ORIGINAL ARTICLE

The Royal London Space Planning: An integration of space analysis and treatment planning

Part I: Assessing the space required to meet treatment objectives

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The Royal London Space Planning process has evolved since 1985 to ensure a disciplined approach to diagnosis and treatment planning and to provide a record to justify treatment decisions for professional accountability. The analysis takes into consideration most aspects of a given malocclusion and aims to quantify the space required in each dental arch to attain the treatment objectives. Space planning also helps determine whether the objectives are likely to be attainable and helps in the planning of treatment mechanics and the control of anchorage. The process of analysis is divided into 2 sections. The first part consists of assessing the original malocclusion according to various component parts, any of which may have an effect on space if altered during treatment. These components are crowding and spacing, occlusal curves, arch width, anteroposterior position of labial segments, mesiodistal angulation, and incisor inclination. The second part of the analysis, which will be published in a separate article, deals with the effect of treatment procedures, such as extractions, tooth-size modifications, distal or mesial molar movements, as well as natural growth, on the space required. Space planning should be regarded only as a useful guide, as many areas of orthodontics—including growth, biological response, and patient compliance—cannot be controlled with total accuracy. (Am J Orthod Dentofacial Orthop 2000;118:448-55)

Over the years, the quality of orthodontic treatment has improved with the increasing sophistication of materials and appliance systems. As ideal occlusion has become a realistic goal for the treatment of many types of malocclusion, the need for a thorough understanding of how space is used within the dental arches increases.

Space analysis as a concept is not new. Most investigations have focused on specific areas, such as predicting the size of unerupted canines and premolars[1-4] or assessing the space required to flatten an occlusal curve.[5-7] The coordination of some of these elements into a space analysis can be found in most standard texts. Merrifield[8] described the comprehensive Total Dentition Space Analysis, in which the dental arch is divided into anterior, midarch, and posterior denture areas. Space in the presenting archform is assessed as being in deficit or in surplus, having made allowances for occlusal curves and incisor positions, using Tweed's diagnostic triangle. Extraction patterns are also suggested according to the analysis findings.

Merrifield et al[9] later presented the Cranial Facial Dental Analysis, which gives a difficulty score in the management of Class II cases by integrating the Total Dentition Space Analysis with the Cranial Facial Analysis.

The Royal London Space Planning has evolved since 1985 as part of the postgraduate training program at the Royal London Hospital. It is undertaken as part of the treatment planning process following a detailed clinical examination and radiographic and cephalometric analyses. It takes into consideration most aspects involved in the correction of a malocclusion. The theoretical basis is derived from the work of Andrews,[10] who stated that a space discrepancy will arise if the teeth do not conform to his "Six Keys to Normal Occlusion."

The purpose of the Royal London Space Planning is to quantify the space required in each dental arch to attain the treatment objectives in the permanent or late mixed dentition and to quantify the space implications of treatment mechanics. The concept is not prescriptive in terms of where the teeth should be or how the movements are to take place. This contrasts with the analyses described by Merrifield, which are associated with the Tweed philosophy and technique.

Specifically, space planning will help the clinician:

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Table I. Space planning form

ROYAL LONDON HOSPITAL - ORTHODONTIC SPACE PLANNING

Patient's name: ____________________ Date: ____________________

Treatment objectives:

1. ____________________
2. ____________________
3. ____________________
4. ____________________
5. ____________________

Space requirements:
+ = Space available or gained
– = Space required or lost

		LOWER		UPPER
Crowding and spacing:		_____mm		_____ mm
Leveling occlusal curve:		_____mm		_____ mm
Arch width change:		_____mm		_____ mm
Incisor A/P change:		_____mm		_____ mm
Angulation/inclination change:		_____mm		_____ mm
TOTAL		_____mm		_____ mm

Space creation/utilization in addition to any planned above

Tooth reduction/enlargement: (+ or –)		_____mm		_____ mm
Extractions:	+	_____mm	+	_____ mm
Space opening for prosthetic replacement:	–	_____mm	–	_____ mm
Molar distal movement:	+	_____mm	+	_____ mm
Molar mesial movement:	–	_____mm	–	_____ mm
Differential U/L growth: (+ or –)		_____mm		_____ mm
RESIDUE (should = 0)		_____mm		_____ mm

- To ensure a disciplined approach to treatment planning
- To define whether the objectives are attainable and modify them if necessary
- To anticipate a shortage of anchorage or excess of space
- To decide the need for extractions and choice of extractions
- To plan the mechanics of anchorage control
- To plan the mechanics of correction of arch relationship
- To improve pretreatment patient information
- To obtain valid informed consent

The process of space planning is carried out in 2 stages. The first is an assessment of space requirement, and the second is an assessment of any additional space to be created or used during treatment, including a prediction of anteroposterior molar movements required for occlusal correction and an estimation of future growth. The analysis is recorded for every patient about to undergo treatment (Table I).

ASSESSMENT OF SPACE REQUIREMENT

Although details of appliance prescription are not considered during the assessment of space, decisions are made regarding the aims of treatment. For example, the desired arch width and anteroposterior position of the labial segments are determined at this stage so that the appropriate space implications can be recorded.

Six specific aspects of the occlusion are considered for which any change has an effect on the space required. Detailed guidance is given below on each of these aspects, and notes on completion of the space planning form are presented in Table II. The measurements are taken and scores recorded to the nearest millimeter or, at times, half millimeter, and are positive when space is present or is created (eg, by incisor advancement) and negative when there is crowding or space is required (eg, for incisor retraction).

Crowding and Spacing

The difficulty when quantifying crowding is to decide "in relation to what." Clearly, crowding will be

Table II. Guidance notes on the completion of the space planning form

Space requirements	
Crowding and spacing:	Measure in relation to the line of arch that reflects the majority of teeth.
Level occlusal curve:	Assess the depth of curve from premolar cusps to a flat plane on distal cusps of first molars and incisors. Only one value is given for the arch, and only if the premolars have not been assessed separately as crowded. Allow 1 mm space for 3 mm depth of curve, 1.5 mm for 4 mm depth, and 2 mm space for a 5 mm curve (usually no allowance is necessary).
Arch width change:	Allow 0.5 mm space for each mm posterior arch width change. An increased amount of space creation can be recorded in cases of rapid palatal expansion.
Incisor A/P change:	Allow 2 mm space for each mm change. Assess the lower arch first and then correct the upper incisors to overjet 2 mm.
Angulation change:	Applies only to maxillary incisors. Allow 0.5 mm space for correction of each parallel sided vertical tooth (usually no allowance is necessary).
Inclination change:	Applies only to maxillary incisors. Allow 1 mm space for every 5° change affecting all 4 incisors, and 0.5 mm space if only 2 teeth are affected. As the space implications are relatively small, the angulation and inclination scores are combined on the space planning form.
The difference between the upper and lower space requirements reflects the molar relationship unless there is an upper/lower Bolton discrepancy.	
Space creation/use	
Tooth reduction:	Record the total mesiodistal enamel reduction for each arch. This may be to reshape an individual tooth or to relieve small amounts of crowding.
Tooth enlargement:	Record the space to be used by building up teeth pretreatment, or to be created if the build up is to be undertaken posttreatment.
Extractions:	Record the mesiodistal width of the permanent teeth to be extracted (excluding second and third molars). The extraction of primary teeth is not recorded except if the permanent successors are absent.
Space opening:	Record any space to be created or kept in the arches for prostheses.
Molar distal change:	Estimate the amount of distal movement required from molars during treatment. This frequently has to be adjusted in order to achieve a zero residue at the end of space planning. It is then necessary to assess whether the anticipated molar movements are realistic.
Molar mesial change:	Estimate the anticipated forward migration of molars, either due to active appliance treatment or anchorage loss.
Differential growth:	Estimate the A/P growth differences between the maxilla and mandible during treatment (not necessary for most patients). A positive upper space assessment applies to forward growing Class II cases, but a negative lower assessment applies for the creation of additional space in Class III cases where a deterioration in arch relationship is anticipated during and after treatment.
The residue should be zero in both arches. It may be necessary to adjust the treatment objectives to achieve this, but these must remain attainable and not simply manipulated in order to achieve the zero residue.	

quantified as less severe if the archform selected passes through the most prominent incisor and buccally displaced canine, and more severe if it passes through lingually displaced teeth.

Crowding and spacing should be quantified in relation to the archform that reflects the majority of teeth, not necessarily the imaginary arch that passes through the incisal edge of the most prominent central incisor in each arch (Fig 1). The line of arch selected does not necessarily represent a treatment objective, as a separate assessment is made for arch width and for the anteroposterior position of the labial segments. However, it is crucial that points of reference remain consistent for each case. For example, the incisor chosen to define the archform used for the assessment of crowding must also be selected for cephalometric analysis and overjet measurement. Failure to do so may lead to double counting with resulting over- or underestimation of space requirement.

The method recommended for assessment is to use a clear ruler over the occlusal or labial surface of study models to measure the mesiodistal width of misaligned teeth and available space in the archform selected (Fig 2). This technique has been found to be preferable to using calipers to measure all the teeth and a brass wire to assess arch length[11]; that method is less reliable, probably because of cumulative error or bias that arises from the need to measure every tooth rather than just the misaligned ones.

The assessment of crowding of 2 adjacent teeth can be undertaken together by measuring the mesiodistal width of each tooth and the combined space available. This method is not recommended for 3 or more teeth as the difference between chord and arc becomes significant, the chord being the space available as measured in a straight-line and the arc being the curved archform occupied by well-aligned teeth.

Crowding and spacing are assessed anterior to the mesial surface of the first molars. The permanent teeth are considered as they present, regardless of size. When the second primary molars are present, up to

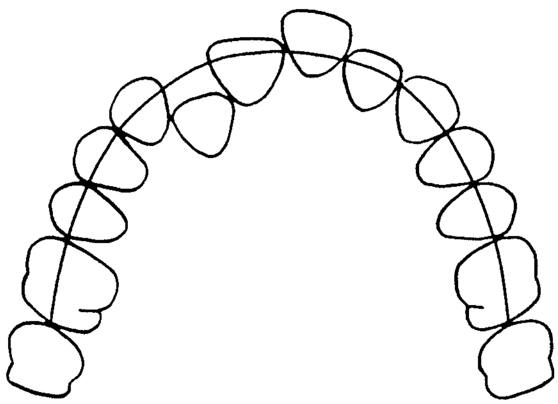

Fig 1. Arch form selected for assessment of crowding reflects majority of teeth, not necessarily most prominent central incisor.

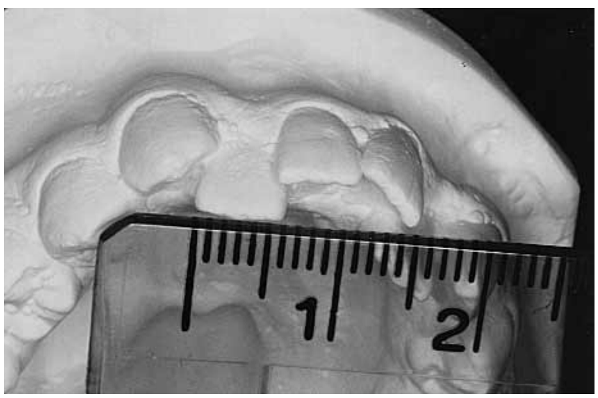

Fig 2. Misaligned teeth *(above)* and space available *(below)* are measured with a clear ruler to nearest 0.5 mm.

1 mm spacing is allowed for upper E space (the size difference between primary and permanent tooth) and up to 2 mm for lower E space. If the patient is at an earlier stage in the mixed dentition, estimations of the size of the permanent unerupted teeth can be made with the aid of radiographs,[1] proportionality tables,[2,3] or both.[4]

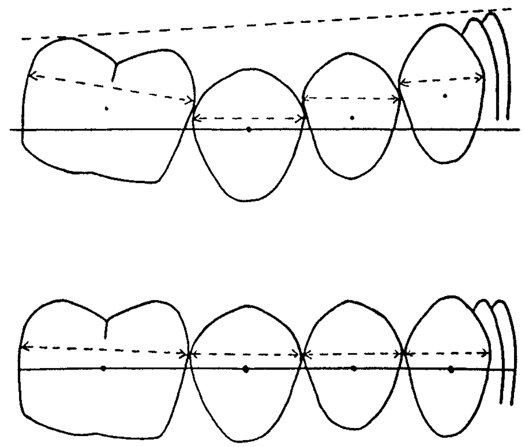

Fig 3. Increased occlusal curves due to slipped contacts in vertical plane *(above)*. Leveling the occlusal plane involves restoring contact point relationships *(below)*.

Leveling Occlusal Curves

Space is required to level a curve of Spee,[5,6] but accurately quantifying this space is very difficult. It is incorrect to assume that the process is equivalent to the 2-dimensional straightening of a curved line, or that the space required is the difference between an arc of a circle and its chord. An increased occlusal curve is due to a series of slipped contact points in the vertical dimension; it is the restoration of the contact point relationships between neighboring teeth that demands increased space within the dental arch (Fig 3). This slippage is usually too slight at any one contact point to be recorded as a form of crowding, but when an arch is taken overall, space is required for leveling.

This also explains the nonlinear relationship reported between depth of curve and the amount of space required.[5,6] The first increment of displacement of the contact point will have less mesiodistal implication than the subsequent increment of vertical displacement, etc. If teeth were parallel-sided (cylindrical), no space would be required when leveling an occlusal curve. Where the teeth are bulbous, the space implications are greater.

A consensus has emerged[5-7] that the clinical practice of allowing 1 mm of space for every millimeter of depth of curve is an overestimate. These studies also took into consideration the 3-dimensional nature of the problem and used a reference plane extending from the distal cusps of second molars to the incisal edges. The inclusion of second molars is understandable as this substantially deepens the curve and there-

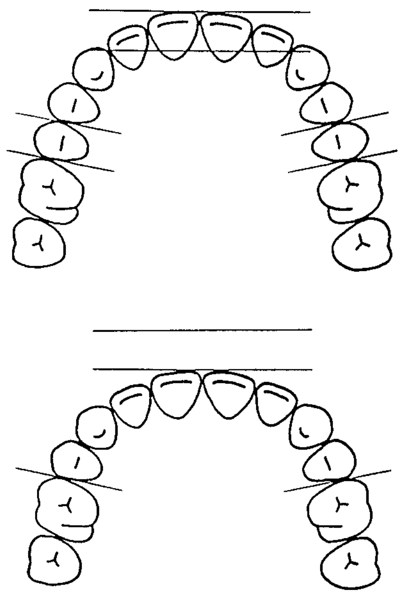

Fig 4. Retraction of incisors by a distance requires the same amount of space in each buccal segment. In *lower* diagram, intermolar distance is equivalent to distance between second premolars in upper diagram.

fore allows assessment of space requirements over a greater range. Rarely will an occlusal curve be deeper than 4 mm when second molars are excluded.

When treatment starts in the early permanent dentition, however, the second molars are usually not fully erupted. The Royal London Space Planning therefore assesses occlusal curves in relation to a plane from the distal cusps of the first molars to the incisal edges. Leveling of the second molars tends to take place by distal movement,[7] whereas the space planning is more concerned with the effect on space in the anterior and midarch regions. The consequence of using first molars for the reference plane, and thus relating space required to an apparently less deep occlusal curve, is to make the effect on space appear greater than that advocated by others.[5,6] The values used in the Royal London analysis are presented in Table II.

Two other considerations are relevant. First, the space implication should be recorded only if the premolars have not been assessed as crowded; it would be another example of double counting for premolars to be assessed both as crowded and as needing space from leveling the occlusal curve. Second, clinical judgment is necessary as occlusal curves need not be leveled in all cases.

Arch Expansion and Contraction

It seems logical there should be a direct one-to-one relationship between arch expansion and the creation of space. However, Adkins et al[12] and Akkaya et al[13] concluded that even rapid palatal expansion (RPE) carried out with the Hyrax appliance produced only 0.7 mm or 0.65 mm increase in maxillary arch perimeter for each millimeter of expansion, although it is possible that the creation of space in these studies was underestimated, as the lack of anterior alignment mechanics did not enable a new anterior archform to be expressed (for example, first premolars expanded by 6.1 mm but canines by just 2.9 mm).[12]

Most expansion mechanics used are less aggressive than RPE, with expansion greatest in the molar region and more moderate anteriorly in the arch. The space implication was investigated, ex vivo, by O'Higgins,[14] who also overcame the problems of anterior crowding. A model of bracketed teeth with ideal alignment was constructed where the maxillary first molars were held within acrylic blocks separated by an orthodontic screw, and all other teeth supported by a rigid (0.021×0.025 inch) archwire. The model design allowed molar expansion while maintaining closed interproximal contacts. Dimensional changes were measured from markers on cusp tips and incisal edges using a reflex microscope linked to a computer. The results demonstrated a linear relationship between expansion of the first molars and a reduction in the anteroposterior dimension of the arch. Each millimeter increase in the intermolar width resulted in a decrease in anteroposterior arch depth of 0.28 mm, equivalent to an increase in arch perimeter length of 0.56 mm if the arch depth had been maintained and spacing allowed to open (as discussed in the next section).

For the purpose of space planning, each millimeter expansion of the intermolar width will create approximately 0.5 mm space within the arch. The space created may be greater when overall arch expansion is achieved by splitting the palatal suture. The buccal or lingual movement of an individual tooth does not constitute a change in arch width, as this would be assessed in the analysis of crowding.

Incisor A/P Change

It may be desirable to alter the anteroposterior position of the lower incisors, in either direction, depending on the specifics of the malocclusion as assessed clinically and cephalometrically. The upper incisors are then corrected in the analysis to an overjet of 2 to 3 mm in relation to the position selected for the lower incisors.

It is essential that the incisors selected for the measurement of overjet and cephalometric tracing correspond to those used to define the archform in relation to which crowding and spacing are assessed.

Changes in the anteroposterior position of labial segments have a profound effect on arch perimeter

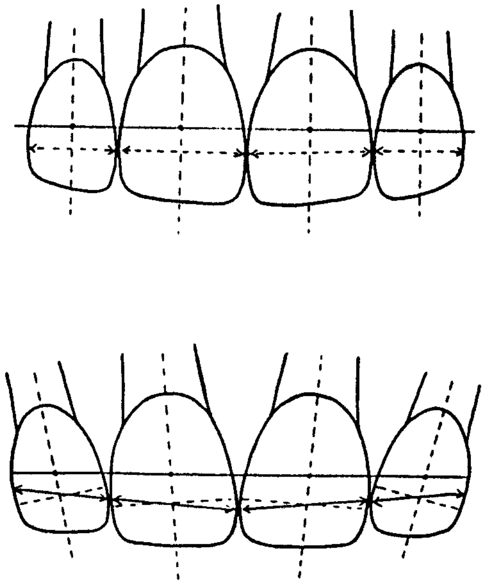

Fig 5. Mesiodistal space occupied by upright maxillary incisors *(above)*. Additional space is required when they are correctly angulated *(below)*. *Solid lines* demonstrate new contact points and apparently wider teeth.

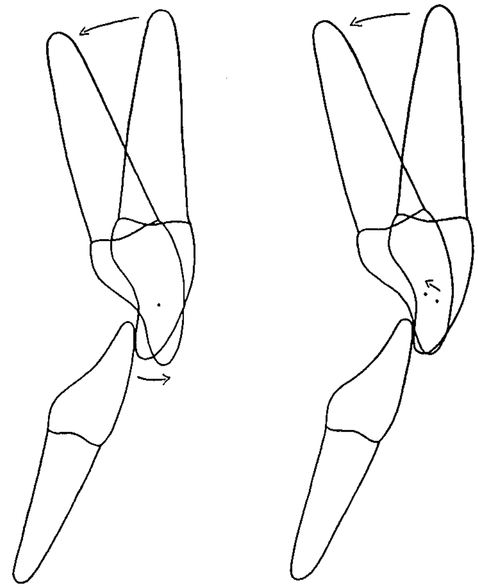

Fig 6. Superimposition of upper incisors before and after palatal root torque. Registration on contact point *(left)* shows an increase in overjet, whereas registration on point of occlusal contact with the lower incisor *(right)* shows palatal and gingival movement of contact point. In either case, additional space is required in arch to accommodate effects of palatal root torque.

length. Using an ex vivo model similar to the one used to study the effects of expansion, O'Higgins and Lee[14] removed the first premolars from the model and closed all spaces. The loss of 7.2 mm from each side of the arch led to incisor retraction of 7.7 to 8.0 mm, depending on intermolar width. The additional amount of incisor retraction is due to a change of anterior archform, ie, intercanine expansion, as the molar width was maintained. In reality, an amount of intermolar contraction may occur after premolar extraction if the molars move mesially. For the purpose of space planning, each millimeter of incisor advancement or retraction will create or consume 2 mm of space within the dental arch (Fig 4).

Angulation (Mesiodistal Tip)

If upper incisors are too vertical, they take up less space in the arch than if correctly angulated (Fig 5). Tuverson[15] demonstrated this with a diagnostic wax set-up and showed that 2 mm of excess space could be absorbed by angulating upright upper incisors. However, incorrect angulation does not necessarily signify that a space requirement exists; for example, a tooth angulated 5° distally may take up no more space than one angulated 5° mesially. Very occasionally, teeth are over angulated, and space is gained by correction to normal angulation.

Few researchers have attempted to quantify the space required for ideal angulation. One study[16] used a mathematical model that assumed the teeth to be rectangular. This may approximate clinical validity when incisors are parallel-sided but not when they are triangular or barrel-shaped. Figures derived from a simple mathematical model are thus prone to overestimation. In the case of canines, the curvature of the mesial and distal surfaces allows moderate changes of angulation with little impact on the space requirement.

An unpublished investigation at the Royal London Hospital supported Tuverson's findings that only small amounts of space are involved (maximum, 0.5 mm per upper incisor). The anchorage implication of mesiodistal apical movements, especially of canines, is likely to be of greater relevance to the clinical management of the case than space considerations.

Inclination (Torque)

Andrews[10] pointed out the importance of the inclination of upper incisors if they are to occupy the correct amount of space, and that failure in this respect would lead either to incorrect buccal occlusion or to spacing. Correct inclination is also important to ensure optimum esthetics.[17,18] Two superimpositions in Fig 6 demonstrate the effect of applying torque to upper incisors.

Fig 7. Ex vivo model of acrylic teeth used to demonstrate influence of incisor inclination on arch perimeter length. Molars and premolars held in acrylic block while canines and incisors are supported by rigid 0.021 × 0.025-inch archwire.

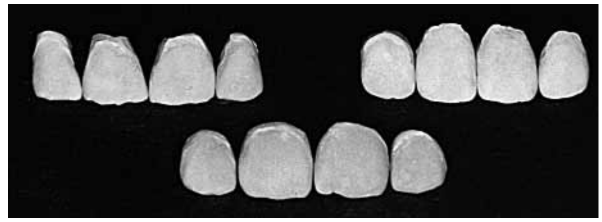

Fig 8. Space implication of changing angulation or inclination of incisors varies according to crown morphology. Triangular-shaped teeth *(left)* require the least space whereas parallel-sided teeth *(right)* have the greatest impact. Barrel-shaped incisors *(center)* require intermediate amount of space.

The space implication of torque has also been the subject of quantification. Tuverson,[15] using a demonstration set-up, suggested that 1 mm of excess maxillary space could be absorbed by applying palatal root torque to maxillary incisors. Hussels and Nanda[16] used a mathematical model to analyze the changes in spatial relationship between the bracket slot and the midcervical point on the mesial or distal surface. However, clinically, the relevant points are the contact point and the point of occlusion with the lower incisor.

To investigate this further, O'Higgins et al[19] constructed an ex vivo model of bracketed acrylic maxillary teeth where the molars and premolars were set in an acrylic block and the canines and incisors supported by a rigid (0.021 × 0.025 inch) archwire (Fig 7). The cusp tips and incisal edges were marked to facilitate measurement of arch perimeter length. The incisors were duplicated and brackets bonded with differing torque values but constant angulation in order to simulate various inclinations. The model was reassembled using incisors with varying inclinations, the contact points closed, and the arch perimeter length recorded using a reflex microscope. This confirmed that there was an increase in the arch perimeter length as the incisor roots were torqued palatally, due to the incisal edges coming forward in relation to the contact points. The buccal segments would thus need to be distalized if overjet is not to increase.

The experiment was repeated with teeth sectioned from stone models of naturally spaced dentitions to ensure intact mesial and distal surfaces of the teeth. An interesting observation was that the space implication varied according to incisor size and morphology. The palatal root torquing of large or parallel-sided teeth required the greatest amount of space within the arch, whereas small or triangular teeth with contact points close to the incisal edges needed the least space. Barrel-shaped teeth needed an intermediate amount of space (Fig 8).

The space required also varies according to the archform. The 3-dimensional dynamics involved are highly complex, and doubts must be cast on the ability of simple mathematical models to quantify the space implication of altering inclination.

For practical purposes, the bodily retraction of upper incisors by 5 mm will necessitate 5 mm of space in each buccal segment, a total of 10 mm. If the incisors are very proclined and cephalometric analysis shows that simple tipping movements are appropriate, a 5-mm palatal movement of the incisal edges will take place with a lesser palatal movement of the contact points of about 4 mm, and the total space required would thus be only 8 mm. In fact, the analysis would record a 10-mm requirement for incisor retraction and a space gain of 2 mm for uprighting proclined incisors. The converse applies to retroclined incisors, with apical torque in a Class II Division 2 case requiring the creation of space, even if the incisal edges remain stationary.

It was found that for average-shaped incisors, a space requirement of 1 mm can be expected if all 4 maxillary incisors are torqued by 5°. This principle does not generally apply to the lower incisors because unless they are particularly proclined the contact points are closer to the incisal edges.

INTEGRATION OF SPACE REQUIREMENT COMPONENTS

A composite score is calculated for each arch from the various components. Among the 6 factors considered, only crowding and spacing, arch width change, and incisor anteroposterior change can have substantial space implications. The other factors—occlusal curves, angulation, and inclination of teeth—are associated with only small amounts of space.

The difference in the total space required for the upper and lower arches requires clarification. The assessment thus far has taken into consideration all the variables on which alignment and occlusion depend, with the exception of the anteroposterior molar relationship, and it is this that is reflected in the difference between the spaces required for upper and lower arches.

Class I molars are thus associated with a space requirement that is equal in both upper and lower arches, unless there is a disproportion in the size or number of teeth between the arches (eg, small or absent maxillary lateral incisors). Assuming 7 mm premolars, bilateral full unit Class II occlusions are associated with an upper space requirement 14 mm greater (more negative) than the lower; a 7-mm discrepancy would imply one half unit Class II molars, etc. The reconciliation of upper and lower space difference with the molar relationship is very useful as it frequently highlights either an error in analysis or a Bolton discrepancy.

CONCLUSIONS

In this first part of a 2-part article, the space implications of various component parts of a given malocclusion have been quantified. In cases of crowding or spacing, the space deficit or surplus is assessed as found in the original malocclusion. For other aspects of the malocclusion, the effects on space are determined by the clinical objectives. Thus, the space analysis integrates with treatment planning decisions on arch width, incisor advancement or retraction, leveling of occlusal curves, and correction of incisor angulation and inclination.

In the second part of this article, which follows, the impact on space from other treatment procedures is considered. These include tooth enlargement or reduction, tooth extraction, the creation of space for prosthetic replacement, and molar mesial and distal movement. The effect of favorable and unfavorable growth will also be considered.

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