# Royal London Space Analysis: Plaster Versus Digital model assessment

**Summary:**

**Aim:** With the advent of digital study models, the importance of being able to evaluate space requirements becomes valuable to treatment planning and the justification for any required extraction pattern. This study was undertaken to compare the validity and reliability of the Royal London space analysis undertaken on plaster as compared to digital models.

**Materials and methods:** A pilot study (n=5) was undertaken on plaster and digital models to evaluate the feasibility of digital space planning. This also helped determine the sample size calculation and as a result, 30 sets of study models with specified inclusion criteria were selected. All five components of the Royal London space analysis, namely: crowding; depth of occlusal curve; arch expansion/ contraction; incisor antero-posterior advancement and inclination (assessed from the pre-treatment lateral cephalogram) were accounted for in relation to both model types. The plaster models served as the gold standard. Intra-operator measurement error (reliability) was evaluated along with a direct comparison of the measured digital values (validity) with the plaster models.

**Results:** The measurement error or coefficient of repeatability was comparable for plaster and digital space analyses and ranged from 0.66 to 0.95 mm. No difference was found between the space analysis performed in either the upper or lower dental arch. Hence, the null hypothesis was accepted. The digital model measurements were consistently larger, albeit by a relatively small amount, than the plaster models (0.35mm upper arch and 0.32 mm lower arch).

**Conclusion:** No difference was detected in the Royal London space analysis when performed using either plaster or digital models. Thus, digital space analysis provides a valid and reproducible alternative method in the new era of digital records.

## Introduction

Plaster study models have limitations related to their ease of breakage and storage (1). With the advance of digital technology, digital study models are becoming a viable replacement for conventional plaster. The reported advantages of digital models include ease of storage, communication between colleagues and automation of analyses (2). There has been substantial research regarding the validity and reliability of measurements undertaken on digital study models as compared to plaster models that has concluded that digital models appear to have sufficient accuracy and validity to be used within the clinical setting for most purposes (3). There has been no research comparing space analysis, more specifically, the Royal London space analysis [RLSA; (4,5)] on digital and plaster models.

Space analysis is very important part of a clinician's assessment of the relative space requirements to address the aims and in turn, the successful delivery of a treatment. It is very important to perform a space analysis from a medico-legal point of view and it helps justify any extraction/non-extraction decision within any given treatment plan. The RLSA takes into account several different aspects of a malocclusion: crowding, occlusal curve, arch width, overjet and incisor inclination. It is relatively simple to perform and does not take much clinical time (4,5).

With increasing use of digital models in Orthodontics, the ability to perform digital space planning will become necessary tool for clinicians and particularly those in training. There has been no research comparing space analysis, more specifically, the RLSA on digital and plaster models. The present study therefore aimed to address this shortcoming by assessing the reliability and validity of digital space planning against the established gold standard of using plaster models.

## Materials and Methods

*Study design and objectives:*

A prospective laboratory based study was undertaken to address the following specific objectives:

1. Undertake a pilot evaluation of the feasibility of digital space planning

2. Test reproducibility and validity of the various components of the Royal London space analysis method, using a digital measurement technique.

As a result, the null hypothesis to be tested was: There is no difference between the manual and digital Royal London space planning methods.

*Selection of models*

Study models for both the pilot and main study, were selected from the current patients undergoing treatment within the Orthodontic Department and coded to render them anonymous. These models were chosen to reflect the prevalence of the corresponding malocclusions in the population as closely as possible [Table 1].

The inclusion criteria were as follows: (1) correctly Angle's trimmed & un-damaged models; (2) erupted permanent dentition from first molar to first molar; (3) crowding present in at least one arch. The exclusion criteria were: (1) caries, heavily restored or hypoplastic teeth; (2) missing or supernumerary teeth; (3) cleft or craniofacial syndromes.

*Sample Size Calculation*

Assuming a coefficient of repeatability of 1mm (based on pilot study results), a power of 100% and a test significance level of 0.05, the sample size required to detect a 1mm difference between the plaster and the digital was found to be 30. A power of 100% was chosen to minimize, as far as possible, any risk of incorrectly rejecting the null hypothesis. The plaster model space analysis served as the 'gold standard' against which the digital space planning was assessed.

*Digitisation of study models*

In an attempt to reduce the error of the method, clinical photographs were used to verify the recorded occlusion on the Angle's trimmed models and a second experienced operator ensured that the occlusion was correctly represented on the digital models.

Angle's trimmed study models were scanned using a desktop model scanner (Ortho Insight scanner, Motion View, TN, USA) to within the manufacturer's reported accuracy of 0.01 mm. To ensure that the models were replicated digitally to a high accuracy the following steps were under taken:

1. The scanner was calibrated according to manufacturer's instructions
2. Care was taken to ensure that the models were correctly Angle's trimmed, before scanning
3. The models were firmly stuck to the scanner platform with double-sided tape to ensure no movement artefacts occurred during the scanning process
4. The articulation of the digital models was carefully checked in all three planes of space by an experienced orthodontist to ensure that the occlusal relationship of the plaster models was correctly replicated.
5. Files were exported in an obj 3D file format (Alias Wavefront Object) from the scanner to the Cloud software (University College London, UK), for digital space analysis of the models.

*Study model assessment*

All digital models were viewed on the same high resolution computer monitor (1280 x 1024 pixels in horizontal and vertical, Hewlett Packard, Palo Alto, USA). The magnifying tool of the Cloud software was used, as required, to assist in landmark identification. Every digital measurement was checked in at least two views or planes, perpendicular to each other to ensure accuracy of measurement. Plaster models were measured with a calibrated digital vernier calliper (RS Component, UK) to within the manufacturers reported accuracy of 0.01mm.

*Model measurements*

The Royal London space analysis (RLSA; (4,5)) is divided into two distinct sections. The first part is an assessment of space requirements and consists of the six different components and forms the basis of the current study: crowding, occlusal curve, arch width, overjet and incisor inclination. Each is given a score which can be positive or negative. A positive score means that space is present or will be created, whereas a negative score means that space is required to meet the treatment objectives. The space analysis is carried out for upper and lower arches separately. All individual scores are then added to provide a final measure of space requirement. The second part of the analysis deals with the methods of space creation. This section was not part of the planned study.

1. Upper and lower arch crowding: Crowding was assessed as the difference between the sum of greatest mesio-distal widths of crowded teeth and arch length available for these teeth, according to the determined ideal arch form. Figures 1 & 2 show crowding being measured with the help of Cloud software.

2. Depth of the curve of Spee: A horizontal plane was constructed using the mandibular incisor and the disto-buccal cusp of the mandibular first molar. The depth was recorded as the vertical distance from this plane to the premolar cusp tip

3. Crossbite: The distance between the mesio-buccal cusp tips of maxillary first molars and the distance between buccal grooves of mandibular first molars was measured. A crossbite needing correction was deemed to exist if this difference was greater or less than the ideal buccal overjet of 2mm.

4. Overjet: Measured from the labial surface of the mandibular incisor to the labial surface of the maxillary incisor. Where the labial inclinations of the maxillary incisors differed, the maximum overjet was recorded. The incisors selected for the measurement of overjet and cephalometric tracing corresponded to those used to define the archform.

5. Labio lingual inclination of incisor teeth: The inclination of the long axis of the most prominent maxillary incisor to the maxillary plane and the inclination of the long axis of the most prominent mandibular incisor to the mandibular plane were assessed on a lateral cephalogram.

*Error Study*

Repeat measurements of all plaster and digital models were performed in a random order, one month apart, by the same operator (BG) to assess intra-operator error. No more than five models were measured at a time to reduce operator fatigue.

The repeatability of the two methods was investigated by comparing the spread of data using standard deviation and the mean difference between the first and the second reading, using the Bland Altman plots (6). For intra-operator repeatability, the coefficient of repeatability was performed. This is defined as 1.96 times the standard deviation of the mean of the differences between the first and second reading. The Coefficient of repeatability (measurement error) ranged from 0.41 to 1.22 mm.

*Data Analysis*

All data was entered into SPSS (Statistical Package for the Social Sciences, version 2015, New York, USA). Parametric statistical analyses were carried out to determine the repeatability of the technique used. Independent samples two-tailed t-tests (assuming unequal variance) were used to test the null hypothesis, at a significance level of 0.05. Mean differences between plaster and digital space analyses as well as the individual components of the RLSA and agreement amongst upper and lower dental arch measurements were ascertained to give a 95% confidence interval in addition to Bland and Altman plots.

**Results:**

The study sample comprised in total of 30 sets of models, which were made into both plaster and digital forms and represented the full range of malocclusions: Class I (n=10); Class II div 1. (n=10); Class II div 2. (n=5); Class III (n=5), with dental crowding present in all.

*Upper plaster versus digital model space analysis*

There was no difference observed in the Coefficient of repeatability between the upper plaster and digital space analysis (p = 0.37). Bland Altman plots were constructed with a mean difference between plaster and digital readings of 0.34 mm and 95% confidence intervals ranging from -0.35 to 1.05 mm. The spread of observations around the mean was even (Figure 3). Equally, no difference was found between the total space analysis measurements between upper plaster and digital models (Table 2; p= 0.79). Hence, the Null Hypothesis was accepted.

*Lower plaster versus digital model space analysis*

There was no difference in the Coefficient of repeatability between the lower plaster and digital space analysis (p = 0.52). The difference in the mean between the plaster and digital measurements was 0.32 mm, with lower digital reading being 0.32 mm greater than the lower plaster readings (Figure 4). This difference was used to construct the Bland Altman plot that showed a 95% confidence interval from -0.54 to 1.19 mm. There was an even spread of observations around the mean with just two outliers, one in either direction.

Equally, no difference was detected (Table 3; p = 0.69) between the total space analysis measurements for lower plaster and lower digital models. Thus the null hypothesis was accepted.

**Discussion**

The current study was carried out to assess the reproducibility and test validity of digital study models as compared to plaster, in performing the Royal London space analysis. Validity was tested against 'gold standard' i.e. plaster cast measurement. There are many studies in the literature comparing plaster and digital models but none have compared space analysis using these techniques.

Plaster study models have been used for many decades as a patient record. However due to their inherent practical disadvantages it has been desirable to find an alternative technique. Digital models provide immediate and easy access, with the added advantages of easy storage, retrieval and minimal risk of being physically damaged. Archiving of models is a lot easier, with minimal costs and furthermore they can then be used as a database for research and audit purposes.

In an increasingly litigious society, it is very important that the orthodontist can justify any extractions carried out as part of the treatment. A pre-treatment space analysis like the RLSA demonstrates a methodological approach and rationale behind any planned extractions or space creation and tooth movements carried out. The RLSA takes into consideration the space implications of the various factors that comprise a malocclusion, specifically: crowding and spacing, antero-posterior changes, levelling the curve of Spee, changes in arch width, angulation changes and inclination (4,5). A study based in Manchester looked at the reliability of the RLSA and whether or not it affected treatment decisions (7). The authors found highest agreement in the lower arch. There was excellent validity for all the examiners against the gold standard scores.

In the present study, a range of malocclusions were evaluated in order to maintain validity and generalizability of the technique to everyday clinical practice. In view of the fact that no previous study had undertaken a comparison of space analysis using these two different media, a pilot study was carried out to determine the repeatability of the measuring process and the results used to calculate the sample size for the main study. The main study was subsequently powered at 100%, to help minimize the risk of incorrectly rejecting the null hypothesis. Further risk of error was reduced by comparing the study models with the clinical photographs to ensure they were correctly Angles trimmed and with a second experienced operator ensuring that the occlusion was correct on the digital models.

No difference was found between either the upper or lower plaster versus digital space analysis. Hence, the null hypothesis was accepted. The plaster model measurements were consistently smaller, albeit by a relatively small amount, than the digital models (0.35mm for upper and 0.32 mm for lower). This concurs with the results of other studies, that have found digital measurements to be slightly larger (8). Overall, the mean discrepancy between plaster and digital measurements was low and in agreement with the results of an earlier systematic review (3). The possible explanations for the slight discrepancy observed and reported in the current study and Fleming et al (3) could be image magnification or lie within the realms of digital measurement error. In view of its small magnitude, the difference was considered to be clinically insignificant.

In the current study the investigator perceived that the digital method of measurements was easier to use than plaster measurements, which is in agreement with another study (9). The measurements were rapidly performed (10,11) although the time taken to do the space analysis was not measured and was not the focus of this study. Studies have found a significant time saving with digital techniques (8,11) although a significant learning curve and period of adjustment is required (3).
The transition from viewing hand held models to 3-dimensional objects on a computer screen is not easy and may make landmark identification more difficult (12). Severity of cross bites has been reported in literature as being difficult to assess on digital models (13), with a seemingly mild cross bite appearing to be more severe at first glance. Once again, a period of orientation and viewing the model in more than one plane was found helpful in the current study. Some digital model systems (Ortho Insight, Motionview, Tennessee, USA) have incorporated 3D viewing technology, with 3D glasses, and this may help improve visualization in the future and maybe worthy of further study.

Ensuring data security can be a concern and as with all other patient records, access should be restricted to personnel authorized to use such records and with the use of a password. Transfer of such records should take place in an anonymised manner using a reference number and secure site (13). The digital models would however, need to be backed up in a similar manner to backing up medical records.

*The present study is not without its limitations*

The Royal London space analysis is a well-established space planning technique and the purpose of this study was not to validate this technique but rather to assess its application to digital models. The RLSA is a very exhaustive analysis and takes into account most aspects of a given malocclusion and quantifies the space required in each dental arch to achieve the treatment objectives. It also determines whether the objectives are likely to be attained, and helps plan treatment mechanics and the control of anchorage. It also provides a record to justify treatment decisions for professional accountability (4,5). This technique, however, is not without limitations. It does not take into account asymmetries and apart from levelling occlusal curves, does not consider the vertical dimension. Furthermore, no account is made of any crowding distal to the first molars.

Although every effort was made to have a full range of malocclusion, it was not possible to include every malocclusion. No study model with an anterior open bite or scissor bite was in the sample. No multi-disciplinary needs malocclusion, such as orthognathic or orthodontic-restorative formed a part of this sample. A single examiner performed all measurements and so no estimation of inter- examiner reproducibility can be assessed.

In such studies, measurement error is always a concern. A single examiner [BG] undertook all measurements and was calibrated in the use of Royal London Space Analysis by attending a 1-day course, followed by performing 15 space planning exercises with a senior experienced clinician manually and digitally. The models were anonymised and selected randomly for measurement, under the same conditions and setting, in order to reduce random error (14). No more than 5 models were measured at a time in order to reduce operator fatigue. For the digital measurement, the image was rendered at high resolution by zooming in the region of interest to improve accuracy of placement of markers. The models were viewed in at least two planes perpendicular to each other before selecting a point for measurement. Inaccuracy of landmark selection contributes greatly to random error (14). This may be due to the operator not being able to identify landmarks due to ill definition. To reduce this error, measurements should be duplicated and an average value selected (14). As a result, the present study adopted this practice too. Measurement error was 0.1- 0.2 mm less with the digital as compared to the plaster method, the difference being so small to be of any clinical relevance. This does, however, highlight the fact that the digital measurements are just as repeatable as the plaster.

## Conclusions

1. No detectable difference was observed in the space analysis between digital and plaster models.

2. Digital measurements produced slightly higher (in the range of 0.35 mm) values when compared with plaster models, the difference not being of any clinical significance. Thus, the repeatability of digital models is comparable to plaster models.

3. Digital study models can be considered for use as an adjunct to clinical assessment and space planning.

## Acknowledgements

We can confirm the study did not receive any external funding and that the authors have no conflict of interest to declare.

## References

1. McGuinness, N.J. and Stephens, C.D. (1992) Storage of orthodontic study models in hospital units in the U.K. *British Journal of Orthodontics,* 19, 227-232.

2. Hajeer, M.Y., Millet, D.T., Ayoub, A.F. and Siebert, J.P. (2004) Applications of 3D imaging in orthodontics: Part II. *Journal of Orthodontics*, 31, 154-162.

3. Fleming PS, Marinho V, Johal A.(2011) Orthodontic measurements on digital study models compared with plaster models: a systematic review. *Orthod Craniofac Res*, 14, 1–16.

4. Kirschen RH, O'higgins EA, Lee RT. (2000) The Royal London Space Planning: an integration of space analysis and treatment planning: Part I: Assessing the space required to meet treatment objectives. *Am J Orthod Dentofacial Orthop*, 118, 448-55.

5. Kirschen RH, O'higgins EA, Lee RT. (2000) The Royal London Space Planning: an integration of space analysis and treatment planning: Part II: The effect of other treatment procedures on space. *Am J Orthod Dentofacial Orthop*, 118, 456-461.

6. Bland, J.M and Altman, D.G. (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet,* 1, 307-310.

7. Al-Abdallah M, Sandler J, O'Brien K (2008) Is the Royal London Space Analysis reliable and does it influence orthodontic treatment decisions? *Eur J Orthod,* 30(5), 503-7.

8. Horton HM, Miller JR, Gaillard PR, Larson BE. (2010) Technique comparison for efficient orthodontic tooth measurements using digital models. *Angle Orthod*, 80, 254–61.

9. Stevens, D.R., Flores-Mir, C., Nebbe, B., Raboud, D.W., Heo, G. and Major, P.W. (2006) Validity, reliability and reproducibility of plaster vs digital study models: comparison of peer assessment rating and Bolton analysis and their constituent measurements. *American Journal of Orthodontics and Dentofacial Orthopaedics,* 129, 794-803.

10. Gracco, A., Buranello, M., Cozzani, M. and Siciliani, G. (2007) Digital and plaster models: a comparison of measurements and times. *Progress in* Orthodontics, 8, 252-259.

11. Mullen, S.R., Martin, C.A., Ngan, P. and Gladwin, M. (2007) Accuracy of space analysis with emodels and plaster models. *American Journal of Orthodontics and Dentofacial Orthopaedics*, 132, 346-35211.

12. Zilberman, O., Huggare, J.A. and Parikakis, K.A. (2003) Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. *Angle Orthodontist,* 73, 301-301-306

13. Abizadeh N, Moles DR, O'Neill J, Noar JH.(2012) Digital versus plaster study models: how accurate and reproducible are they? *J Orthod,* 39, 151–59

14. Houston, W.J.B. (1983) The analysis of errors in orthodontic measurements. *American Journal of Orthodontics*, 83, 382-390.

Legends:

**Figure 1**: The red line and blue lines represent two profiles that cross Point A along the coronal and sagittal planes of the model.

**Figure 2**: Shows the interested region in marking the mesio-distal width defined by points A & B.

**Figure 3:** Bland and Altman plot for upper plaster versus digital model space analysis (n=30).

**Figure 4:** Bland Altman plot for lower plaster versus digital model space analysis (n=30).

| Malocclusion type | Pilot study (n=5) | Main study (n=30) |
|---|---|---|
| Class I | 1 | 10 |
| Class II/I | 2 | 10 |
| Class II/II | 1 | 5 |
| Class III | 1 | 5 |

**Table 1:** Sample size selection for the Pilot (n=5) and Main study (n=30)

| Parameter | Mean differences (mm) | Standard deviation (mm) | Limits of agreement (mm) | | p-value |
|---|---|---|---|---|---|
| | | | Lower limit | Upper Limit | |
| Total Space Analysis | -0.35 | 0.34 | -0.34 | 1.04 | 0.37 |
| Crowding | -0.38 | 0.40 | -1.0 | 0.70 | 0.58 |
| Occlusal Curve | 0 | 0 | 0 | 0 | 1.00 |
| Expansion | 0.03 | 0.12 | 0 | 0.50 | 0.80 |
| Overjet | -0.03 | 0.31 | -1.0 | 1.0 | 0.98 |
| Inclination | 0.03 | 0.18 | 0 | 1.0 | 0.79 |

**Table 2:** Comparison of space analysis performed on the upper plaster and digital models (n=30).

| Parameter | Mean Differences (mm) | Standard deviation (mm) | Limits of Agreement | | p-value |
|---|---|---|---|---|---|
| | | | Lower limit | Upper limit | |
| Total Space Analysis | -0.32 | 0.43 | -0.53 | 1.19 | 0.52 |
| Crowding | -0.32 | 0.43 | -1.40 | 0.60 | 0.83 |
| Occlusal Curve | 0 | 0 | 0 | 0 | 0.9 |
| Expansion | 0 | 0 | 0 | 0 | 1.0 |
| Overjet | 0 | 0 | 0 | 0 | 0.96 |
| Inclination | 0 | 0 | 0 | 0 | 1.0 |

**Table 3:** Comparison of lower plaster and digital model space analysis (n=30).