predictors of the age of maximum pubertal growth in body height. His subjects consisted of twenty girls and thirty-two boys participating in a longitudinal study of facial growth. He found a close association between maximum growth in body height, ossification of the ulnar sesamoid of the thumb, and the age of menarche in girls. The sesamoid usually ossified one year before maximum skeletal growth, and menarche normally occurred after maximum growth. Dental development was determined to be a poor predictor of maximum skeletal growth as it occurred several years before or after maximum pubertal skeletal growth.

Mitani and Sato[14] compared growth characteristics of the mandible during puberty with the hyoid bone, cervical vertebrae, hand bones and standing height. Thirty-three Japanese girls participated in the study. The mandibular growth rate differed from the other growth rates and timing of its maximum growth velocity also varied. While the size of the mandible, body height, hand bone and cervical vertebrae all correlated strongly with each other, the correlation between any two parameters weakened after age 11. In addition, ultimate mandibular size was determined to be independent of the other parameters. However, body height, hand bone, and cervical vertebrae all showed a significant correlation in total growth.

In many studies the findings did not agree with regard to the timing, magnitude, or the ability to predict the timing of the peak mandibular growth. Pileski[16] studied 91 males and 108 females from the serial experimental group of the Burlington Orthodontic Research Center. Longitudinal data was gathered from annual radiographs. The purpose of his study was to determine if there was a relationship between the appearance of the ulnar sesamoid of the thumb and the maximum rate of mandibular growth during puberty. The mean appearance of the sesamoid bone preceded the mean maximum mandibular velocity by 0.72 years in males and 1.09 years in females. While the correlation is statistically significant, its clinical significance is debatable since in 25.3% of males and 19.5% of females the ulnar sesamoid bone was not apparent radiographically until after peak mandibular velocity was complete.

Bishara[15] examined the changes in mandibular dimensions and statural height in 20 males and 15 females between the ages of 8 and 17 years. He found that the growth profile of statural height was significantly different from the growth velocity of mandibular length and that statural height was not reliable predictor of mandibular growth. As expected, between 8 and 17 years there was significant growth for all parameters measured. Therefore, Bishara recommends beginning treatment as soon as it is indicated rather than waiting for the circumpubertal growth period. During the waiting period most patients would undergo enough growth to help improve treatment outcomes.

Other studies along with Bishara's have questioned the efficacy of using hand-wrist radiographs along with clinical height measurements to predict craniofacial growth. Serial annual lateral cephalograms and hand-wrist radiographs from a sample of 47 girls and 39 boys from the Bolton-Brush data base were examined by Moore,[1] et al, to determine if there was a correlation between skeletal maturation and craniofacial growth. The linear measurements SN, GoGn, SGo, and NMe, along with hand-wrist radiographs were assessed. While a significant relationship was found between statural height and hand-wrist skeletal maturation for both sexes, the relationship between craniofacial growth and skeletal maturity was not clinically significant. A large variety of growth patterns and growth accelerations were observed, and growth spurts were not always evident.

Maturation Indices

The relationship of peak height velocity and mandibular growth to maturational stages in the hand and wrist has been well documented. While some studies question the validity of the research, numerous studies examining different populations have shown that ossification of the ulnar sesamoid precedes peak height velocity by 9 to 18 months, depending on the study. [5,18,19,20] From longitudinal population data derived from the Denver Child Research Study, Fishman[21] developed a system for evaluating the skeletal maturity of an individual from hand-wrist radiographs. The Skeletal Maturity Indicators (SMI) evaluates at 4 stages of bone maturation found at 6 anatomical sites located on the thumb, third finger, fifth finger, and radius.

Eleven discrete maturational indicators spanning the entire adolescent development are found at these sites. At SMI 6, approximately 50% of adolescent growth was complete for statural height and the mandible. As the growth velocity decreased during late adolescence, mandibular growth lagged behind skeletal growth. The mandible reached its maximum growth rate at SMI 7.

This Skeletal Maturation Assessment (SMA) provides a more accurate way than chronological age for determining skeletal age. Individuals display a wide variation in their maturational development. An early pattern of average, delayed or accelerated maturation may change over time. Silviera[22] examined mandibular growth during the late stages of puberty for early, average, and late maturers. Seventy patients from an orthodontic private practice and the orthodontic department of the Eastman Dental Center were divided into 3 maturation groups representing the later stages of maturation (SMI 8-11, SMI 9-11, and SMI 10-11). Sub-groups were then formed based upon early, average, and late maturers. The results demonstrated statistically significant growth differences between the sub-groups. Late maturing individuals had larger mandibular growth increments as compared to early and average maturing individuals. Average maturing individuals showed significantly more mandibular growth when compared to early maturers.

While the SMA utilizing hand-wrist radiographs is a useful indicator to predict if peak mandibular growth has occurred, it requires an extra radiograph. At the University of Pittsburgh, Lamparski[23] found cervical vertebrae to be as reliable as the hand-wrist area for assessing skeletal age. He developed an index to determine skeletal age for males and females. As the cervical vertebrae are captured on a lateral cephalometric radiograph, this method has the advantage of eliminating the need for additional radiographs.

Using Lamparski's 6 stages of cervical maturation, O'Reilly[24] studied the relationship of these stages to growth changes in the mandible. She found that stages 2 and 3 frequently occurred in the year preceding the maximum increment of mandibular growth. Stage 2 is identified by a concavity in the inferior border of the second vertebra and the anterior vertical heights of C-3 through 6 have increased. During Stage 3 a concavity has developed in the interior border of the third vertebra while the other inferior borders are still flat. Stages 4 through 6 were observed during the decelerative phase of growth after peak velocity. Stage 4 is identified by the vertebral bodies becoming rectangular in shape, a distinct concavity on the inferior border of C-4 and concavities on C5 and 6 just beginning to form. During Stage 5 and 6 the bodies become square in shape, increase in vertical height, concavities are well defined on all bodies, and intervertebral spaces become visibly smaller.

Using the Bolton-Brush growth study at Case Western Reserve, Hassel[8] developed another growth index by correlating the SMI groupings to cervical vertebrae maturation. The 11 SMI groupings identified by Fishman were condensed into 6 cervical vertebrae maturation index (CVMI). The 6 categories were: 1. initiation, 2. acceleration, 3. transition, 4. deceleration, 5. maturation, and 6. completion. Significant to moderate growth was expected from CVMI 1 to 3 with the amount of adolescent growth expected decreasing in CVMI 4 through 6.

Franchi[23] modified Lamparski's original maturation index to allow for the appraisal of skeletal age in both boys and girls, regardless of chronological age. The sample used in this study was comprised of 24 individuals selected from the University of Michigan Elementary and Secondary School Growth Study. Lateral cephalograms were studied at the 6 stages of maturation (Cvs1 through Cvs6). Traced lateral cephalograms were analyzed and mandibular size and position to other craniofacial structures were recorded. Changes in body height showed increments from Cvs1 to

Cvs2 through Cvs3 to Cvs4 and decreased during intervals Cvs4 to Cvs5 and Cvs5 to Cvs6. On average, peak velocity in statural height occurred between Cvs3 to Cvs4 with 100% of the boys and 87% of the girls experiencing peak growth during this interval.

Comparisons were also made between stage 3, which is the maturation stage closest to the onset of the peak statural height for almost all examined subjects, and the distribution of chronological age for both sexes. At stage 3, individual chronological age for girls ranged from 8 years 6 months to 11 years 5 months, and for boys ranged from 10 years to 14 years. This broad range indicates that chronological age is a poor parameter for the appraisal of skeletal maturation and for determining treatment timing.

CSMI as a Predictor of Mandibular Growth

The cervical skeletal maturity index (CSMI) is a ratio of the anterior inter-vertebral distance C2-3 and the anterior vertical body length of C3 (figure 1). Kim developed this index as a way for clinicians to predict the amount of facial bone growth remaining. In her study she compared CSMI to Fishman's SMI, chronological age, and percent facial bone growth remaining. From this study she concluded[4]:

1. The anterior intervertebral space of C2-3 decreases with age while the anterior cervical vertebral body increases with age.
2. CSMI decreases exponentially with chronological age. A CSMI of 1.10 or greater indicates a high growth potential while a CSMI under 0.3 indicates very little growth remaining.

3. CSMI was a better predictor of percent growth remaining than chronological age but not as accurate as Fishman's SMI.
4. The growth spurt occurred between CSMI 0.76 to 0.56, which corresponded to 30% to 70% adolescent growth remaining.
5. A CSMI of 0.68 indicated that 50% of adolescent growth was complete.

Materials and Methods

Longitudinal cephalograms of 20 subjects from the Oregon Health Sciences University growth study were used in this study. The subjects were Caucasians of predominantly Northwestern European ancestry. Ten boys and ten girls were randomly selected. Inclusion criteria included having lateral cephalograms at ages 8, 12, 16, and 20, plus or minus 6 months (T1-T4). The mandible and cervical vertebrae 2 and 3 had to be clearly visible. A Broadbent-Bolton Cephalometer was used to take the radiographs. Radiographic enlargement is approximately 6%.

Cephalograms most closely corresponding to the 8th, 12th, 16th, and 20th birthday were selected from the subject's file. Tracings onto acetate paper were made of the patient's mandible and of cervical vertebrae 2 and 3 (figure 1).

To obtain the CSMI, the protocol outlined by Kim was followed[4]. The anterior inter-vertebral distance between C2 and C3 and the anterior vertical body height of C3 were measured in each lateral cephalograms. The measurements were performed using a digital caliper manufactured by Mitutoyo Co, named the Digimatic Caliper. All measurements were rounded to the nearest 0.1mm.

The mandibular body length (S-Gn) was recorded to the nearest 0.1mm. From the series of measurements taken, the percent of total growth remaining was calculated at ages 8, 12, and 16. For this study, it was assumed that growth was complete at age 20.

The formula used was:

$$\%\ \text{Total Mandibular Growth Remaining} \quad \frac{\text{Final mandibular length (20Y) - mandibular length}}{\text{Final mandibular length (20Y)}} \times 100$$

The percent adolescent growth remaining was also calculated for ages 12 and 16. For this study, adolescent growth is defined as any growth after age 8.

The formula used was:

$$\%\ \text{Adolescent Mandibular Growth Remaining} \quad \frac{\text{(Mn length 20y - Mn length 8y) - Mn length at 12y or 16y}}{\text{(Mn length 20y - Mn length 8y)}} \times 100$$

Statistical analysis was performed to determine the correlation between:

1. CSMI and % total growth remaining for males, females, and both sexes.
2. CSMI and % adolescent growth remaining for males, females, and both sexes.
3. CSMI and chronological age for males, females, and both sexes.
4. Chronological age and % total growth remaining for males, females, and both sexes.
5. Chronological age and % adolescent growth remaining for males, females, and both sexes.

Intraoperator error was calculated by re-tracing and re-measuring 8 randomly selected radiographs 4 weeks later by the same person. All measurements were within 0.75 mm ($r= .99$).

Results

CSMI Related to % Mandibular Growth Remaining

There was a high correlation between CSMI and % growth remaining (Table 1). The % growth remaining was calculated two ways: total growth remaining (TGR) and the amount of growth remaining from T1 to T4, or adolescent growth remaining (AGR). While both TGR and AGR are listed in the tables and graphs, the results will be primarily described in terms of AGR in the results and discussion sections as the amount of growth remaining for each individual is the same regardless of which average is used.

The correlation coefficient was higher for males than for females, 0.89 and 0.82 respectively with an r value of 0.86 for both sexes combined. Figure 1 graphs the correlation between CSMI and % Adolescent Growth Remaining for each subject. Figures 2 and 3 are broken down by gender. A comparison between % AGR and CSMI with all subjects is illustrated in Figures 4 and 5, with subjects separated by gender in Figure 5. The slope for both the male and female subjects was similar. While the females tended to have a slightly greater amount of growth remaining versus the males at the same CSMI, the difference between them was minimal, and statistically and clinically insignificant.

Descriptive statistics for the % AGR and % TGR to CSMI are found in Table 2. Mean and standard deviation results are summarized in Figures 6, 7, and 8. The standard deviation was greatest at T1 in % TGR and decreased at T2 and T3. As discussed in materials and methods, for the purpose of this study growth was considered complete at T4, so the values for the mean, median, standard deviation, and range at T4 were 0.

Chronological Age vs. % Growth Remaining and CSMI

Figures 9 and 10 graph out the % growth remaining of each individual to chronological age. The correlation between chronological age and % growth remaining was quite high with male and female r values of 0.95. Conversely, the correlation between chronological age and CSMI was not as strong with r values of 0.77, 0.84, and 0.81 for females, males, and both genders combined.

Discussion

The purpose of the CSMI, or any skeletal maturity index, is to help the clinician predict how much remaining growth a patient has. This can be especially critical when dealing with both Angle Class II and Class III patients when mandibular growth is working either with treatment or against it. The amount of growth remaining can influence whether a case is treated with orthognathic surgery, extraction, or non-extraction. The ability to evaluate skeletal maturity by performing a simple and reliable measurement based on the cervical vertebrae on a lateral cephalometric radiograph is an invaluable tool. This study attempted to test the validity of the CSMI as described by Kim in its ability to predict % remaining growth.

Kim[4] asserted that when the CSMI is above 1.01, the growth potential of an individual is very high. She also estimated that 50% of adolescent growth was complete at CSMI 0.68 +/- 0.13 and that growth is most likely complete at CSMI 0.30. The results of this study seem to support Kim's general findings. Figures 8 and 9 look at the mean and standard deviation for the % growth remaining and CSMI. The mean values for CSMI at T1 for males and females were 0.89 and 0.76 with standard deviations of 0.18 and 0.15. As T1 in this study was 8 years +/- 6 months, it is assumed that the adolescent growth spurt has not yet occurred and that the growth potential is high. While the mean CSMI at T1 in this study was not as high as what Kim's study found, it nonetheless supports the general trend. The value of the CSMI with 50% of adolescent growth complete was also a little lower than what Kim found (figures 5-8). Again, while the numbers may not exactly mirror Kim's study, for all practical purposes, the general trend rather than exact numbers is what is important.

The correlation between chronological age and % growth remaining was surprisingly high. In fact, the r values for this correlation were higher than the r values for the CSMI and % growth remaining. Numerous studies have shown that chronological age is a poor growth predictor.[3,13,26,27] The high correlation found in this study may have several explanations. First, the population used in this study may have a higher correlation of % growth remaining and chronological age than the general population. A more plausible explanation may be in the design of the study. As measurements were taken 4 years apart, and most individuals experience an adolescent growth spurt between 12 and 14 years of age, the study was not sensitive enough to separate those going through an early, average, or late growth spurt.

If more measurements had been collected at shorter intervals of time, the comparisons between CSMI and % growth remaining would be more accurate. In addition, the same sample population was used in this study and in Kim's original study. The CSMI should be tested against another growth study population to determine if the CSMI is an accurate predictor of growth.

As with any skeletal maturity index, the CSMI does have limitations. While it seems to accurately predict when the growth potential is either very high or low, its accuracy at predicting exactly when the growth spurt occurs is questionable. According to Kim, the growth spurt on average occurs between CSMI 0.76 and 0.56 and corresponds to the 30-70% of adolescent growth remaining. These numbers are based on the CSMI and mandibular % growth remaining means. If one looks at the % of mandibular growth remaining range based on one standard deviation, a CSMI between 0.56 and 0.76 could correspond to 26% to 90% of growth remaining, which is a large range.

However, even within the scope of this study, CSMI seems to be a good general indicator of % growth remaining. It allows the orthodontist to generally assess the % of mandibular growth remaining without taking an extra radiograph. A good follow-up study would be to compare the CSMI to the cervical vertebral maturation index as described by Franchi, Baccetti, and McNamara. [25]

Conclusions

1. CSMI is a skeletal maturity index which relates the ratio of C2-3/C3 to % adolescent growth remaining.
2. CSMI is a good general indicator of % growth remaining. A CSMI closer to 1.0 indicates a high growth potential while a CSMI around 0.3 indicates that growth is almost complete.
3. CSMI allows the orthodontist to estimate % growth remaining without having to take an extra radiograph and can be performed quickly and easily.

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CSMI: Ratio = A/B

A: anterior intervertebral space of C2-3
B: anterior vertical height of C3

Mandibular body length measured from S to Gn

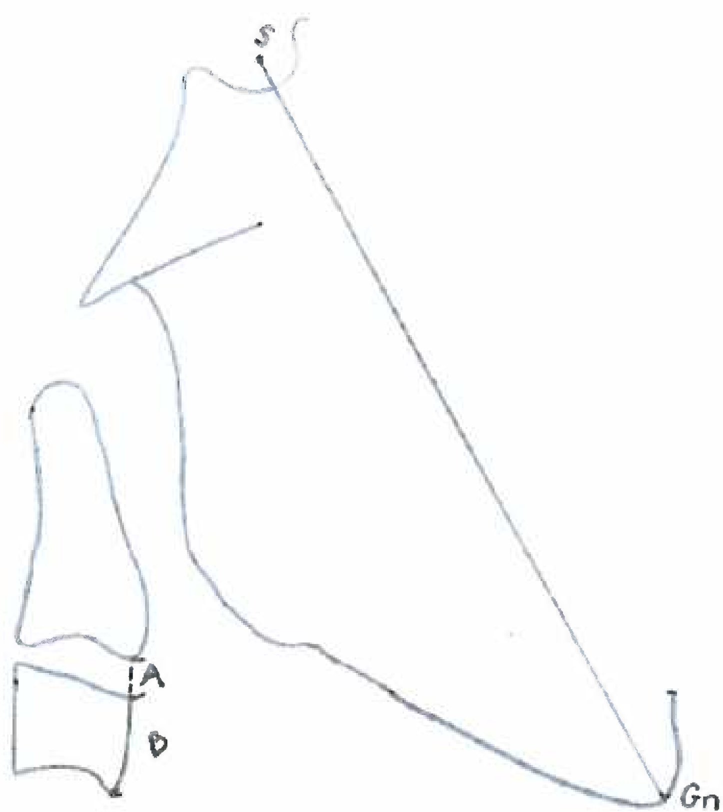

Fig. 1: Sample Tracing

Table 1. Correlation Coefficient Between CSMI and Chronological Age to % Growth Remaining

	%Adolescent Growth Remaining			% Total Growth Remaining		
	Male	Female	Male and Female	Male	Female	Male and Female
CSMI	0.89	0.82	0.86	0.89	0.81	0.87
Chronological Age	0.95	0.95	0.95	0.94	0.94	0.92

Table 2. Correlation Coefficient Between Chronological Age and CSMI

	Chronological Age		
	Male	Female	Male and Female
CSMI	0.84	0.77	0.81

Table 3. Mean, Median, Standard Deviation and Range For Females

	T1: Age 8			T2: Age 12			T3: Age 16			T4: Age 20		
	CMSI	% AGR	% TGR	CMSI	% AGR	% TGR	CMSI	% AGR	% TGR	CMSI	% AGR	% TGR
Mean	0.76	100.00	14.39	0.65	50.67	7.36	0.26	7.18	1.06	0.28	0.00	0.00
Median	0.80	100.00	14.51	0.57	53.53	7.58	0.28	7.50	1.15	0.27	0.00	0.00
Std. Dev.	0.15	0.00	1.42	0.20	12.17	2.00	0.10	3.66	0.56	0.05	0.00	0.00
Minimum	0.51	100.00	11.45	0.43	27.75	3.18	0.05	0.71	0.08	0.21	0.00	0.00
Maximum	1.00	100.00	16.50	1.05	66.86	9.74	0.41	12.49	1.94	0.36	0.00	0.00

Table 4. Mean, Median, Standard Deviation and Range For Males

	T1: Age 8			T2: Age 12			T3: Age 16			T4: Age 20		
	CMSI	% AGR	% TGR	CMSI	% AGR	% TGR	CMSI	% AGR	% TGR	CMSI	% AGR	% TGR
Mean	0.89	100.00	19.73	0.73	59.07	11.71	0.32	11.25	2.20	0.27	0.00	0.00
Median	0.95	100.00	19.82	0.71	58.25	11.85	0.33	13.09	2.45	0.27	0.00	0.00
Std. Dev.	0.18	0.00	1.09	0.15	12.29	2.39	0.11	7.46	1.47	0.08	0.00	0.00
Minimum	0.65	100.00	17.83	0.54	33.89	6.48	0.17	0.40	0.08	0.13	0.00	0.00
Maximum	1.11	100.00	20.86	1.00	72.96	14.93	0.56	19.76	3.95	0.40	0.00	0.00

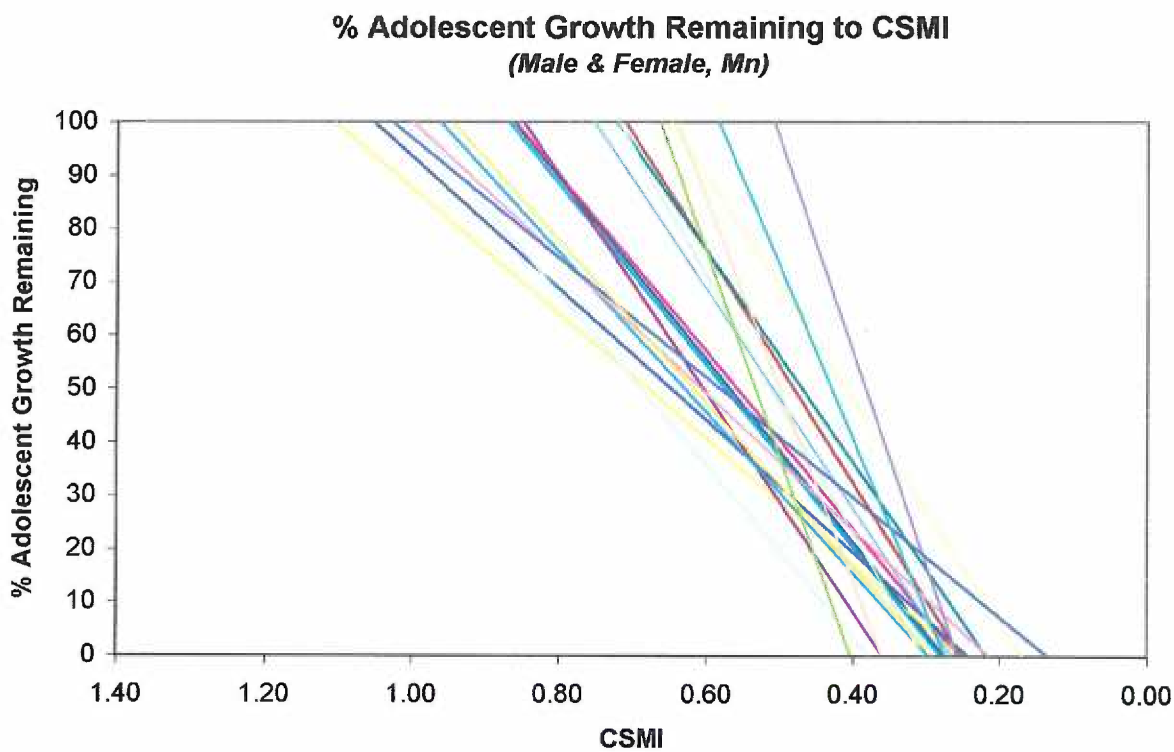

Fig. 2A: %Adolescent Growth Remaining to CSMI

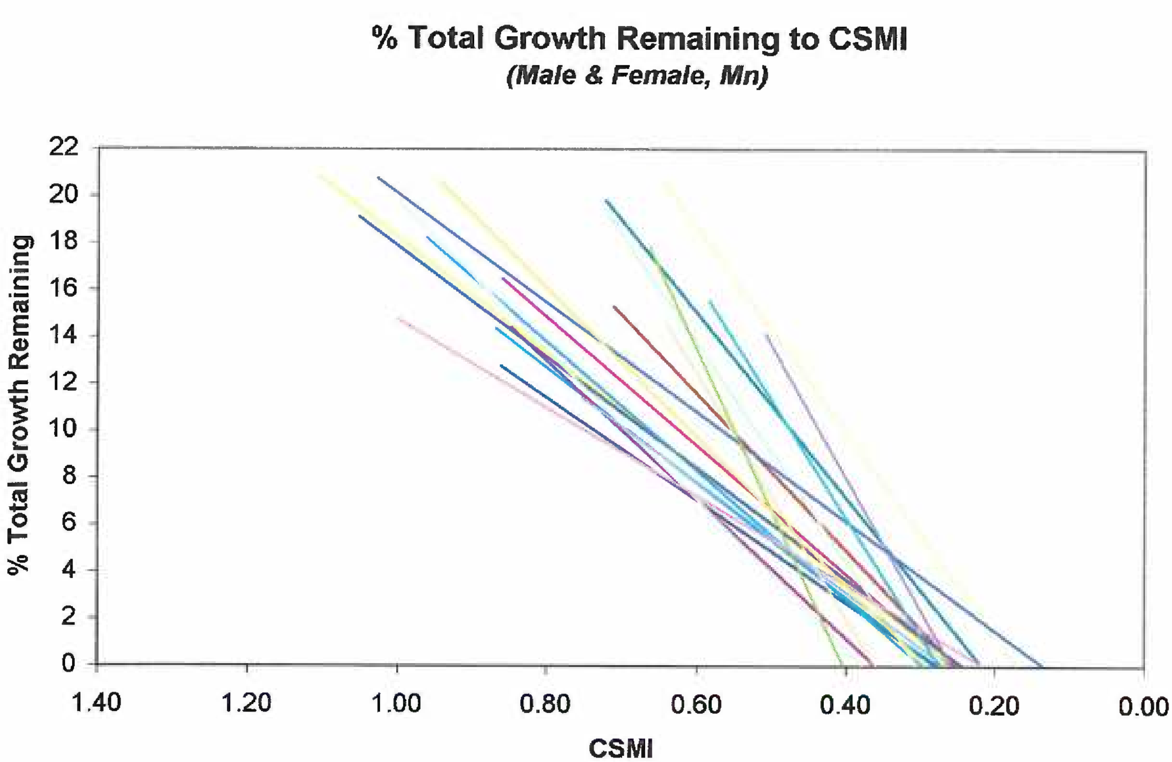

Fig. 2B: % Total Growth Remaining to CSMI

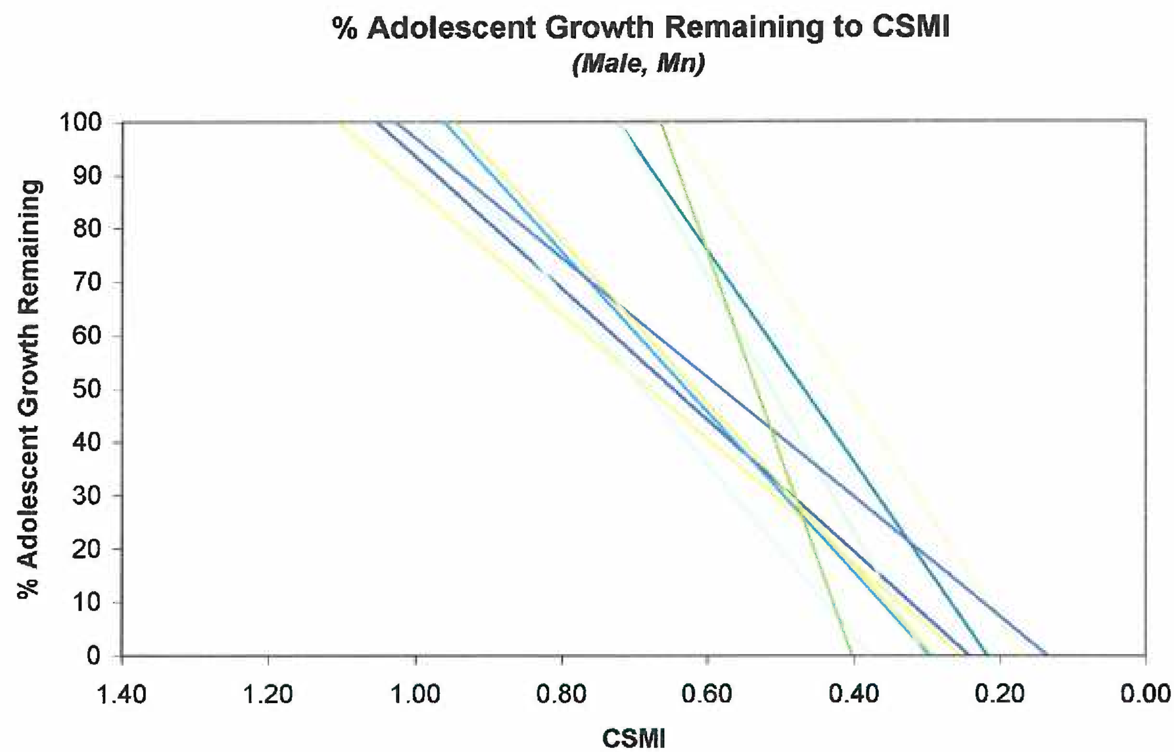

Fig. 3A: %Adolescent Growth Remaining to CSMI

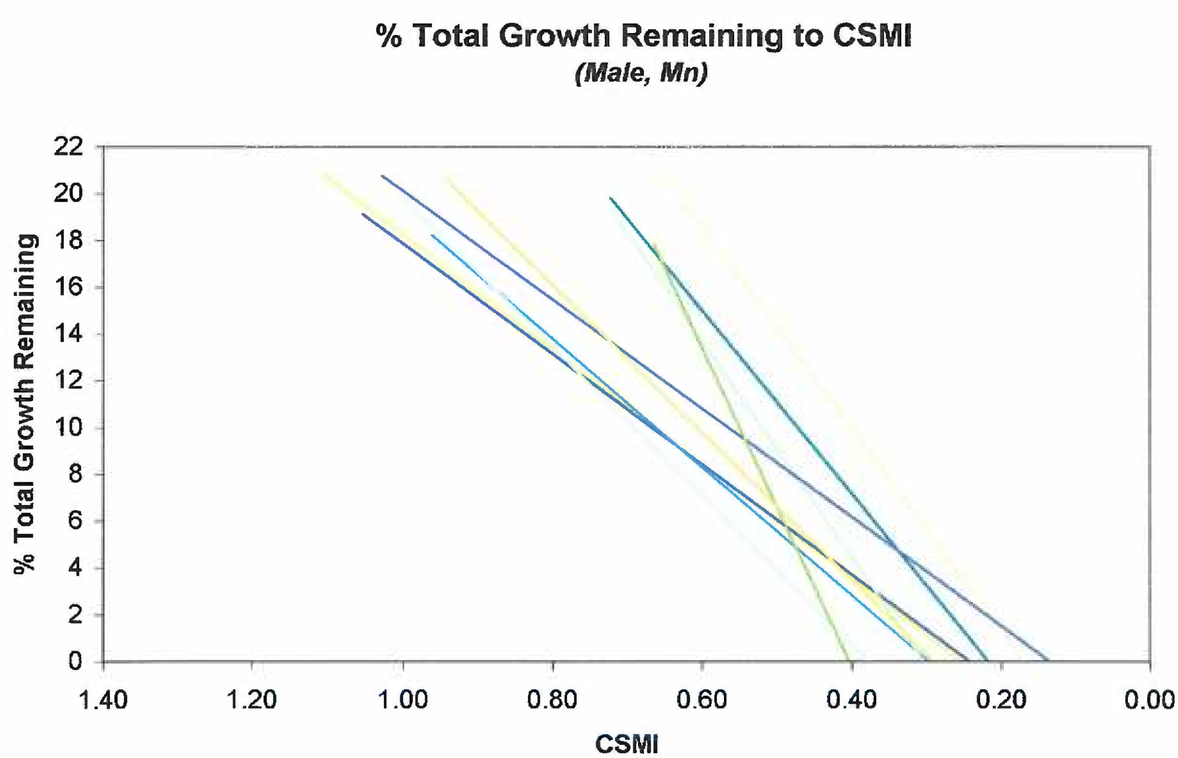

Fig. 3B: % Total Growth Remaining to CSMI

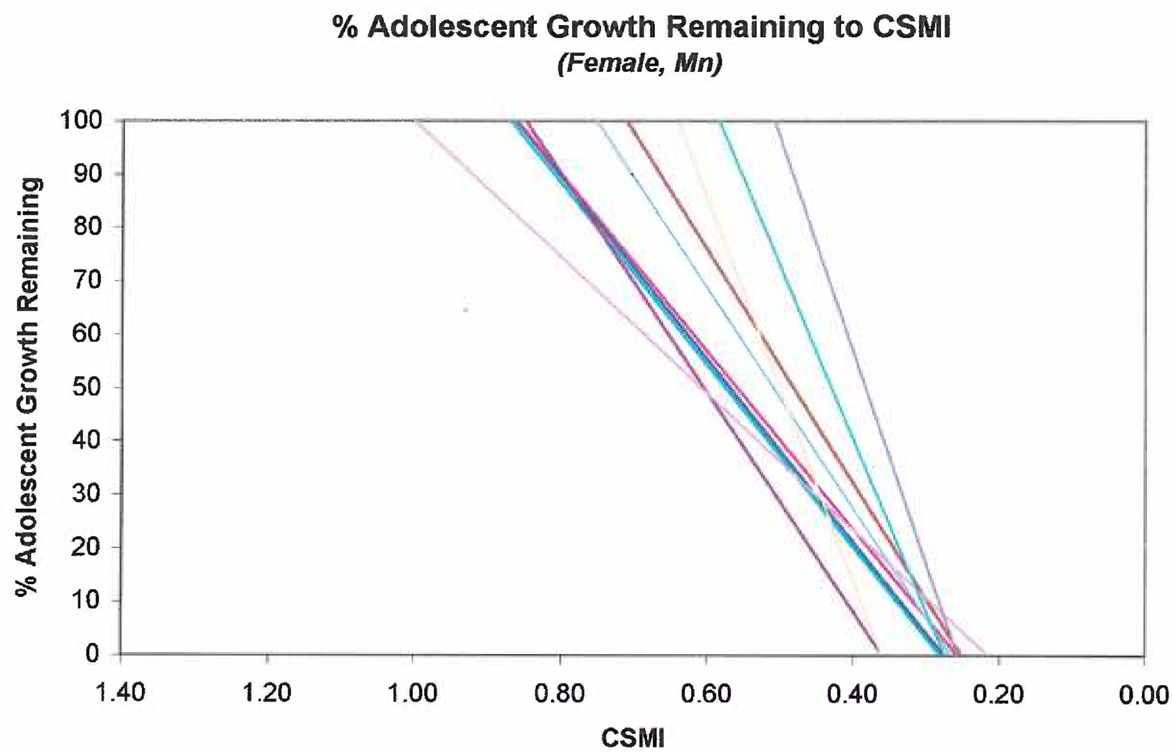

Fig. 4A: %Adolescent Growth Remaining to CSMI

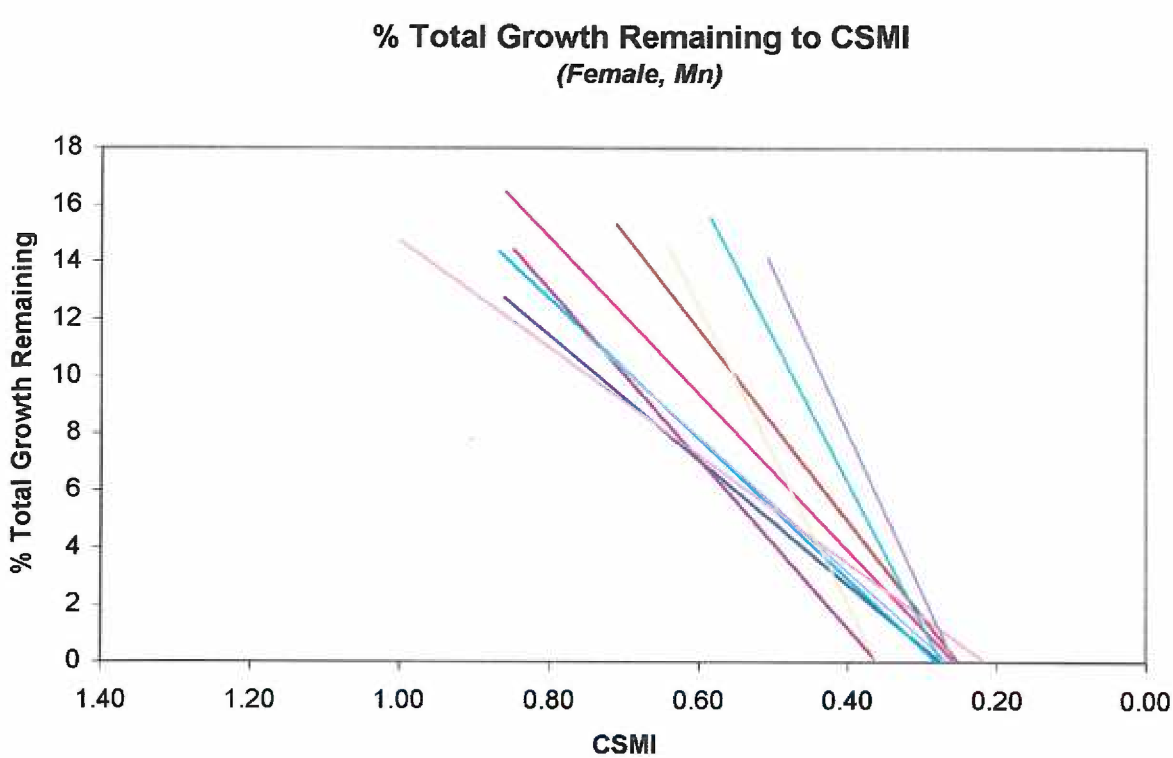

Fig. 4B: % Total Growth Remaining to CSMI

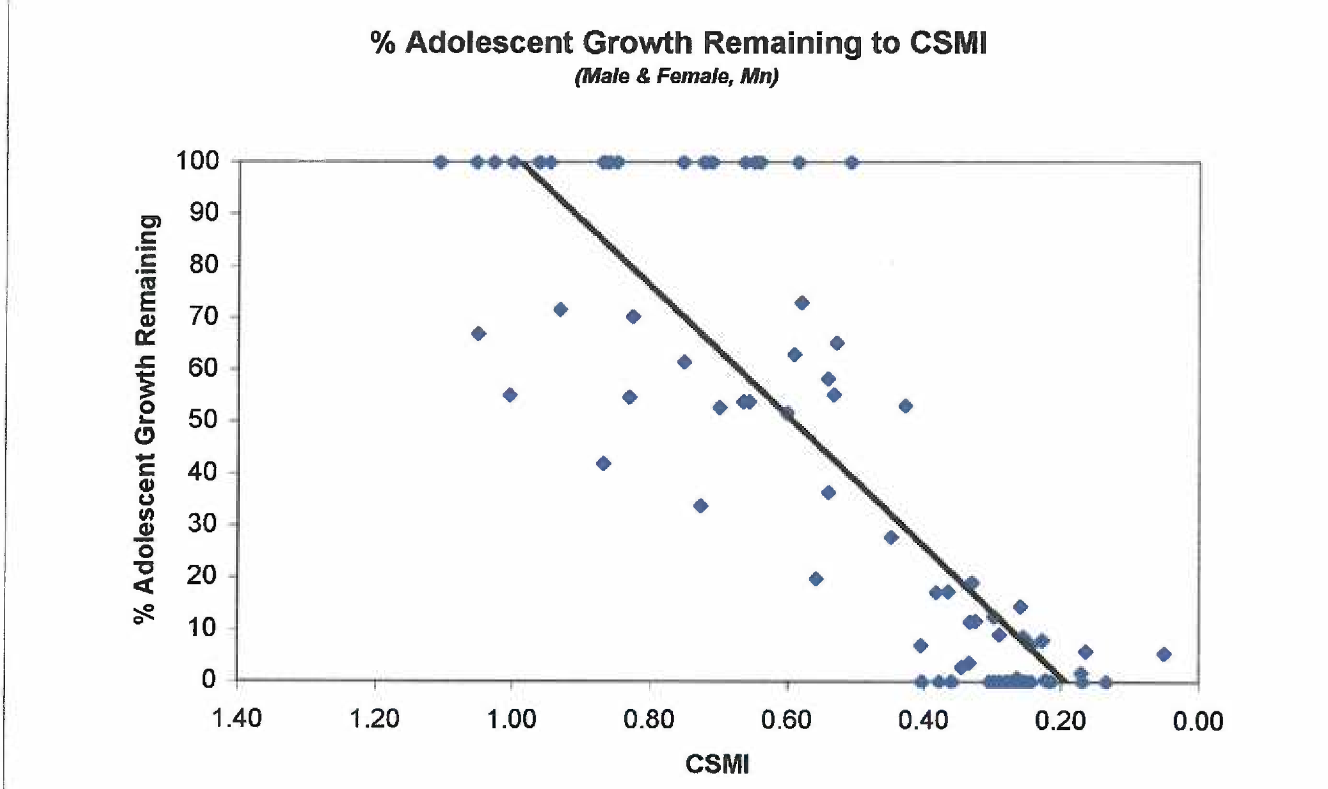

Fig. 5A: %Adolescent Growth Remaining to CSMI

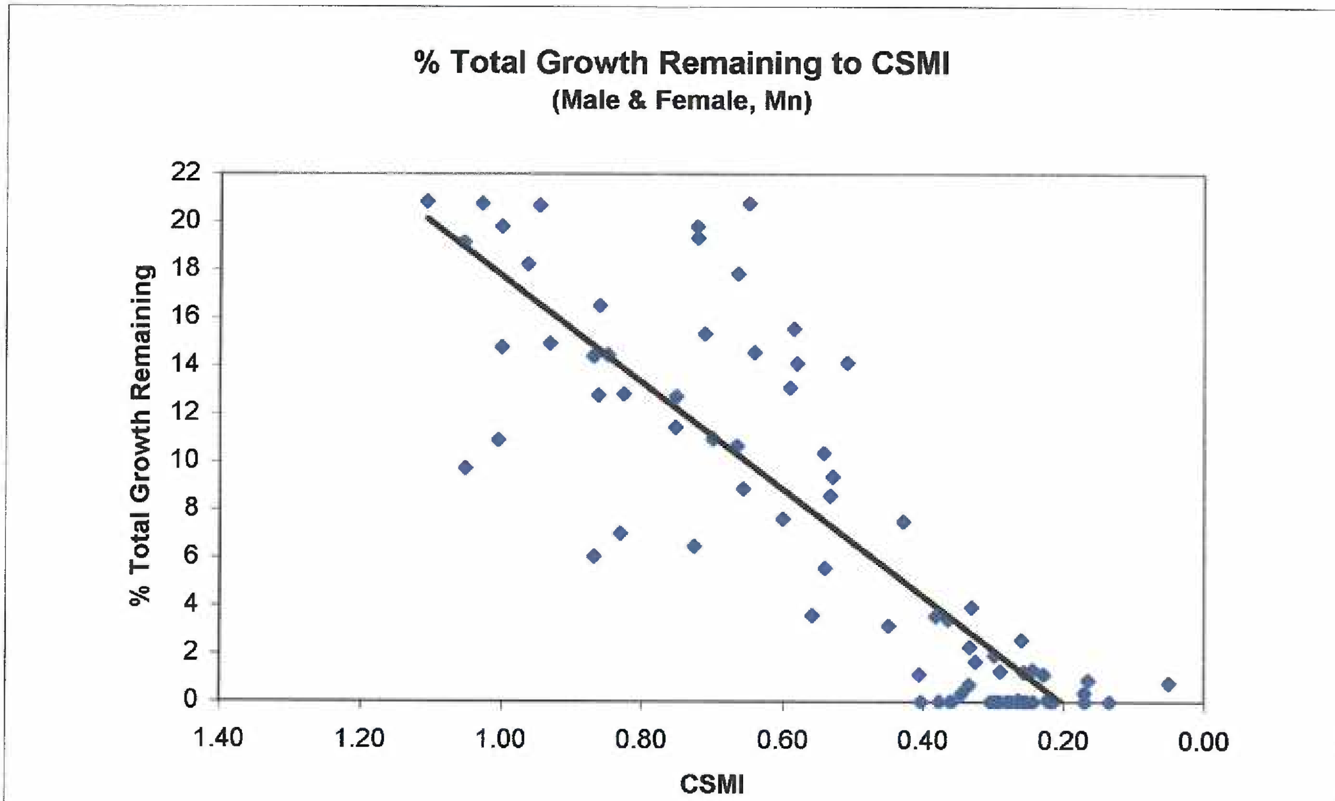

Fig. 5B: % Total Growth Remaining to CSMI

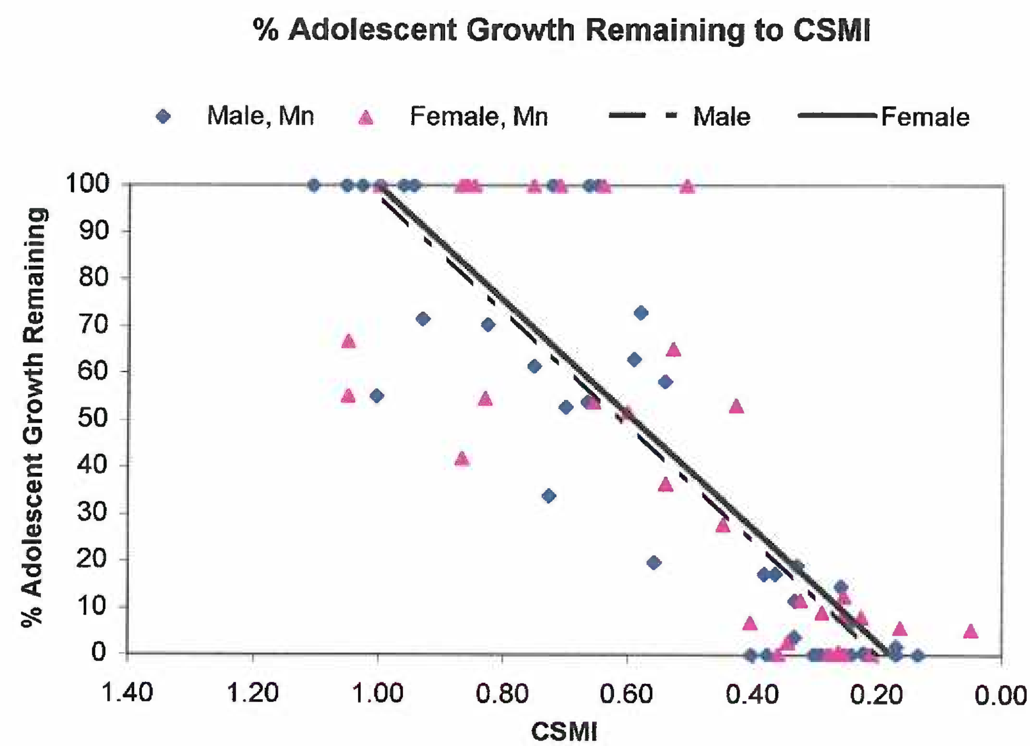

Fig. 6A: %Adolescent Growth Remaining to CSMI

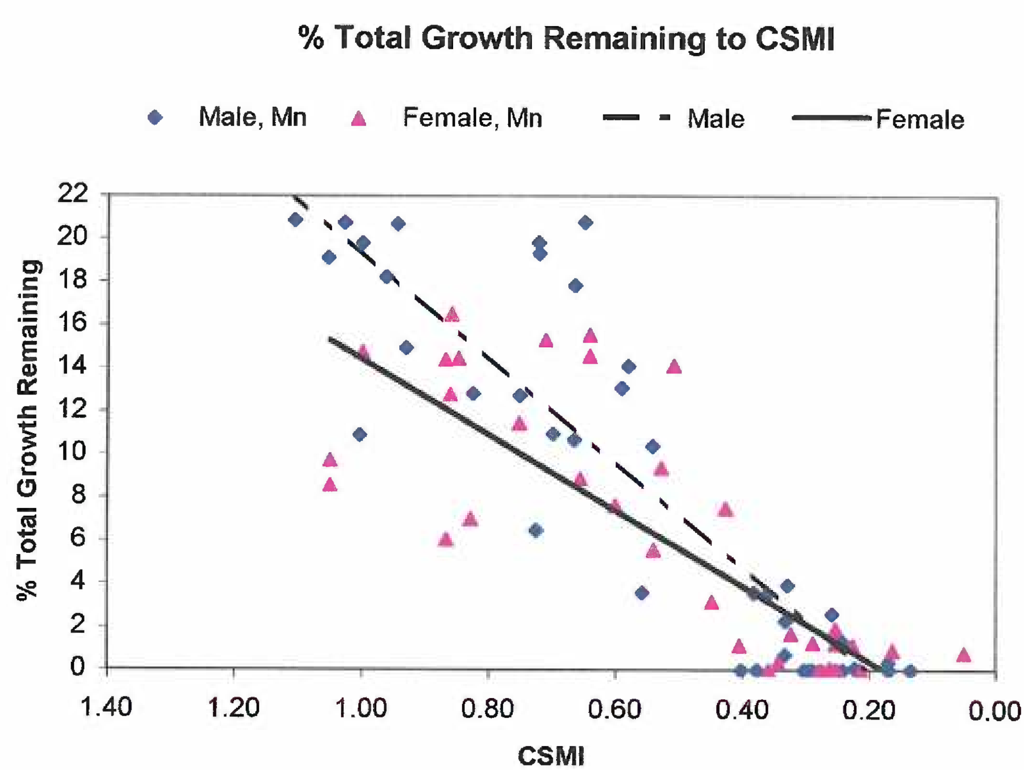

Fig. 6B: % Total Growth Remaining to CSMI

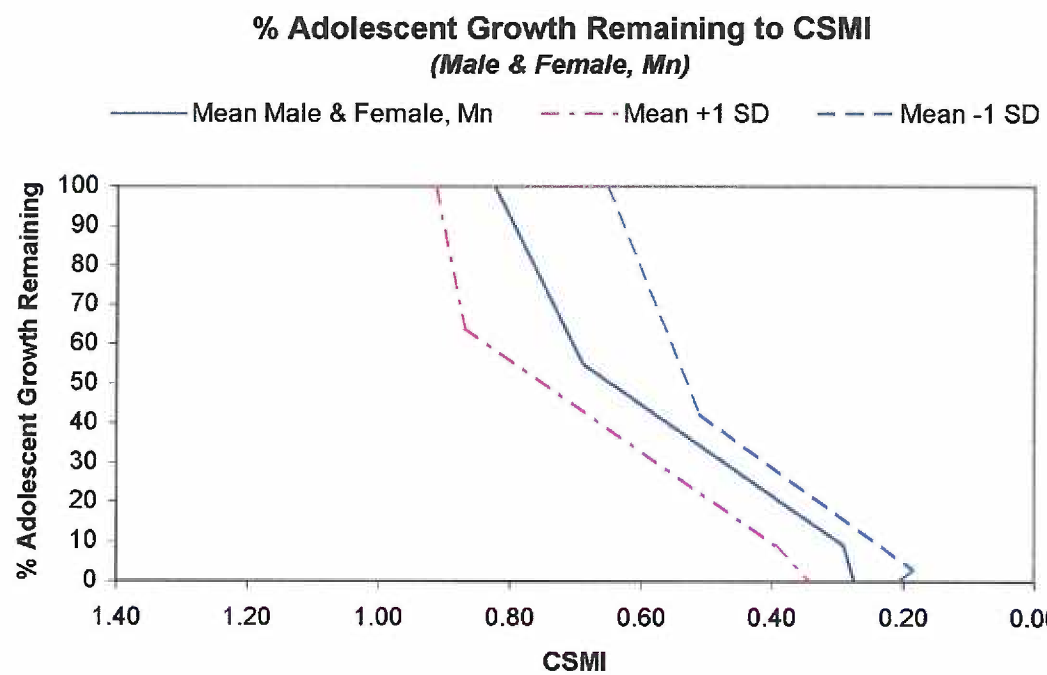

Fig. 7A: % Adolescent Growth Remaining to CSMI (Mean & Standard Deviation)

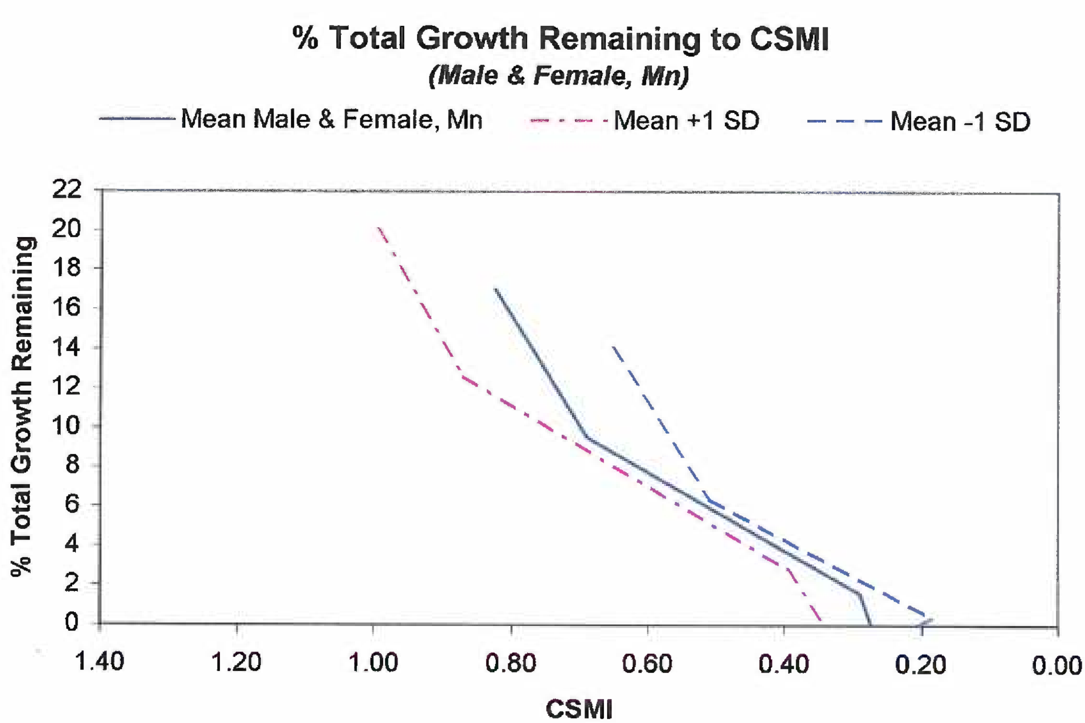

Fig. 7B: % Total Growth Remaining to CSMI (Mean & Standard Deviation)

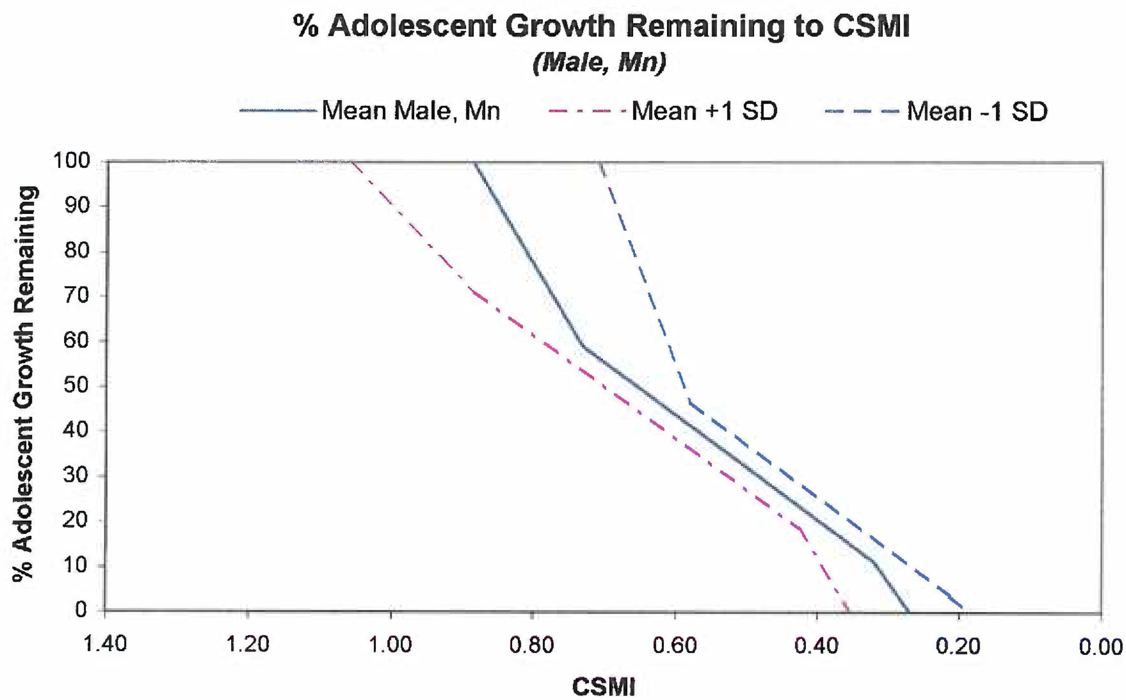

Fig. 8A: % Adolescent Growth Remaining to CSMI (Mean & Standard Deviation)

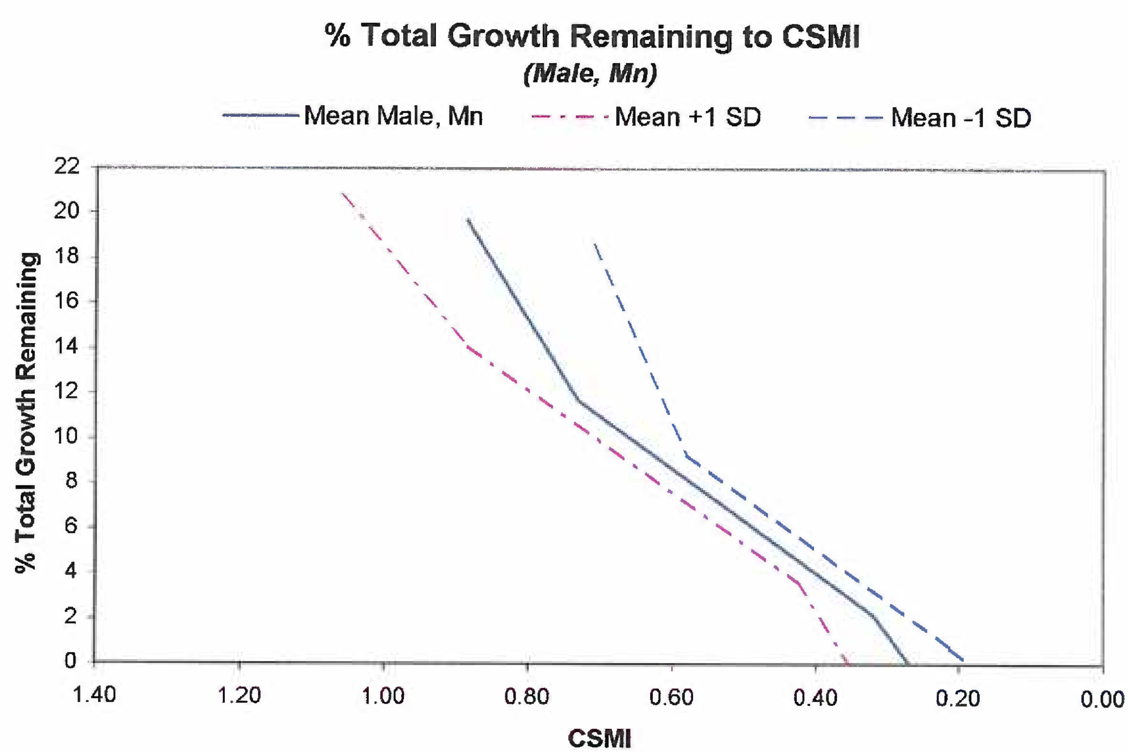

Fig. 8B: % Total Growth Remaining to CSMI (Mean & Standard Deviation)

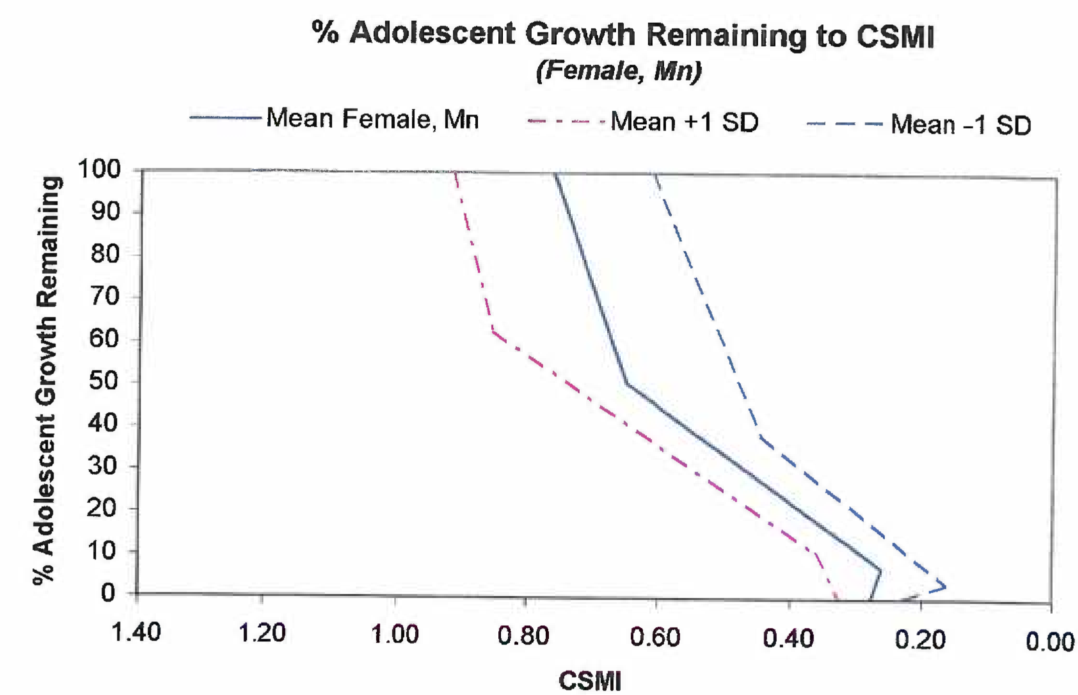

Fig. 9A: % Adolescent Growth Remaining to CSMI (Mean & Standard Deviation)

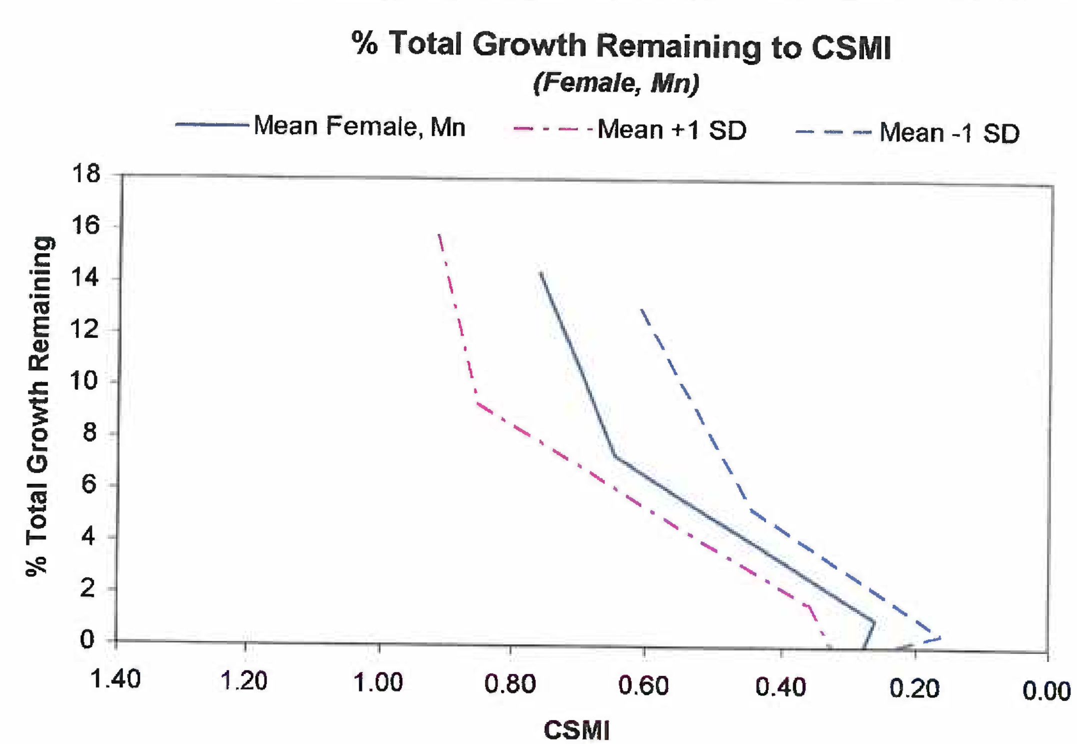

Fig. 9B: % Total Growth Remaining to CSMI (Mean & Standard Deviation)