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Invited Paper

The primal sagittal plane of the head: a new concept

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Abstract. To assess facial form, one has to determine the size, position, orientation, shape, and symmetry of the different facial units. Many of these assessments require a frame of reference. The customary coordinate system used for these assessments is the 'standard anatomical frame of reference', a three-dimensional Cartesian system made by three planes: the sagittal, the axial, and the coronal. Constructing the sagittal plane seems simple, but because of universal facial asymmetry, it is complicated. Depending on the method one selects, one can build hundreds of different planes, never knowing which one is correct. This conundrum can be solved by estimating the sagittal plane a patient would have had if his or her face had developed symmetrically. We call this the 'primal sagittal plane'. To estimate this plane we have developed a mathematical algorithm called LAGER (Landmark Geometric Routine). In this paper, we explain the concept of the primal sagittal plane and present the structure of the LAGER algorithm.

Key words: primal frame of reference; primal sagittal plane; midsagittal plane; three-dimensional; head; anatomical; geometry; deformity quantification; orthognathic; craniomaxillofacial; dentofacial.

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At first glance, building a sagittal plane for a head seems simple. This simplicity stems from the fact that when we envision this task, we picture doing it on a perfectly symmetrical subject. Unfortunately, no human head is perfectly symmetrical.[1,2] In facial asymmetry, we can build hundreds of different sagittal planes, not knowing which one is correct.

So, how can we build a sagittal plane for an asymmetric head? One solution is to use the 'orthogonal best-fit method'. In this method, a computer algorithm first creates a three-dimensional (3D) Cartesian system comprised of three orthogonal planes. Then the algorithm translates and rotates the frame of reference until the sum of distances between the planes and key craniofacial landmarks is minimal. Unfortunately, the orthogonal best-fit method is flawed.

Another solution for building a sagittal plane for patients with asymmetric heads is to use the natural head posture (NHP).[6,8] Unfortunately, the NHP method is inconsistent for two reasons. First, some patients have difficulty aligning their heads in the NHP. Second, even within the same patient, there are temporal variations in the NHP.

In order to solve this clinical problem, we first sought to answer a fundamental question: What is the ideal plane of symmetry for any patient? At conception, our genes are programmed to produce perfect facial symmetry, yet this never occurs. We know this because no individual has perfect facial symmetry.[1,2] To various degrees, we are all asymmetric; a multitude of stressors influence craniofacial development, resulting in asymmetry. Yet to measure facial deformity and to plan its correction there is no better frame of reference than the one a subject would have had if he or she did not have asymmetry.[4] We call this the 'primal frame of reference'.

To estimate this plane we have developed a mathematical algorithm called LAGER (Landmark Geometric Routine). In this paper, we explain the concept of the primal sagittal plane and present the structure of the LAGER algorithm.

Estimation of the primal sagittal plane

The estimation of the primal sagittal plane is a challenging and fascinating problem. Fortunately, we have made significant progress, and now have a method that works very well in most circumstances. We have codified the solution in an algorithm we call LAGER, for Landmark Geometric Routine.

Landmark Geometric Routine (LAGER)

The goal of LAGER is to estimate the best plane of symmetry for an asymmetric individual. As its name implies, it uses landmarks—discrete anatomical points—for its calculations. The sagittal plane (the plane of symmetry of the body) can be easily calculated for an individual with body symmetry. The difficulty arises when the body is asymmetric. In this circumstance, asymmetric landmarks skew the sagittal plane. Yet removing the displaced landmarks can prevent the distortion. Our algorithm uses this principle to determine the best plane of symmetry.

LAGER is easier to comprehend by looking at a simple example. Consider a young butterfly that is exposed to pesticides early in life. Because of the exposure, its right hind-wing overgrows (Fig. 1). We get to see the butterfly, for the first time, as a deformed adult. To analyze its form, we take a picture looking at it from above. On the picture, we identify two midline landmarks and five bilateral landmarks. The midline landmarks m1 and m2 delimit the butterfly's body, m1 being anterior and m2 being posterior. The bilateral landmarks demarcate the outline of the wings (Fig. 2).

When trying to examine the butterfly's asymmetry, our first inclination is to compare the right and left sides after we have superimposed them. For the superimposition, we will most likely fold one of the butterfly's sides on its body axis—the line demarcated by m1 and m2. As a result of the assessment, we will conclude that the forewings and the hind-wings are asymmetric (Fig. 3). Yet we know that only the hind-wing was deformed (Fig. 1).

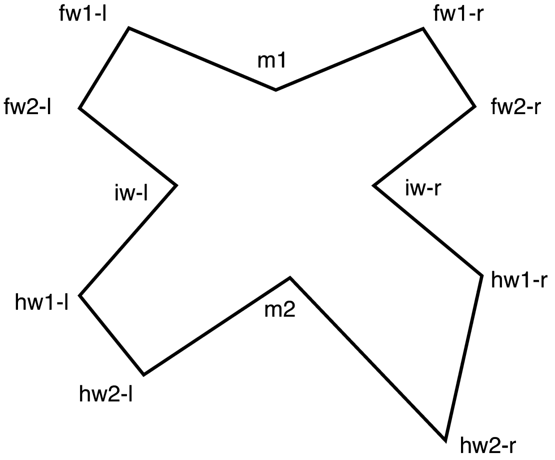

Fig. 2. The mature butterfly as seen for the first time by an observer. Two midline landmarks (m1 and m2) delimit the body. Five bilateral landmarks delineate the wings: forewing 1 (fw1), forewing 2 (fw2), interwing (iw), hind-wing 1 (hw1), and hind-wing 2 (hw2); '-r' denotes right, '-l' denotes left.

But what if we knew the primal sagittal plane for the butterfly? Would an analysis of form based on this plane have shown us the truth? Conveniently, our butterfly is synthetic (a man-made thought experiment). Thus, we can answer this question. In Fig. 4, we superimpose the right and left sides of the butterfly by folding one of its sides on the primal axis of symmetry. As you can see, this approach correctly shows that the forewings are symmetrical, only the hind-wings are uneven.

LAGER estimates the best plane of symmetry in three steps. The first step scores all landmarks for their degree of asymmetry, the second step removes the most asymmetric landmarks, and the third step calculates the sagittal plane.

To detect asymmetric structures, LAGER uses a Procrustes method.[7,9] Geometric objects have four basic characteristics: size, location, orientation, and shape. An ordinary Procrustes analysis is a mathematical method that detects shape differences between similar objects. The analysis begins by superimposing the objects optimally. For the superimposition, the objects are first translated to the same location. Next, they are scaled to the same size. Then, one of them is kept static as a target, while the other is rotated until the sum of the (squared) distances between corresponding landmarks is minimized.

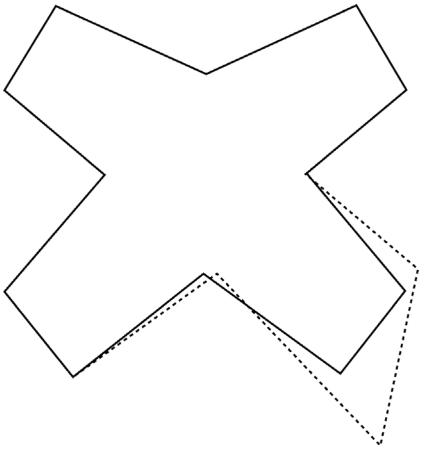

Fig. 1. A young butterfly (solid line) grows abnormally (dashed line). Its right hind-wing overgrows. The dashed drawing is scaled down to show the differences in shape.

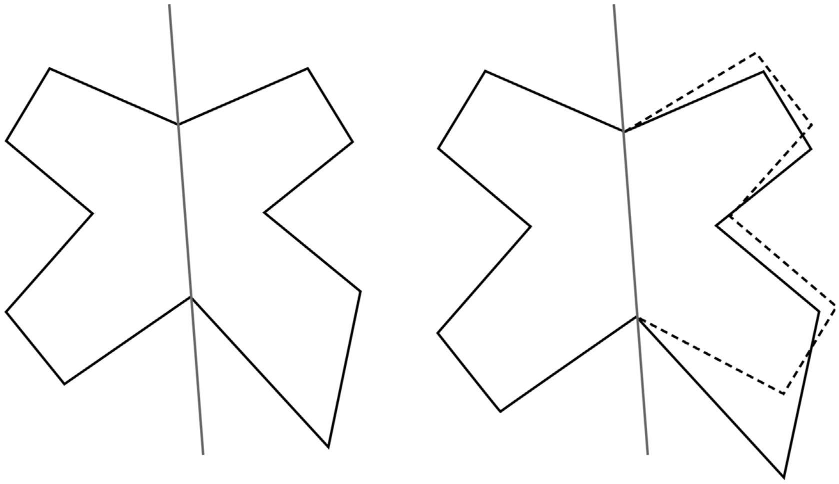

Fig. 3. Our intention is to evaluate the butterfly's form by superimposing one side over the other. For the superimposition, we will fold one of the sides over the visible midline. This analysis will lead us to conclude that both the forewing and the hind-wing are deformed. Yet we know this is not true.