Individualized Ideal Arches

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The search for a universal, ideal arch form has been one of the most persistent but elusive tasks that orthodontic researchers have pursued. Practically every arch form study has used similar raw material — namely, a collection of orthodontically untreated, superior occlusions. And yet, very few of the published studies come close to agreement about the natural shape of dental arches. Why the lack of agreement? It would seem that if a scientific conclusion were valid, it could easily be reproduced and verified. But, that certainly has not been true with arch form determination.

Even though various researchers have arrived at different conclusions while using similar data, a review of the literature shows that most have labored under at least three common presumptions. The first presumption is that there must be an algebraic or geometric formula to determine ideal arch form. A second presumption is that every ideal arch form must adhere to a generalized scheme; that is, a form that is of the same quality, differing only in size. A third and very important presumption is that every ideal arch is considered to be symmetrical. This last presumption is directly related to the mathematical equations used, which make it impossible to produce asymmetry. Equations are, by definition, equal values.

Current Techniques of Arch Form Predetermination

There are four currently popular formulae for arch shape determination: the Bonwill-Hawley formula, the Brader arch forms, the catenary arch design, and the Rocky Mountain Data Systems computer-derived formulae.

Bonwill-Hawley Arch Design

The Bonwill-Hawley arch formula produces a geometric design, based upon the combined mesiodistal widths of the incisors and cuspids. The reader is referred to other sources for the exact construction technique.[6] Bonwill felt that the arc of the anterior teeth could be related to an equilateral triangle. Although the Bonwill-Hawley theory has largely been discredited,[7] it is still widely used. The shape of an ideal archwire purchased from an orthodontic supply company will most likely be of the Bonwill-Hawley design.

Brader Arch Design

The Brader arch designs[8] which are known as trifocal ellipses excited orthodontists in 1972 because their design and mathematical basis seemed to make sense in that it could explain, by the formula PR=C, how teeth arranged themselves in response to the pressures exerted on them. The selection of a Brader form is based on arch width at the second molars as measured at the facial, gingival surface. The Brader arch adapts to the facial surfaces of the teeth and all of the forms are alike in shape. They differ in size as dictated by the widths at the second molars.

The Brader arches offered a convenience heretofore unavailable to orthodontists, since one simple measurement provided arch forms for both

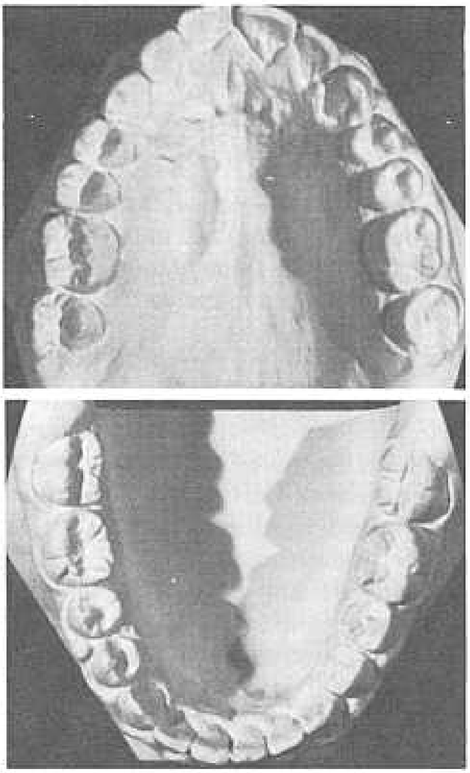

Fig. 1 Typical narrowing of cuspids treated with Brader arch forms.

arches. The maxillary arch form is always one size larger than the mandibular and coordination of working archwires throughout treatment is greatly simplified.

The main clinical criticism of the Brader arches is that when those forms are followed explicitly, there is often severe narrowing in the cuspid areas (Fig. 1).

Catenary Arch Design

The catenary design is also determined by intermolar widths, but measured from central fossa to central fossa.[9] The catenary curve is simply that curve which results when a fine chain is suspended at its two ends. The catenary curve could be described as a central core or central perimeter around which the teeth arrange themselves.

A great deal of time has been spent proving and disproving that catenary arches are Nature's way of arranging the dental arcade.[10,11,12] The primary intellectual force behind the catenary's popularity is the work of MacConaill and Scher.[13] They feel that, from biological and engineering points of view, the catenary is the simplest curve possible, and the catenary is easily explained mathematically. MacConaill and Scher acknowledge some deviations from this "pure form", but suggest that these are due to pathological forces that occur during eruption of the teeth and subsequent alveolar development. Burdie and Lillie[14] found that a basic bony arch is established as early as 9.5 weeks in utero and they suggested that this basic arch was of a catenary design. However, their own evidence shows many arches which were arranged outside of the catenary form and certainly this is before any pathological force has disturbed the catenary "pure form".

Computer-derived Arch Design

The Rocky Mountain Data Systems computer-derived formula relies upon measurements taken from intermolar width, intercuspid width, and arch depth as measured from the facial surface of the incisor to the distal surface of the terminal molar. This allows the computer to be programmed with Cartesian x and y coordinates that are necessary for a two-dimensional, computer-derived formula. Facial type is also considered in this arch computation.[15,16,17]

All of these techniques have one common area of agreement, acknowledging that the anterior part of the dental arch is part of a curve. That is about as far as the agreement goes, because the shape of that anterior arc is a point of contention. This curve has been described as an ellipse,[1] a parabola,[2] part of a trifocal ellipse,[3] and a catenary.[4,5] Each advocate can, of course, demonstrate why his description is the most accurate.

This study was undertaken to see how a collection of ideal, untreated arches conformed to the predetermined arch forms of the most popular formulae, and to come to conclusions, if possible, about how reasonable, ideal arch forms can be derived for individual patients. Dental casts of twenty-four orthodontically untreated, superior, adult occlusions were collected. Tracings of the teeth were made on acetate paper and overlays were constructed and superimposed.

Evaluation of Closeness of Fit

The simplest system for evaluating the closeness of fit of our collection of arches with the various arch designs was to score them in some reasonably standardized fashion as "good fit", "moderately good fit", or "poor fit" (Fig. 2). This evaluation is, of course, subjective and not without some degree of error. Yet, the results (Table I) are interesting.

Only 8% of the Bonwill-Hawley designs could be considered a good fit, while 52% were poor fits. The Brader designs had two more good fits, but the percentage was still low at 12.5%. Catenaries had more good fits than the previous two combined, but the percentage was still only 27%; and there was an equal percentage of poor fits. The RMDS computer-derived arch designs, impressively, had no poor fitting designs, but had only two arches that could be called good fitting designs. Since only lower arches are computed by RMDS, the sample number is one half that of the other designs. 92% of the RMDS designs were judged to be moderately good fits.

After this study was completed, RMDS recognized the possibility of arch asymmetry and changed its computer analysis method to use a different mathematical curve for each side of the asymmetric patient. This can be expected to greatly increase the number of "good fits" in the RMDS results shown in Table I.

Absence of Arch Symmetry

Aside from providing a comparison of various techniques currently used for arch form selection, this study also provided information contradic-

TABLE I
24 untreated superior adult occlusions evaluated for fit to various arch designs.

	Good Fit		Moderately Good Fit		Poor Fit	
	#	%	#	%	#	%
Bonwill-Hawley	4	8.33%	19	39.58%	25	52.08%
Brader	6	12.50%	21	43.75%	21	43.75%
Catenary	13	27.08%	22	45.83%	13	27.08%
RMDS	2	8.33%	22	91.67%	—	—

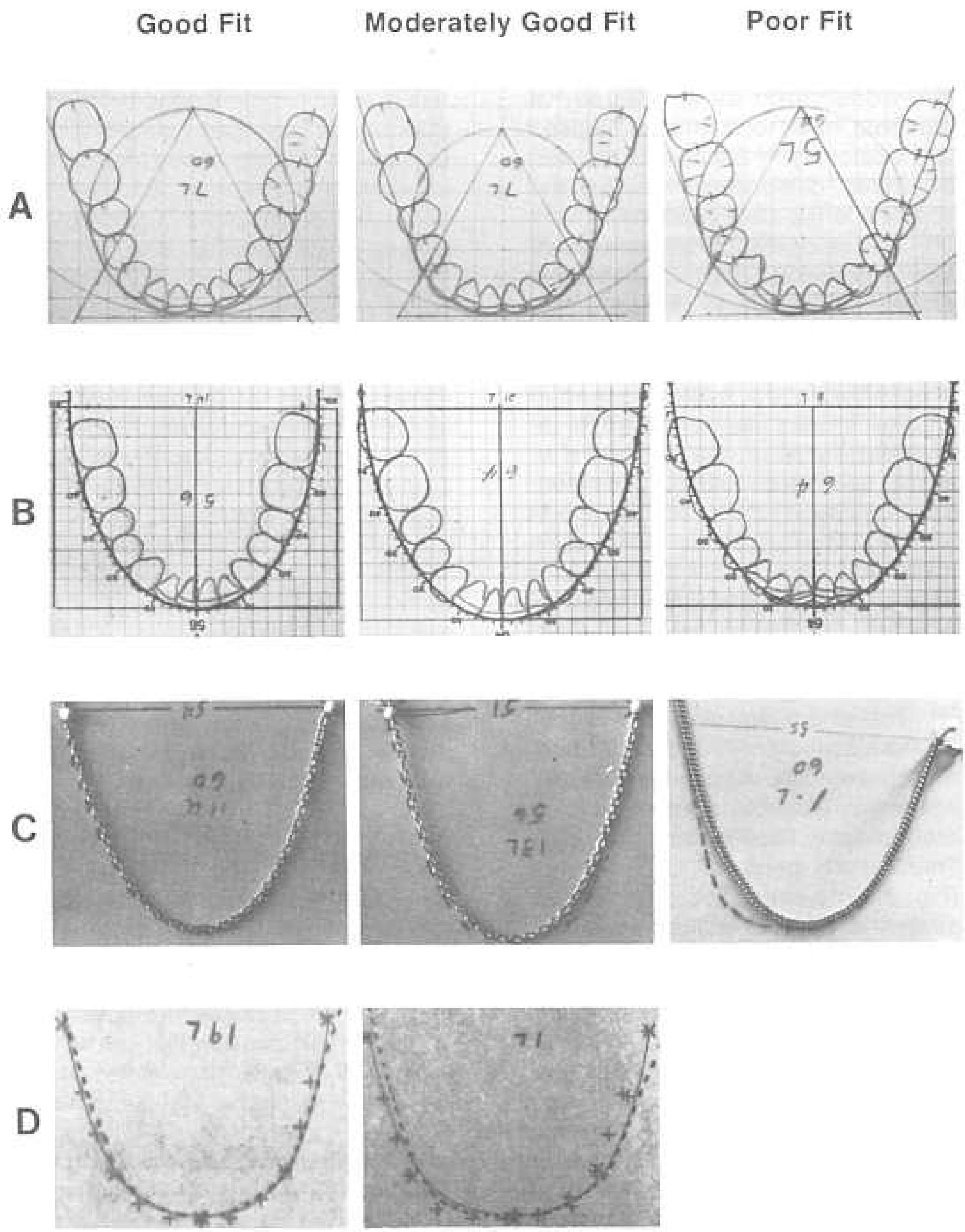

Fig. 2 Method used to evaluate fit of various predetermined ideal arches by superimposition on tracing of natural occlusion in sample of 24 untreated superior adult occlusions. A. Bonwill-Hawley. B. Brader. C. Catenary. D. RMDS.

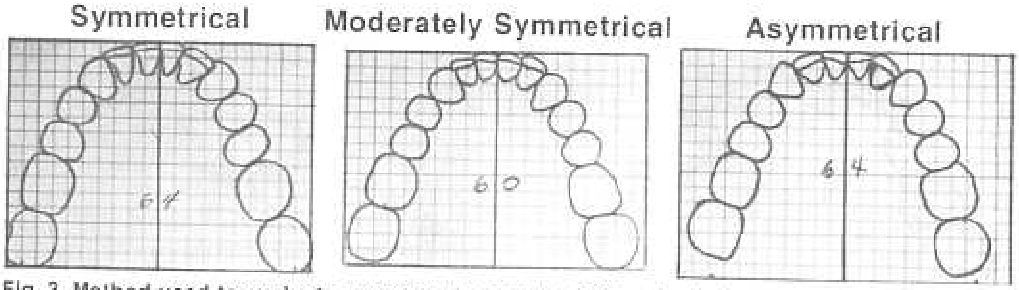

Fig. 3 Method used to evaluate symmetry in sample of 24 untreated superior adult occlusions.

tory to one of the three basic presumptions, symmetry of arches. The most conspicuous finding was the almost total absence of true arch symmetry among our collection of models. Each occlusal tracing was copied onto graph paper and set within a rectangle to study arch symmetry. Symmetry displayed by the arches was scored as "symmetrical", "moderately symmetrical", and "asymmetrical" (Fig. 3). Tabulation (Table II) showed that only 6.25% were evaluated as symmetrical.

This discovery of an asymmetric tendency tempts one to ask if, perhaps, the pursuit of a symmetrical arch is not an affront to Nature that guarantees a degree of relapse. It would seem that a more accurate arch form would allow for any asymmetry that Nature provides because of tooth size, muscle attachments, or anatomical variations.

Another obvious discovery was that no generalized, universal arch form seems to be applicable. Although a number of cases showed some similarities, this study offers abundant evidence that arch form is the unique expression of individual development and probably no universal design will ever be able to account for the many small, but significant, variations in the arch shape of individuals.

Although algebraic and geometric formulae have been used to design ideal arch forms, they have all relied upon the presumption of symmetry which this study now brings into question. Any mathematical formula that is accurate in predetermining arch form will have to account for the many nuances and variations individuals have, and to date, none of the formulae offered have done that.

Fabrication of Ideal Arch Forms

While it is instructive to know what doesn't work in arch form predetermination, that knowledge doesn't provide much help for the clinical orthodontist

TABLE II
24 untreated superior adult occlusions evaluated for symmetry.

	Symmetrical	Moderately Symmetrical	Asymmetrical
Number	3	27	18
Percent	6.25%	56.25%	37.5%

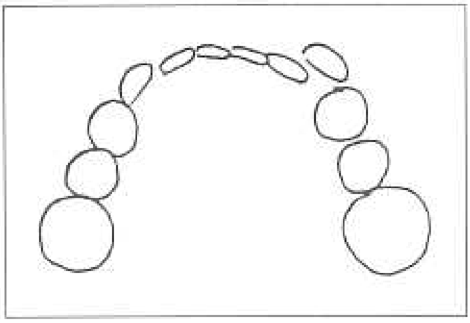

Fig. 4 Occlusal map of lower arch.

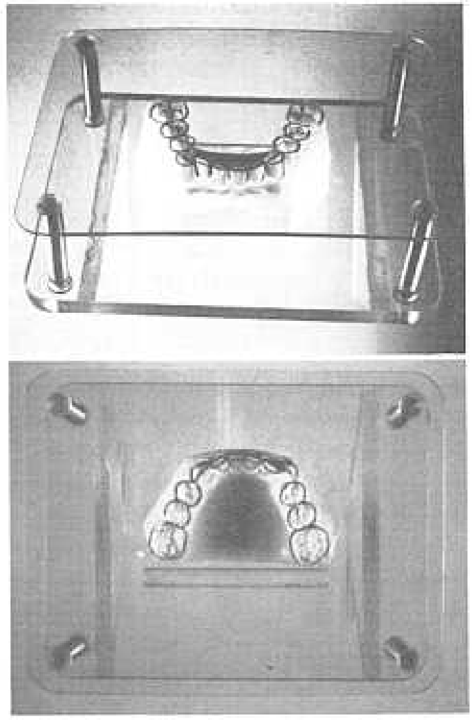

Fig. 5 Occlusal map maker.

who is still faced with the dilemma of selecting an accurate and reasonable arch form for a particular patient.

One of the most clinically significant findings in this study is that teeth apparently arrange themselves in an arc that is dictated mainly by the osseous bases of the jaws. These natural arch perimeters can be found by drawing a dotted line through the mesiodistal dimension of each tooth and connecting the lines across the proximal contacts. This line will represent the center of the basic arch perimeter that is available for the support of the teeth. Even when the occlusion is imperfect and the teeth are badly rotated, this osseous supportive arc can still be outlined on a piece of acetate paper that is placed over a 1:1 occlusal reproduction (Fig. 4). This reproduction may be fabricated from an occlusal x-ray or photo, or with a simple occlusal map maker (Fig. 5). Teeth that are outside this smooth, continuous natural arc are easily identified and should not confuse the clinician as he outlines the central perimeter (Fig. 6 A,B). The occlusal shape of each tooth can then be traced in an ideal position on this basic arc and a customized ideal arch form can be constructed and

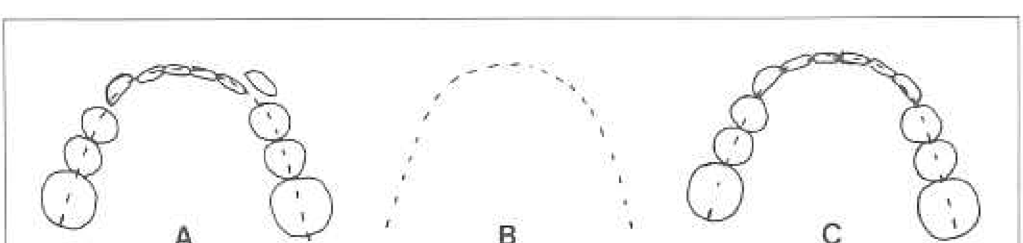

Fig. 6 Occlusal mapping. A. Natural arch perimeter drawn on occlusal map. B. Natural arch perimeter without map. C. Idealized occlusal map drawn by lining up teeth on natural arch perimeter.

used throughout treatment (Fig. 6 C).

This occlusal map also permits the clinician to make highly accurate arch length discrepancy measurements by superimposing the idealized arch form on the original (Fig. 7). There isn't any feature of orthodontic diagnosis and treatment planning more arbitrary than these measurements.[25,26,27,28] But, highly accurate arch discrepancy measurements are possible with this approach.

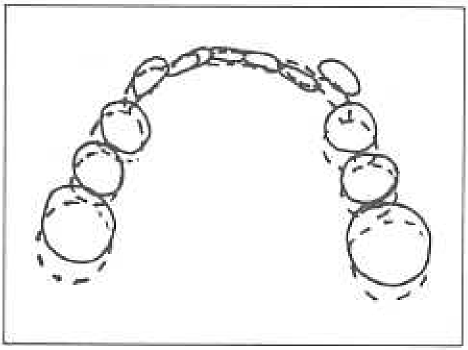

Fig. 7 Arch length discrepancy measured by superimposing idealized arch form on the original.

Eyeballing Versus Mapping

It is interesting to compare eyeballed discrepancy measurements with those done using an occlusal map. There is often as much as 3-4mm difference between the two methods, and this can easily change a treatment plan. Here are two cases in point.

The first case was a patient with a Class II malocclusion with what appeared to be a great deal of arch length discrepancy (6-8mm). There was a moderately large convexity and overjet, and a deep overbite. The treatment plan decided upon was to extract four second bicuspids. The esthetic result was less than gratifying.

As arch length reassessment was made post-treatment, using the technique of occlusal mapping (Fig. 8). It revealed that there never was a real discrepancy, and this case should have been treated nonextraction. This mode of treatment would have produced much less flattening of the profile.

The second case was a patient with a Class I malocclusion with what appeared to the eye to be a little arch length discrepancy, needing only enough space to allow the cuspids to erupt. The profile was rather flat, so a nonextraction treatment plan was begun. Within six months it became obvious that there was too much crowding to expect success with nonextraction treatment, and a reassessment was done using the occlusal

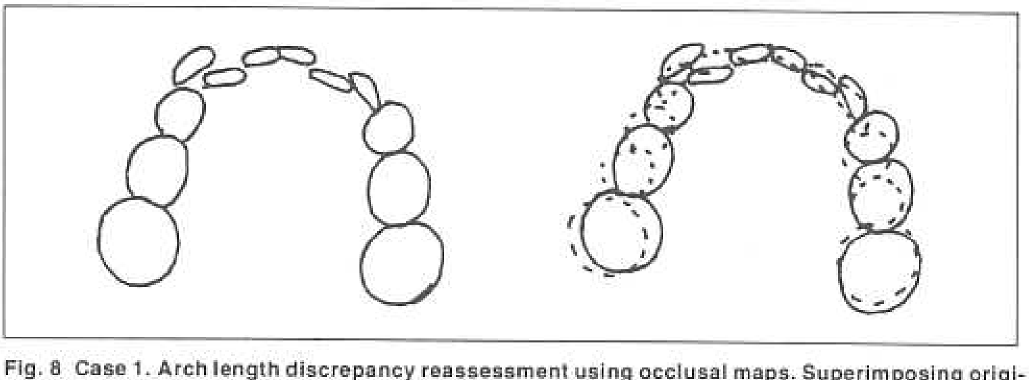

Fig. 8 Case 1. Arch length discrepancy reassessment using occlusal maps. Superimposing original (solid) and idealized (broken) reveals zero net discrepancy.

map technique (Fig. 9). The "little" discrepancy we now discovered amounted to 5mm. The treatment plan was altered to extraction of maxillary first and mandibular second bicuspids and treatment proceeded to a successful conclusion.

These cases illustrate the importance of accurate arch length discrepancy measurements and how occlusal map technique can facilitate these measurements.

Arch Expansion

Apparently, under ordinary circumstances, Nature does little to change the effective arch size. A study at the University of Michigan[18] showed that even though the distance between cuspids, premolars, and molars usually increased during growth, the effective arch perimeter (which is an arc constructed from the mesial midpoint of one mandibular first permanent molar through the proximal contacts of adjacent teeth and around to the mesial midpoint of the other mandibular first permanent molar) reaches a maximum around 9-10 years of age and then begins to decrease, possibly in response to proximal wear. From this work, it seems fairly clear that the arch dimension with which the orthodontist must work does not have an innate ability to enlarge and, in fact, can be depended upon to decrease in size.

Further studies by Riedel, et al[19,20,21] have shown that expanded cuspids and molars should not be expected to hold their expansion in the post-retention phase. Gardner and Chaconas[22] made an exhaustive review of the literature on arch enlargement and did an independent study. Their findings were that one should not expect cuspids to retain expansion, but that occasionally molars could retain up to 2mm expansion. It is interesting to note that the arch depth of these expanded (nonextraction) cases as measured from first molars to incisors, decreased, so that the effective arch perimeter was not greatly altered.

So, advocating expanded arches on a routine basis seems to be risky. At least until someone can show, through a controlled study, that expanded arches can survive, dimensionally intact, in the post-retention phase, orthodontists might be well-advised to be wary of any technique that routinely advocates cuspid and molar expansion.

Maxillofacial surgery drastically alters the oral environment, but there aren't many fixed appliance orthodontic therapies that have been able to

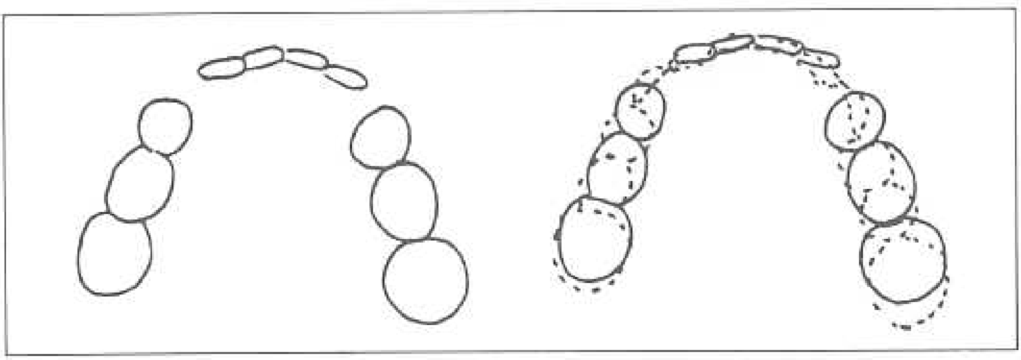

Fig. 9 Case 2. Arch length discrepancy reassessment using occlusal maps. Superimposing original (solid) and idealized (broken) reveals 5mm discrepancy.

demonstrate consistently successful enlargements in the inherited mandibular arch perimeter. Dr. Rolf Frankel is reported to have a collection of more than 400 cases that show conspicuous, permanent mandibular expansion, but this material has not been published and evaluated. Maxillary arches, of course, are more malleable and there is good evidence that enlargement can occur there and be permanently successful.[24]

Clinical experience has taught many orthodontists that the least change that occurs in the movement of teeth, the more enduring the change will be. That is, the teeth most prone to relapse are those that have had the most radical movement during treatment; and the most stable teeth are those that have had the least movement. If this empirical, clinical impression is biologically true, it only seems reasonable to work, as far as possible, within the environmental confines Nature has provided to an individual, and to avoid any unnatural movements, such as mandibular arch expansion.

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