THE AAOF CRANIOFACIAL GROWTH LEGACY COLLECTION: A POWERFUL NEW TOOL FOR ORTHODONTIC TEACHING AND RESEARCH

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ABSTRACT

This chapter reports and illustrates a multi-institutional project that uses the capabilities of cloud computing and the Internet to collect and share craniofacial images and numerical data of importance to orthodontic education and research. The project will provide interested investigators all over the world with near-instantaneous access to longitudinal information on the spontaneous craniofacial growth of untreated children with various kinds of malocclusion. The collection will facilitate investigations on the spontaneous course of development in children with malocclusions of different types. In addition, the AAOF Legacy Collection constitutes a unique source of control samples for testing the validity of consensually accepted beliefs about the effects of orthodontic treatment.

KEY WORDS: cephalometrics, lateral headfilm, *American Association of Orthodontists Foundation*, landmarks, normal growth

INTRODUCTION

With support from the *American Association of Orthodontists Foundation* (AAOF), nine of the twelve known collections of longitudinal craniofacial growth records in the United States (U.S.) and Canada have joined together to create a website of cephalometric images with an underlying numerical database. The first implementation of this joint effort already is available for use by orthodontists everywhere with any standard Internet browser. Its purpose is to make representative materials from the participating collections readily available to clinicians, craniofacial investigators, students of craniofacial growth and interested members of the public.

The participating collections represent the work of hundreds of investigators. The materials they contain literally are irreplaceable. The contents of the several collections include longitudinal skull x-ray im-

ages of various sorts – intraoral radiographs, study casts, hand-wrist films and facial photographs, as well as written records charting the physical and educational development of children of different ethnicities and growth patterns.

These longitudinal records have been gathered, catalogued and studied over more than 75 years. Each collection is independent from the others and has pursued its own strategies of sampling and data collection. The product of these different and complementary strategies constitutes a rich longitudinal record of craniofacial development among children who never received orthodontic treatment. The intent of the AAOF is to gather representative subsets of records from all available collections and to make the combined materials freely available to all interested clinicians and craniofacial investigators *via* the Internet.

HISTORY OF THE PROJECT

Scattered throughout the U.S. and Canada are a number of longitudinal collections of x-ray images and other physical records of craniofacial development of growing children with normal occlusions and children with malocclusions who did not receive orthodontic treatment. Most of these collections are located at major universities. The longitudinal records they contain were acquired during a historically brief window in time roughly between 1930 and 1985.

Prior to 1930, the technological capacity for tracking and recording the growth of the internal structures of the human head through time did not exist. Yet well before the end of the 20th century, the continued gathering of such information from untreated children was precluded by the recognition of the possibility of deleterious effects from the excessive use of ionizing radiation for diagnostic purposes. Clearly longitudinal studies of this kind never can be repeated. It seems imperative, therefore, that the available records be preserved in digital form before the deterioration or loss of the original images makes that impossible.

In 1988, out of concern for the preservation of this important research legacy, The *National Institute of Dental Research* (NIDR) sponsored a survey of existing longitudinal records collections in the U.S. and Canada by Hunter and associates (1993). Their report identified twelve extant collections containing various combinations of x-ray cephalograms, plaster study casts, demographic documentation and other physical records. Taken together, these collections have been the source of a large portion of the available published information on longi-

tudinal craniofacial growth, including more that 200 peer reviewed papers in major scientific journals.

The bibliography of this paper lists a subset of these publications, including four major dental and craniofacial atlases (Riolo *et al.,* 1974; Broadbent *et al.,* 1975; Moyers *et al.,* 1976; Behrents, 1985) and representative papers from several collections (Lewis and Roche, 1977, 1988; McNamara, 1981; Ohtsuki *et al.,* 1982; Lewis *et al.,* 1985; McNamara *et al.,* 1985, 1990; Behrents, 1986; Baumrind *et al.,* 1987*a,b,* 1992*a,b*, 1996; Korn and Baumrind, 1990; Baumrind and Korn, 1992; Snodell *et al.,* 1993; Formby *et al.,* 1994; Nanda and Ghosh, 1995; Blanchette *et al.,* 1996; Hunter *et al.,* 2002, 2007; Baccetti *et al.,* 2005; Hesby *et al.,* 2006; Edwards *et al.,* 2007; Gu and McNamara, 2007, 2009; Sherwood *et al.,* 2011).

Many of these publications are required reading for orthodontic and oral and maxillofacial surgery residents in the U.S. and elsewhere. Some of them, particularly the three atlases, have contributed strongly to the belief systems from which clinicians approach the delivery of orthodontic and maxillofacial surgical treatment throughout the world. As valuable as the data in these publications are, they represent only a small portion of the irreplaceable information contained in the original images in the several collections.

The idea of preserving a substantial subset of these irreplaceable images and their associated numerical data in digital form had been a dream of clinicians and craniofacial investigators for many years. Such a merged collection, if organized systematically, would provide a major resource for future orthodontic teaching and research. For this reason, it seemed imperative that the original images in the collections be preserved in digital form as soon as possible in order to facilitate continued examination and hypothesis-driven study by craniofacial investigators, clinicians, physical anthropologists and other interested scholars.

In 2008, Mark Hans and his Case Western Reserve University associates received support from the AAOF to organize a meeting of representatives from a number of interested institutions to investigate the potential for developing a shared virtual resource of longitudinal craniofacial growth records. This meeting led to the formation of a consortium among the separate collections to test the feasibility of constructing a sharable image base and database with continuing support from AAOF.

Nine of the twelve collections identified in the paper by Hunter and colleagues (1993) collaborated in this consortium. The universities

and institutes involved include Case Western University, The University of Michigan, The University of Iowa, The University of Oklahoma, The Oregon Health and Science University, The University of the Pacific, The University of Toronto, The Forsyth Institute and The Wright State University-Fels Institute. In the early stages of the project, Leslie Will (then at Tufts School of Dentistry) served as liaison between the AAOF and the consortium, and Carla Evans (at The University of Illinois Chicago, School of Dentistry) provided a link to the *American Association of Orthodontists*.

Stage I (the initial phase of the project) started in 2009 and was designed specifically as a test of feasibility. The representatives of the nine participating collections, meeting together, designated the *Craniofacial Research Instrumentation Laboratory* (CRIL) at The University of the Pacific as the site for the development of a prototype sharable database and website to which each of the collections would contribute materials for a small sample of cases. The framework for this database and its associated website was constructed using prototype components that had been developed previously at CRIL with NIH support (1971-1990), coupled with supplementary assistance from The University of the Pacific, The University of California San Francisco, a Center grant from AAOF and the family of the late Dr. J. Rodney Mathews.

Stage I lasted from June 2009 to December 2010. During this period, the consortium successfully developed a functional craniofacial database and website that demonstrated conclusively the feasibility of collaboration among our several independent collections. The status of the website as of June 2011 (essentially as it looked at the end of stage I) is illustrated in tables and figures that follow.

The home page of the AAOF Legacy Collection is shown in Figure 1. It can be accessed on any Internet-capable device *via* any standard browser or directly at www.AAOFLegacyCollection.org. The information content of this page, and indeed of the rest of the website, is packed rather densely. Even though we have sought to make the site attractive, little attention has been given to making it look pretty. The left hand column on the home page is a navigation bar, directing the user through the major categories of the website and database holdings. The uppermost category of the navigation bar directs the user to information about the site itself (Fig. 2).

Figure 1. The AAOF Legacy website home page (December 2010).

Tables 1 and 2 and Figure 3 summarize collection statistics at the end of stage I. All nine collections were represented in the sample that contained serial lateral cephalogram for 149 individual subjects. The total number of lateral cephalograms was 1285, of which searchable numerical data had been encoded for 1168. Of the 149 cases, 93 were described as Angle Class I, 44 as Angle Class II and 11 as Angle Class III. There were 76 girls and 73 boys in the sample.
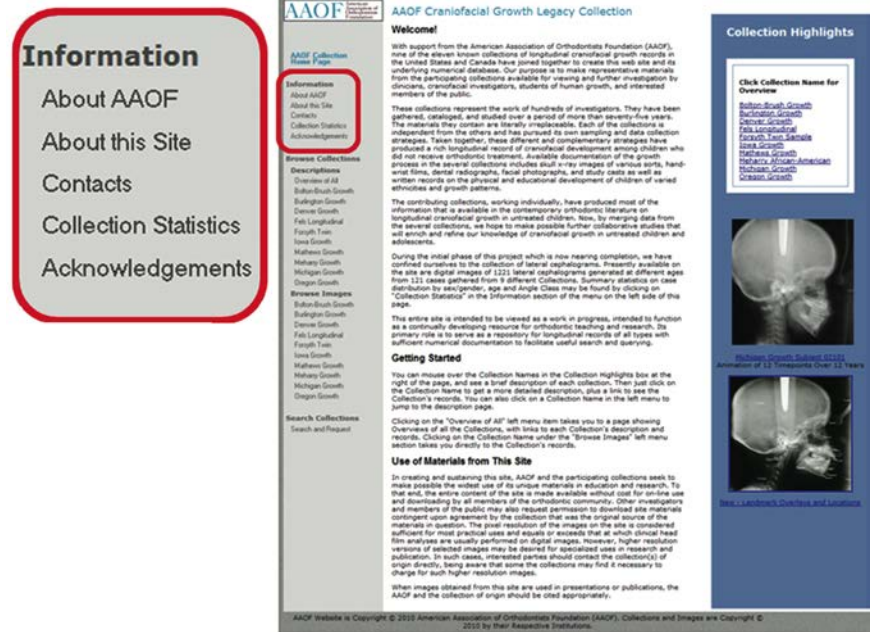
Figure 2. Accessing information on the site *via* the navigation bar on the home page.

Table 1. Contents of the AAOF Legacy Collection website at the end of stage I.

Number of collections represented	9
Number of cases	149
Total number of images*	1285
Total images searchable in database	1168
Average number of images per case	8.6

* Lateral cephalograms only. Site also includes 472 PA (frontal) cephalograms for 52 cases.

Table 2. Frequencies by Angle class and sex.

	Class I	Class II	Class III	TOTALS
Female	48	24	4	76
Male	46	20	7	73
TOTALS	**94**	**44**	**11**	**149**
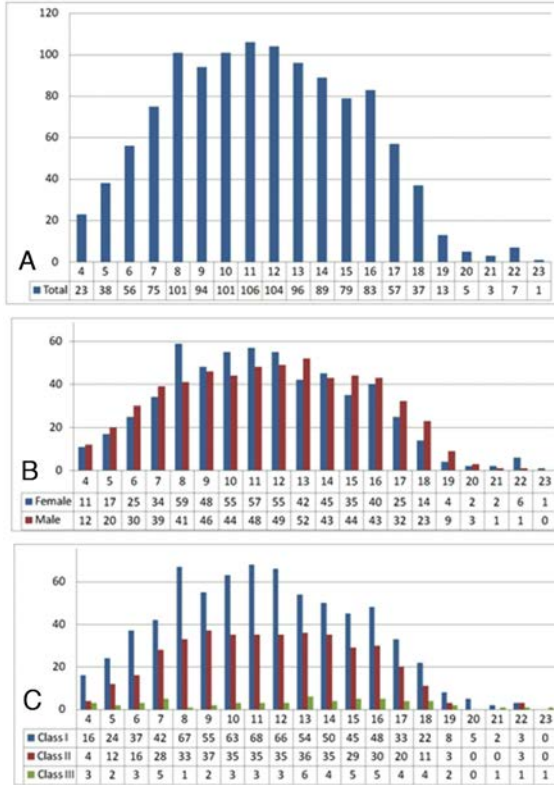
Figure 3. *A:* Number of available images (y) at each age (x), all cases. *B:* Number of available images (y) at each age (x), by sex. *C:* Number of available images (y) at each age (x), by Angle class.

Figure 3 illustrates the distribution of lateral cephalograms by age and reflects the primary focus on the time interval between ages seven and 20 years, the period of growth in which most orthodontic treatment occurs. (This focus since has been extended downward to five years of age in order to get a better sense of the conditions associated with the eruption of the first permanent molar.) Figure 3*A* shows that even in this early stage, the number of images available at each age between six and seventeen is greater than number of untreated control subjects in almost all studies of orthodontic treatment outcome that have been published to date.

The distribution of images by sex (Fig. 3*B*) is matched surprisingly evenly but the number of images for girls slightly exceeds that for boys between the ages of eight and twelve while the number of images of boys is slightly greater than that for girls that an earlier and later time points; there is no obvious explanation for this variation. The distribution of images by Angle class (Fig. 3*C*) shows the heavy concentration of Class I cases and the relatively limited number of Class III cases. This distribution is fairly representative of that in the normal population but does not necessarily reflect the focus of interest among orthodontic clinicians who generally would prefer to have more information about the spontaneous development of Class II and Class III malocclusions.

General information on the composition of the several collections from which the AAOF sample has been drawn may be found by clicking on the links in the *Browse Collections Descriptions* section of the navigation bar (Fig. 4). These descriptions highlight the features of the individual collections and may be browsed by the reader at will.

Direct access to the images of the AAOF collection is possible through the links in the lower area of the home page navigation bar (Fig. 5). Selecting an individual collection here will bring the viewer to a new page on which the images from all cases of the chosen collection are ordered sequentially. Data for each case in the chosen collection then may be examined in greater detail. For example, clicking on the *Mathews Growth* entry in Figure 5 takes the viewer to the first case of a detailed inventory of the available cases and images from the Mathews implant study originally conducted at The University of California San Francisco (Fig. 6). The special feature of this participating collection is that the subjects had implants of the Björk type placed prior to the collection of longitudinal records. It may be seen that records for this subject are available at ten time points ranging from six years eleven months to sixteen years one month.

The user now can select the lateral cephalogram from any available age or time point for this case. For example, if one selects the image represented by the highlighted grey bar in Figure 6, a full-screen view of the lateral cephalogram taken at age nine years seven months is presented (Fig. 7). Note the two rows of function buttons below the image in this enlarged view. They represent links to additional information available

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→ Figure 5. Accessing the images in the collection. (At present, the Meharry Collection is not part of this project.)

Figure 4. Browsing descriptive information on the individual component collections.

Figure 6. Typical collection inventory page entry for a single subject.

from the database that powers the website itself. Similar arrays are available for most but not all of the images in the collection. An enlarged view four of these buttons is shown at the bottom of Figure 7. The next four figures demonstrate the data-accessing function of these four buttons.

Clicking on the *Preview Images* button shown in Figure 7 yields a display of thumbnail lateral cephalograms for all time points available for the subject being viewed (Fig. 8). By clicking on any thumbnail of interest, the viewer can transfer attention immediately to enlarged images from that time point that is analogous to Figure 7. (Figure 7 has been reformatted for display in the current paper. The individual thumbnails in the actual display are larger considerably and more detailed than the ones shown here.)

Clicking on the *Data Tables* button in Figure 7 implements the display of tabulated numerical data available for this individual subject (Fig. 9). The first table contains Case 001's measured value for each of approximately twenty conventional hard tissue cephalometric measures at each age and their changes through time. A second table containing the

Figure 7. Full screen view of an image from a single time point with two rows of function buttons beneath.

coordinate values for each landmark used in the calculation of these measures also is available.

Behind the images displayed on the site is a numerical database of cephalometric landmark locations. This database is used to facilitate searches of the website images based on standard cephalometric measurements. The measurements are based on the previously determined locations of a number of anatomical cephalometric landmarks. Although each landmark in the database is the average of two or more independent estimates, it is to be expected that different clinicians and investigators may differ in their precise definitions of the landmarks and, hence, disagree about their precise locations.
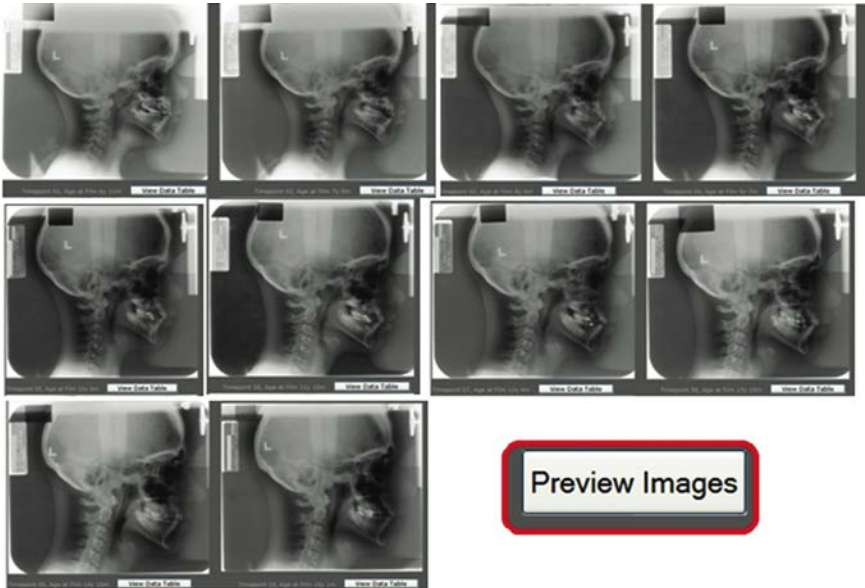
Figure 8. Thumbnail images for the lateral cephalograms at all available time points for Case 001 of the Mathews collection.

| Measurements | Sella Nasion Hard | Super ACB | Super Palatal Plane | Super Mandibular Border | Sella Nasion Soft | Super ACB Soft |

Anatomic Angular and Linear Measurements

Collection UOP Mathews Growth Study Subject 001

Image	1 - Age 7	2 - Age 8		3 - Age 8		4 - Age 10		5 - Age 11		6 - Age 12		7 - Age 13		8 - Age 14		9 - Age 15		10 - Age 16	
Measure	Value	Value	Delta	Value	Delta	Value	Delta	Value	Delta	Value	Delta	Value	Delta	Value	Delta	Value	Delta	Value	Delta
SNA	81.6	81.8	-0.?	82.3	0.7	81.9	0.3	82.2	0.6	83.9	2.3	82.5	0.9	83.4	1.8	84.2	2.6	84.0	2.4
SNB	75.1	76.6	1.?		2.1	77.2	2.1	77.0	1.9	78.4	3.3	77.4	2.3	78.3	3.2	79.0	3.9	80.1	5.0
ANB	6.5	5.3	-1.2	4.0	-1.?	4.7	-1.8	5.3	-1.2	5.4	-1.1	5.0	-1.5	5.0	-1.5	5.2	-1.3	3.9	-2.6
NP2PA	-2.2	-0.7	1.5	-2.0	0.2	-0.3	-?	-2.4	-0.2	-2.8	-0.6	-2.1	0.1	-2.2	0.0	-0.4	1.8	-0.5	1.7
NP2PO	6.4	7.3	0.9	4.0	-2.4	6.4	0.0	3.?	-2.9	3.4	-3.0	4.3	-?						
SNDST	71.8	72.4	0.6	72.7	0.9	73.7	1.9	74.9	3.1	75.9	4.1	78.0	6.?						
SNFHA	11.0	9.0	-2.0	9.9	-1.1	8.4	-2.6	10.2	-0.8	8.8	-2.0	9.4	-?						
CONVX	163.2	164.3	1.1	162.6	-0.6	164.7	1.5	166.0	2.8	165.5	2.3	167							
WITSA	N/A	-0.4	N/A	0.7	N/A	1.1	N/A	3.4	N/A	3.3	N/A	2.6	N						
AB2FH	8.5	7.9	-0.6	6.5	-2.0	7.6	-0.9	7.3	-1.2	7.7	-0.8	8.0	-0						
OB_FH	N/A	3.5	N/A	4.2	N/A	4.2	N/A	3.9	N/A	3.3	N/A	4.1	N						
OJ_OC	N/A	3.6	N/A	4.4	N/A	4.6	N/A	4.1	N/A	3.6	N/A	4.2	N						
U6L6D	N/A	0.5	N/A	-0.2	N/A	0.1	N/A	1.9	N/A	2.4	N/A	2.7	N						
TFHNP	104.4	106.4	2.0	108.8	4.4	111.7	7.3	116.2	11.8	119.9	15.5	126.7	22						
LFHNP	60.0	61.3	1.3	62.7	2.7	63.5	3.5	66.4	6.4	69.2	9.2	72.5	12						
PLHNP	0.57	0.58	0.0	0.58	0.0	0.57	0.0	0.57	0.0	0.57	0.0	0.57							
IIANG	N/A	138.7	N/A	131.5	N/A	131.3	N/A	129.7	N/A	127.7	N/A	127.0	N						
IMPA	N/A	86.9	N/A	92.3	N/A	91.1	N/A	94.6	N/A	95.5	N/A	97.0	N						
U1SNA	N/A	79.6	N/A	76.4	N/A	74.6	N/A	76.7	N/A	74.4	N/A	75.8	N						
COPAD	88.7	90.0	1.3	89.9	1.2	89.6	0.9	92.9	4.2	97.1	8.4	99.6	10						
COPOD	101.1	105.6	4.5	106.6	5.5	107.3	6.2	111.4	10.3	116.8	15.7	120.2	19						
SADLA	130.9	129.3	-1.6	127.0	-3.9	129.4	-1.5	128.7	-2.2	127.2	-3.7	128.7	-2						
NLANG	282.6	275.4	-7.2	269.1	-13.5	270.6	-12.0	270.4	-12.2	271.2	-11.4	267.6	-15						
ULIPE	-1.7	-2.0	-0.3	-1.2	0.5	-0.7	1.0	0.0	1.7	-0.7	1.0	1.2	2						
LLIPE	-1.6	-3.2	-1.6	-1.8	-0.2	-1.6	0.0	-0.6	1.0	-2.1	-0.5	-0.7							

Anatomic Angular and Lin[ear]

Collection UOP Mathews

Image	1 - Age 7	2 - Ag[e 8]
Measure	Value	Value
SNA	81.6	81.8
SNB	75.1	76.6
ANB	6.5	5.3
NP2PA	-2.2	-0.7
NP2PO	6.4	7.3
SNDST	71.8	72.4
SNFHA	11.0	9.0

Figure 9. A representative portion of the available tables for Case 001 of the Mathews collection.

For this reason, it is desirable that viewers have available a mechanism for knowing where each landmark actually was located on each image in the data set; the *Overlay* button, therefore, is provided. Pressing on this button yields the display of a map of the current image showing the precise position at which each landmark has been located (Fig. 10). As a further control against ambiguity, the name of each landmark can be displayed at its location by pressing the *Labels* button (Fig. 11). We believe that information from Figures 10 and 11 will be of considerable utility in the teaching of cephalometric principles to dental students and novice orthodontic residents.
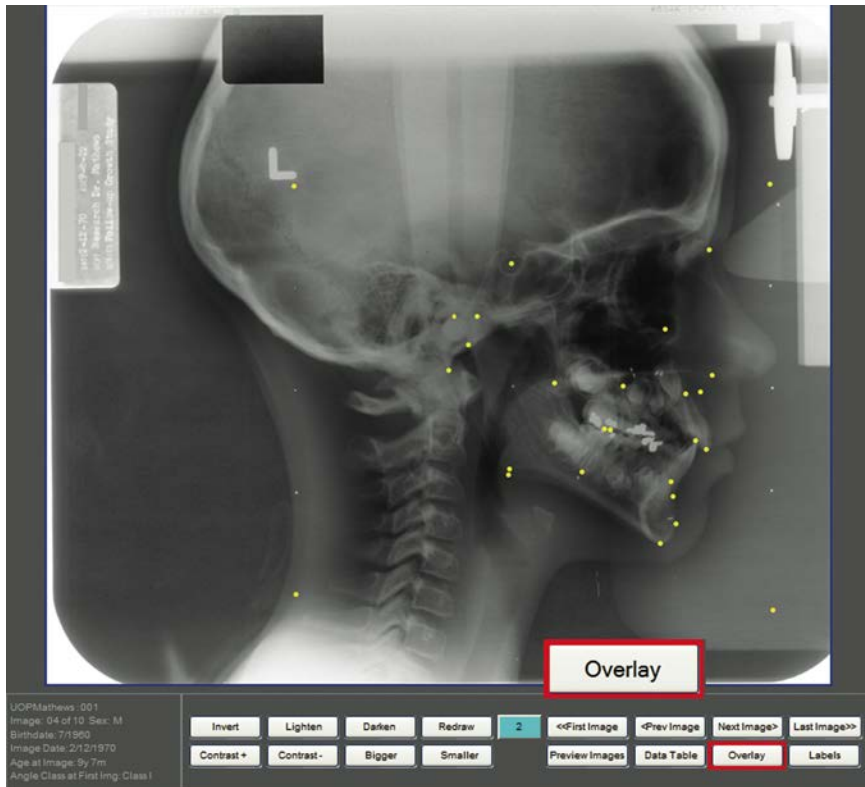
Figure 10. Overlay showing locations of all landmarks whose coordinates are available on the nine year four month lateral cephalogram for case 001 of the Mathews sample.
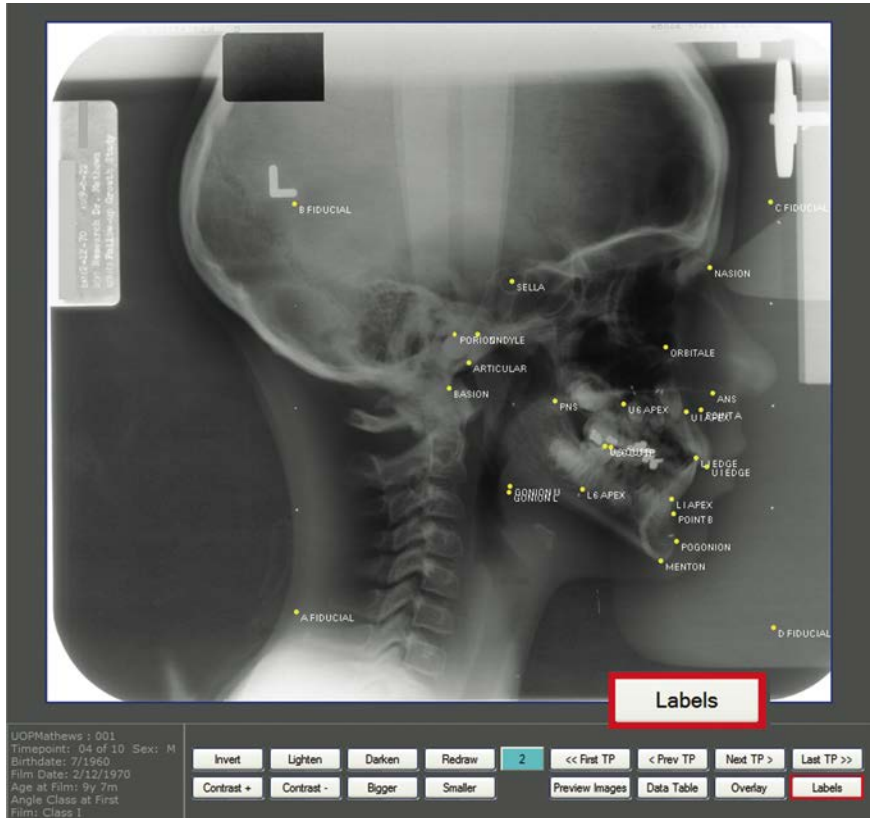
Figure 11. The lateral cephalogram from Figure 10 with the names of all available landmarks displayed.

A number of other functions were developed during phase 1 and already are available on the website. The most notable of these is the *Search* mechanism accessible through a link located at the bottom of the homepage navigation bar (Fig. 12). Even at its early stage of development, the search function already enables the user to query any or all collections on the site for cases for specific demographic characteristics or for particular values for any cephalometric measurement available in the database. When numerical values found through search are found to be of special interest, the images from which they originated can be displayed directly through links made available in the searching process. We believe this mechanism has great potential value for use in constructing subsamples from the collection for future hypothesis testing research.

Figure 12. Query form for searching the collections.

IMPLEMENTATION OF STAGE II

Based on the success of stage I, the AAOF has authorized funding of the second and final stage of its participation in the legacy collection project. The goal is to acquire and make available a set of approximately 1000 case series that roughly are distributed equally among participating collections. In this phase, a strong attempt is being made to collect a stratified random sample that is representative of the holdings of the individual collections weighted to represent Angle Class III and Angle Class II cases more heavily than they are represented in the general population. This approach is being taken on the grounds that these categories generally represent the greatest challenges to therapeutic intervention in orthodontics.

The system will be capable of incorporating data from serial images of various types including lateral, frontal, oblique, panoramic and periapical x-ray images of the skull and teeth, as well as quantifiable three-dimensional (3D) renderings of dental study casts. Collateral growth records such as wrist and long bone x-ray images and anthropometric measurements may be included when available. The system will be designed to accommodate remote input from craniofacial investi-

gators, clinicians and students at different venues throughout the world. The input part of the system will include provision for remote data acquisition including image calibration and will accommodate replicate estimates of landmark location from evaluators at different locations.

A search mechanism integrated into the system will make it possible to output statistics for individuals and groups of subjects with different patterns of craniofacial and dental development. Searches by remotely located users will be executable based on demographic characteristics as well as large number of measured and computed parameters.

The availability of this system will facilitate the collection of otherwise unobtainable historical control data on developmental changes through time in untreated subjects with different craniofacial patterns and dental configurations. In this way, it will become possible to partition growth effects from treatment effects in future studies of the effectiveness of various therapeutic interventions.

CONCLUSIONS

In addition to its primary role of preserving irreplaceable longitudinal records of craniofacial development, the AAOF Lexington Legacy Growth Collection represents an important landmark in the development of open collaborative databases for orthodontic research and teaching. For the first time, investigators from several different institutions have joined together to make original materials from their collections available to their colleagues at other institutions and to the orthodontic community *via* the Internet. The collaborating curators and their institutions are listed in Table 3.

This important collaboration has been made possible through the combined efforts of the orthodontic community under the leadership of the AAOF, its Board of Directors and its Executive Vice President, Robert Hazel. The project they conceived and sponsored has been funded by the members and friends of the AAO acting through the Legacy 300, a group of orthodontists and friends organized specifically to support this project.

In addition, we need to recognize the seminal contributions of the founders and investigators who conceived and developed the individual participating collections many years ago and whose devoted work will be memorialized on the website itself. Finally, we wish to recognize the support and dedication of the faculty and residents of a large number of

Table 3. Available growth collections.

PARTICIPATING COLLECTION	INSTITUTION	CURATOR
Bolton-Brush Growth	Case Western University	Dr. Mark Hans
Burlington Growth	University of Toronto	Dr. Bryan Tompson
Denver Growth	University of Oklahoma	Dr. Frans Currier
Fels Longitudinal	Wright State University	Dr. Richard Sherwood
Forsyth Twin	Forsyth Institute	Dr. Phil Stashenko
Iowa Growth	University of Iowa	Dr. Tom Southard
Mathews Growth	University of the Pacific	Drs. Shelly Baumrind & Heesoo Oh
Michigan Growth	University of Michigan	Dr. James A. McNamara
Oregon Growth	Oregon Health & Sciences University	Drs. David Covell & Jennifer Crowe

teaching programs who have helped in gathering the data that make it possible for the first time to search a substantial collection of craniofacial growth records remotely using classical orthodontic criteria.

Thus, the AAOF Legacy Collection is both a link to the past and a vision of the future of the orthodontic specialty. It is a work in progress, dynamically changing with the addition of new material and new search capabilities. We invite the reader to explore its current status at www.AAOFLegacyCollection.org.

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