3D Laser Scanning of EPG Palates: Benefits of Using a 3D EPG Model in the Analysis of Tongue-to-Palate Contacts

Justine V. Goozée[†], Timothy D. McAleer[‡†], Dion H. Scott[†] and Bruce E. Murdoch[†]

† Motor Speech Research Unit, Department of Speech Pathology and Audiology, The University of Queensland

‡ Centre for Plant Architecture and Informatics, The University of Queensland, Australia

E-mail: j.goozee@uq.edu.au, tdm@maths.uq.edu.au, d.scott@shrs.uq.edu.au, b.murdoch@uq.edu.au

ABSTRACT

The present study describes a new method of generating 3D computer graphics models of the palate using a hand-held laser-scanning device, and investigates the advantages of the models in EPG analysis. Two speech-language pathologists (SLPs) examined a set of 2D EPG diagrams generated by a control speaker and three subjects with dysarthria. The SLPs judged whether there was an observable difference in the tongue-to-palate contacts and suggested possible reasons for any differences. After a three to five month interval, the SLPs were asked to reanalyse the contacts, which were this time displayed on 3D computer models of the subjects' palates generated using the laser-scanning device. Palate shape was considered, albeit inconsistently, as a possible factor influencing amount of tongue contact when the contacts were displayed in 3D, but not in 2D. The implications of the findings for future EPG analyses and treatment of dysarthric speech will be discussed.

1. INTRODUCTION

The physiological, instrumental technique of electropalatography (EPG) has become a well-established assessment and therapy tool in speech pathology research centres and clinics [1]. EPG records the location and timing of tongue contacts against the hard palate during speech using an artificial palate containing an array of small touch-sensitive electrodes. Changes in tongue-to-palate contacts are sampled over time and recorded as a series of EPG frames or tongue-to-palate contact diagrams (see [2] for further details).

Conventional EPG diagrams display tongue contacts against the hard palate as simple two-dimensional diagrams without regard to the unique geometry of a person's palate or the relative spacing between EPG electrodes [3]. It has been found, however, that palatal shape, including the width and length of the palate and the height of the palatal vault, can influence tongue-to-palate contact patterns produced during speech [4],[5]. Indeed, articulatory structures and processes are fundamentally three-dimensional. A two-dimensional diagram of tongue-to-palate contacts, like those that are currently used in speech pathology clinics and research centres to interpret EPG data (see Figure 1) may, therefore, be misleading when comparisons of the amount, location and pattern of contacts are to be made between different speakers. Contact patterns that appear to be deviant based on an analysis of a 2D display and considered possibly to be the result of disturbances in tongue motor control, for example, may in fact have simply resulted from constraints imposed by the physical geometry of the palate.

A number of different methods of displaying 3D tongue-to-palate contacts have been devised. Hiki and Itoh [4] superimposed the boundaries of contacts obtained using EPG and static palatography onto photographs of actual palates displaying 3D contours. Heath et al. [6] discussed the use of light-emitting diodes (LEDs) mounted to physical models of palates to show the sites of lingual contact during speech. Such methods would be too time consuming and costly, however, for researchers and clinicians to carry out on a routine basis. Simply attempting to continually refer to the actual palate when analysing two-dimensional displays may also prove too cumbersome, with the possibility of errors being introduced if care is not taken in matching the electrodes on the 2D display with the actual palate.

The optimal solution would be improved visualisation of the tongue-to-palate contacts through a computer generated, interactive 3D model of the palate that would display the actual position of the electrodes on the palate and would indicate which electrodes had been contacted. The spatial geometry of the palate would thus be integrated simultaneously with details of the tongue contacts. Such improved visualisation of the palate and tongue contacts would be expected to benefit researchers and clinicians in gaining insights into the possible factors underlying different tongue-to-palate contact configurations.

Previous attempts to create such 3D models of the palate for the purpose of displaying EPG data have seen the development of 3D wire frame models of the palate [7], [8], which provide structural information regarding the hard palate, but which are relatively abstract and omit the teeth. The models also require the manual acquisition of 3D coordinates. Other methods of creating 3D palate models have involved advanced computing techniques and complex procedures (e.g. [3],[9]). The present study employs new 3D scanning technology involving a hand-held laser scanner, and describes a simpler method for displaying palate geometries with EPG data that would be feasible for clinics and research centres. The results of a

ISBN 1-876346-48-5 © 2003 UAB

study designed to investigate whether the 3D model of the hard palate enhances the analysis and interpretation of EPG data will be discussed.

2. METHOD

2.1 Generating the 3D computer graphics palate models. First, a dental cast taken of the hard palate and teeth is scanned using the portable Polhemus FastSCAN hand-held laser profile scanner connected to a personal computer. The scanner scores 3D co-ordinates from the surface of the cast using a projected laser line and cameras mounted at an angle to this line. This technique is known as profilometry. The collection of 3D co-ordinates or point cloud can then be converted to a surface of triangle mesh elements using the meshing algorithms provided with the laser scanner.

A 3D EPG Viewer has been developed in Visual C++ for Windows. To attain maximum flexibility this program has been implemented as an ActiveX control, allowing easy integration with other programs and languages. This program uses the meshes to render a full 3D representation of the palate on an interactive display. The user is free to rotate, zoom and dolly the rendering, to achieve the best possible view. The user is also able to change the colour and shading of the mesh and can remove unwanted surface elements.

A 2D digital image of the EPG palate is superimposed over the 3D palate mesh using semitransparent rendering to locate the positions of the individual EPG electrodes on the mesh. The 3D mesh is rotated and scaled until it is aligned with the 2D digital photograph. The user of the program then selects each electrode using the cursor. The triangle mesh elements beneath the cursor are selected as a "population" and their centroid replaced with a small sphere, whose colour changes according to the state (i.e., active or inactive) of the corresponding EPG electrode (see Figure 1). Approximately half an hour is required to prepare a 3D model with all electrode positions defined.

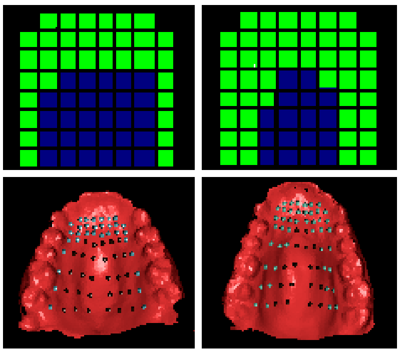

Figure 1. 3D laser scanned images of hard palates displaying tongue-to-palate contacts (bottom) and corresponding 2D displays (top).

When EPG data is loaded into the 3D EPG Viewer program, the user can watch the virtual electrodes change colour according to the position and timing of tongue contacts against the EPG palate. Many facets of the view, including the surface properties of the 3D model, can be customised by the user to enable better visualisation of tongue-to-palate contacts in 3D.

2.2 Examination of the 3D palate models in EPG analysis and interpretation. Two speech-language pathologists (SLPs) experienced in EPG research and who were naïve to the purpose of the study first examined a series of two-dimensional EPG diagrams of maximum contact generated by a non-neurologically impaired control speaker and three subjects with dysarthria following traumatic brain injury (TBI). Three productions of four word-initial consonants were examined: /t, s, k, ʃ/. The SLPs were asked to independently judge whether there were any observable, potentially clinically relevant differences in the spatial characteristics (i.e., amount, location and pattern) of the tongue-to-palate contacts exhibited by the dysarthric speakers compared to the control speaker and to suggest possible reasons for any differences observed.

The SLPs were made aware that all of the subjects were male and between 20 to 30 years of age. Details regarding the type and severity of dysarthria exhibited by each of the TBI subjects were also provided. The dysarthria types and severities included: mild spastic, moderate spastic, and moderate spastic-ataxic.

Three to five months after the initial 2D rating session, the two SLPs were asked to reanalyse approximately 55% to 65% of those TBI subjects' frames of maximum contact that had been observed to differ from the control subject's contacts in the first analysis session. In the second analysis session, the tongue-to-palate contacts were displayed on 3D models of the subjects' palates, which had been generated using the portable laser-scanning device. Two 3D palate models were presented to the SLPs simultaneously; one being the control subject's model, the other being a TBI subject's model. Unlimited time was provided for the SLPs to interact with the 3D palate models (i.e., rotate, zoom) prior to noting down whether there was a difference between the control subject's and TBI subject's contacts and possible reasons for the difference as per the first analysis session.

3. RESULTS

3.1 SLPs ratings of tongue-to-palate contacts presented in 2D versus 3D. Observable differences between the TBI subjects' and control subject's tongue-to-palate contacts were noted for 59% of the pairs of 2D frames of maximum contact (i.e., control vs TBI subject) by Rater 1 and 94% of the contact pairs by Rater 2. Suspected reasons for the differences in contacts offered by the raters were largely neuromotor based (e.g., reduced neuromotor control, spasticity). Palate shape was not considered by either rater to be a possible factor underlying the differences in contacts between the TBI subjects and the control subject.

When the frames of maximum contact were viewed upon the 3D computer palate models, palate shape was suggested

ISBN 1-876346-48-5 © 2003 UAB

to be one of the underlying bases for differences in tongue-to-palate contacts observed by Rater 1 for TBI subject 1 and observed by Rater 2 for TBI subject 2. Palate shape was not suggested by either rater to be a factor underlying differences in tongue-to-palate contacts observed for TBI subject 3 compared to the control subject.

Palate shape appeared to be used to partly explain findings of overshoot or increased contacts. Rater 1 suggested that TBI subject 1 may have exhibited increased contacts and reduced groove widths for /s/ and /ʃ/ as a result of his narrower palate and higher palatal arch. Similarly, Rater 2 suggested that the narrower palate of TBI subject 2 may have resulted in increased lateral contact for /t/ and /ʃ/. Palate shape was mentioned inconsistently, however, by both raters, with only 40% of instances of increased contact for each subject being suggested to be related to palate shape. The suggestion of palate shape appeared to be more likely applied as an explanation for increased contacts occurring for the anterior consonants, rather than the velar consonant /k/.

Palate dimensions, or more specifically electrode positions, were considered by one of the raters (Rater 2) during the 3D analysis to explain the reduced amount of contact observed for one TBI subject's (TBI 3) /k/ productions. It was suggested that the last row of electrodes might have been too far forward to detect closure possibly occurring more posteriorly on the palate.

3.2 Inter-rater and intra-rater agreement. Moderate to total agreement (62.5%-2D; 100%-3D) was calculated between raters in determining whether there was an observable, potentially clinically relevant difference between the control subject's and TBI subjects' tongue-to-palate contacts displayed in 2D and 3D. Poorer inter-rater agreement (35%-2D; 0%-3D) was noted for specifying the nature of the differences (i.e., location, pattern and/or amount of contact).

Intra-rater reliability could be calculated for just one rater. Approximately 25% of the 2D and 3D displays, selected at random, were reanalysed by Rater 2 close to two weeks following the 3D analysis session. The rater was 100% reliable in determining whether there was an observable difference between the control subject's and the TBI subjects' contacts displayed in both 2D and 3D. Only 28.6% of the 2D samples that were re-analysed were consistent, however, with the original ratings regarding the nature of the difference. In contrast, 83.33% of the reanalysed 3D samples were consistent with the original ratings.

4. DISCUSSION

For dysarthric individuals who present with articulatory disturbances evidenced by tongue-to-palate contacts that are incongruent with "normal" contact patterns, it is imperative that the full range of potential underlying bases for the discrepant tongue-to-palate contacts be considered before EPG treatment commences. As shown in the present study, a 2D display of tongue-to-palate contacts may "blind" a SLP into considering only potential neuromotor problems. Palate structure may also influence the contact patterns being produced, however, as suggested albeit inconsistently by the SLPs in the present study when details regarding palate shape and size were displayed in the form of 3D graphical computer models. The SLPs noted that narrower palates might result in increased contacts. This finding, therefore, has implications for the treatment of overshoot and in assessing the effectiveness of therapy designed to improve neuromuscular control. First, consideration should be given as to whether the patient is physically capable of changing the location, pattern and/or amount of tongue contact given the structure of his or her palate. Second, any improvements gained in neuromuscular control and tongue precision with therapy may not be apparent for tongue-to-palate contacts that are influenced more so by palate structure.

A number of factors may have resulted in the two raters considering the effects of palate shape for two different subjects. The first potential factor relates to the order in which the palates were displayed to the raters. The TBI subjects' palates and EPG contacts were displayed in random order to Rater 1, while for Rater 2, all of TBI subject 1's contacts were displayed first, followed by TBI subject 2's contacts, and then TBI subject 3's contacts. As Rater 2 noted palate shape for TBI subject 2, and not TBI subject 1 as per Rater 1, it could be hypothesised that a period of time was required for Rater 2 to become accustomed to the 3D models. By being presented with different palates from one trial to another, Rater 1 may have found it easier to judge differences in palate geometry and to determine the significance of structural differences on tongue-to-palate contacts. The extent to which the raters interacted with the 3D palate models may also have affected how well the raters accommodated to the 3D palate displays. Rater 2 was noted to interact less with the palate models than Rater 1. There appears to be a need, therefore, to provide time and perhaps even training for raters to become accustomed to analysing and interpreting EPG data presented on 3D palate computer graphics models, particularly for those raters who are practiced in analysing 2D palate diagrams, as per the two raters in this study.

In the present study, the surface properties (i.e., colour, reflectiveness) of the 3D palates were kept constant throughout the rating sessions and across raters. Different surface properties may, however, better facilitate visualisation and accommodation to the 3D palates. The particular display characteristics used in the present study and/or the factors listed above may have facilitated Rater 1's observations since she noted a narrower palate for TBI subject 1, which was confirmed by actual measurements of palate dimensions. Measurements of TBI subject 2's palate did not confirm, however, the narrower palate that was noted by Rater 2.

Finally, the differences noted between the two raters' observations might be related to the subjective nature of the task, where relatively ambiguous judgements, such as "is

ISBN 1-876346-48-5 © 2003 UAB

there an observable, potentially clinically relevant difference?", were required. Indeed, inter-rater agreement ranged from total to poor. The finding of high intra-rater reliability for 3D displays compared to 2D displays poses an interesting question as to whether 3D displays facilitate more reliable analyses. The finding may, however, be simply an artifact of the time period between the original analysis and re-analysis sessions (i.e., 2D = approx. 5 months; 3D = approx. 2 weeks).

5. CONCLUSIONS

The present study described a new, time-efficient and relatively simple method of generating 3D computer graphics models of the palate for displaying EPG data using laser scanning technology. When two SLPs were presented with 3D computer models of the palates of three individuals with dysarthria following TBI, palate shape was considered and a particular structural feature identified (i.e., narrower palate), albeit inconsistently, as a possible factor influencing the amount of tongue contact exhibited. Initial analyses based on traditional 2D displays of the tongue-to-palate contacts elicited no such consideration of palate shape, demonstrating that interpretations regarding the underlying bases for particular tongue contacts can be restricted and indeed misguided when only 2D EPG displays are utilised.

The inconsistency with which palate shape was mentioned in the 3D analyses suggests that time and possibly training is required for individuals to become accustomed to interpreting the 3D graphics models and/or that certain surface properties (e.g., colour, reflectiveness) of the 3D displays may need to be customised for different individuals. Objective measurements of the width, length and height of the palate could be presented to the individuals to hasten this accommodation and to assist in determining whether observed differences in palate structure are in fact "real".

Given that palate shape was considered to influence at least two of the three TBI subjects' tongue-to-palate contacts, it would be prudent to suggest that palate shape be considered in all EPG analyses. The need for efficient analysis, as is afforded with 2D EPG displays, may mean, however, that 3D models may best be used in the final stages of analysis when hypotheses regarding the underlying bases for contacts that appear deviant on a 2D display are to be made.

Attempts to change tongue-to-palate contacts in therapy must be tempered with knowledge of palate structure and the constraints that palate structure places on tongue-to-palate contacts. Further investigation is required now into how particular palate shapes may influence the location, pattern and amount of tongue contact against the palate. In the present study, palate shape was only suggested to influence the amount of contact, and not the location or pattern.

Future improvements to the method of generating 3D EPG computer graphics models include the use of a magnetically referenced stylus attachment for the FastSCAN laser scanner that allows 3D points (i.e., electrode positions) to be individually picked and automatically displayed on the 3D model, making redundant the palate transparency.

ACKNOWLEDGEMENTS

This study was supported by funding received from the Centre of National Research on Disability and Rehabilitation Medicine (CONROD). The authors would like to thank the EPG subjects and the two SLPs for their participation in the study and Yan Cheng for her helpful comments regarding the manuscript.

REFERENCES

[1] W.J. Hardcastle, "Current developments in instrumentation for studying supraglottal structures," in *Advances in Clinical Phonetics*, M.J. Ball and M. Duckworth, Eds., pp. 27-49. Amsterdam: John Benjamins, 1996.

[2] W.J. Hardcastle, F.E. Gibbon and W. Jones, "Visual display of tongue-palate contact: Electropalatography in the assessment and remediation of speech disorders", *British Journal of Disorders of Communication*, vol. 26, pp. 41-74, 1991.

[3] M. Wakumoto and S. Masaki, "Three-dimensional visualisation of electropalatographic data", *Journal of the Acoustical Society of Japan*, vol. 20, pp. 137-141, 1999.

[4] S. Hiki and H. Itoh, "Influence of palate shape on lingual articulation", *Speech Communication*, vol. 5, pp. 148-158, 1986.

[5] M.K. Tiede, "Palate shape effects on characteristic vowel tongue postures", *The Journal of the Acoustical Society of America*, vol. 103, pp. 2893-2894, 1998.

[6] M.R. Heath, A.M. Ferman and R. Mollard, "Electropalatography: Thermo-formed pseudopalates and the use of three-dimensional display", *Journal of Biomedical Engineering*, vol. 2, pp. 145-147, 1980.

[7] C.C. Saw, "Customized 3-D electropalatography display", *UCLA Working Papers in Phonetics*, vol. 85, pp. 71-96, 1993.

[8] W. Jones and W.J. Hardcastle, "New developments in EPG3 software", *European Journal of Disorders of Communication*, vol. 30, pp. 183-192, 1995.

[9] W.S.C. Chiu, C.H. Shadle and J.N. Carter, "I: Technical Developments. Quantitative measures of the palate using enhanced electropalatography", *European Journal of Disorders of Communication*, vol. 30, pp. 149-160, 1995.