Chapter 3.20

Software Support for Advanced Cephalometric Analysis in Orthodontics

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ABSTRACT

Cephalometric analysis has been a routine diagnostic procedure in Orthodontics for more than 60 years, traditionally employing the measurement of angles and distances on lateral cephalometric radiographs. Recently, advances in geometric morphometric (GM) methods and computed tomography (CT) hardware, together with increased power of personal computers, have created a synergic effect that is revolutionizing the cephalometric field. This chapter starts with a brief introduction of GM methods, including Procrustes superimposition, Principal Component Analysis, and semilandmarks. CT technology is discussed next, with a more detailed explanation of how the CT data are manipulated in order to visualize the patient's anatomy. Direct and indirect volume rendering methods are explained and their application is shown with clinical cases. Finally, the Viewbox software is described, a tool that enables practical application of sophisticated diagnostic and research methods in Orthodontics.

INTRODUCTION

Diagnostic procedures in Orthodontics have remained relatively unaltered since the advent of cephalometrics in the early 30's and 40's. Recently, however, the picture is beginning to change, as advances in two scientific fields and dissemination of knowledge and techniques to the Orthodontic community are already making a discernible impact. One field is the theoretical domain of geometric morphometrics (GM), which provides new mathematical tools for the study of shape, and the other is the technological field of computed tomography (CT), which provides data for three-dimensional visualization of craniofacial structures.

This chapter is divided into three main parts. The first part gives an overview of basic mathematical tools of GM, such as Procrustes superimposition, Principal Component Analysis, and sliding semilandmarks, as they apply to cephalometric analysis. The second part discusses the principles of CT, giving particular emphasis to the recent development of cone-beam computed tomography (CBCT). The final part reports on the Viewbox software that enables visualization and measurement of 2D and 3D data, particularly those related to cephalometrics and orthodontic diagnosis.

GEOMETRIC MORPHOMETRICS

Geometric morphometrics uses mathematical and statistical tools to quantify and study shape (Bookstein, 1991; Dryden & Mardia, 1998; Slice, 2005). In the domain of GM, shape is defined as the geometric properties of an object that are invariant to location, orientation and scale (Dryden & Mardia, 1998). Thus, the concept of shape is restricted to the geometric properties of an object, without regard to other characteristics such as, for example, material or colour. Relating this definition to cephalometrics, one could consider the conventional cephalometric measurements of angles, distances and ratios as shape variables. Angles and ratios have the advantage that they are location- and scale-invariant, whereas distances, although not scale-invariant, can be adjusted to a common size. Unfortunately, such variables pose significant limitations, a major one being that they need to be of sufficient number and carefully chosen in order to describe the shape of the object in a comprehensive, unambiguous manner. Consider, for example, a typical cephalometric analysis, which may consist of 15 angles, defined between some 20 landmarks. It is obvious that the position of the landmarks cannot be recreated from the 15 measurements, even if these have been carefully selected. The information inherent in these shape variables is limited and biased; multiple landmark configurations exist that give the same set of measurements. A solution to this problem (not without its own difficulties) is to use the Cartesian (x, y) coordinates of the landmarks as the shape variables. Notice that these coordinates are also distance data (the distance of each landmark to a set of reference axes), so they include location and orientation information, in addition to shape. However, the removal of this 'nuisance' information is now more easily accomplished, using what is known as Procrustes superimposition.

Procrustes Superimposition

Procrustes superimposition is one of the most widely used methods in GM (Dryden & Mardia, 1998; O'Higgins, 1999; Slice, 2005). It aims to superimpose two or more sets of landmarks so that the difference between them achieves a minimum. There are various metrics to measure the difference between two sets of landmarks, but the most widely used is the sum of squared distances between corresponding points, also known as the Procrustes distance. Therefore, Procrustes superimposition scales the objects to a common size (various metrics can be used here as well, but centroid size (Dryden & Mardia,

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