Teeth aesthetic improvement using a Bayesian spatial joint analysis for independent regular lattices

Rui Martins[1,2], Inês Lopes[2], Jorge Caldeira[2] & José Mendes[2]
(1) c.a. ruimartins@egasmoniz.edu.pt
(2) Centro de Investigação Interdisciplinar Egas Moniz (CiiEM)

CENTRO DE INVESTIGAÇÃO INTERDISCIPLINAR EGAS MONIZ

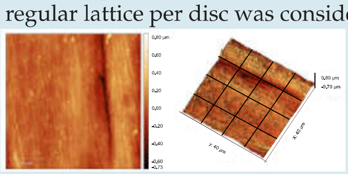
Overview

An important feature in dentistry is teeth gloss [3]. During the intervention the doctor has to apply a resin and then a polishing protocol to achieve the final result, i.e, the lowest roughness and the highest gloss (brightness) possible. The smaller the roughness the greater the gloss. In order to achieve excellent aesthetic appearance and high durability of the direct restoration, it is important to initially select the appropriate biomaterial for use and then to base preference for a polishing technique for achieving perfect results in the surface texture.
A surface should be capable of attaining and maintaining an average roughness below $0.2\mu m$ *in vitro*, since values above this threshold cause plaque retention. For this reason that irregularities in restoration influence the plaque accumulation, the durability, the discoloration and aesthetic appearance of the used material.

The aim of this study was to evaluate the combined effect of 4 polishing protocols with 2 resins in teeth surface roughness and gloss.

Dataset

- 2 resins: 0 = nanofilled Filtek Supreme XT; 1 = nanohybrid Brilliant Everglow.
- 4 polishing protocols: 0: sof-lex discs/ enhance/spiral/diamond paste; 1: Sof-Lex discs/ spirals; 2: sof-lex spirals; 3: swiss-flex discs/Diatech Shapeguard.
- $N = 40$ discs – prepared as a surrogate for teeth surface.
- Sets of 5 discs – randomly assigned to each of the 8 resin*polishing groups, $v_1, \ldots, v_8$.
- Analysis of the surface roughness – Atomic Force Microscope (AFM).
- 4×4 regular lattice per disc was considered



AFM: 2D and 3D images of the roughness of a surface;

- 16 roughness measurements per disc, r_{ij}, in the $40\mu m \times 40\mu m$ lattice.
- A unique gloss measure per disc, g_i, – gloss meter with incidence at 60º.

References

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Material

Polishing disc - Sof-Lex^{TM} XT Disc (medium grain).

AFM - Atomic force microscope.

Gloss Meter - Frontal view.

Bayesian spatial joint model

Assuming independence of the discs, i.e. the lattices, the statistical model for the spatially correlated roughness measures within each lattice considers disc and group specific random effects and spatially varying intercepts for different groups. The group spatial dependence is introduced through a CAR prior [2], which smooths the spatially correlated random-effects toward its neighbours. Neighbourhood is defined via an adjacency matrix. The model to analyse the observed gloss for each disk considers the impact of those random-effects and the spatial variance of the roughness into the gloss, i.e., the model shares some parameters with the roughness model which allows us to interpret how the heterogeneity and the variability of the surface roughness impacts the tooth gloss.

Consider the 16 roughness measurements, $\mathbf{r}_{ik} = (r_{ik1}, \ldots, r_{ik,16})$, for the ith disc in group k; $i=1,\ldots,5$; $k = 1,\ldots,8$; and the unique observed gloss, g_{ik}, per disc.
Roughness measure in each square is described by a **linear mixed effects model**,

$$\log(r_{ikj})|b_{ik}, q_k, W_{kj}, \sigma_k^2 \sim \mathcal{N}(r^*_{ikj}, \sigma_k^2), \quad j = 1, \ldots, 16, \tag{1}$$

$$r^*_{ikj} = \mathbf{x}_{ik}^\top \boldsymbol{\beta} + b_{ik} + q_k + W_{kj}, \tag{2}$$

where b_{ik} and q_k are the disc and group random intercepts, respectively. $\boldsymbol{\beta} = (\beta_1, \ldots, \beta_s)^\top$, whose elements are assumed to be mutually independent, represents the fixed effects of the disc-specific vector of covariates. W_{kj} is a square-specific random-effect for group k, $W_{kj}|\sigma^2_{W_k} \sim ICAR(\sigma^2_{W_k})$, which allows the roughness to vary across the squares and groups.
To study the **association between the roughness and the gloss processes** we consider the inclusion of some characteristics of the former into a **linear mixed effects model** for the gloss in each disc,

$$g_{ik}|b_{ik}, q_k, \mathbf{W}_k, \tau_k^2 \sim \mathcal{N}(g^*_{ik}, \tau_k^2), \tag{3}$$

$$g^*_{ik} = \mathbf{z}_{ik}^\top \boldsymbol{\gamma} + \mathcal{C}_{ik}\{r^*_{ikj}; \boldsymbol{\alpha}\}, \tag{4}$$

where $\mathbf{W}_k = (W_{k1}, \ldots, W_{k,16})$. $\mathbf{z}_{ik}$ is a subject-specific design vector of baseline covariates and $\boldsymbol{\gamma}$ the respective coefficients vector. $\mathcal{C}_{ik}\{.\}$ is a function specifying which components of the roughness model are related to g_{ik} and $\boldsymbol{\alpha}$ is an appropriate vector of parameters representing the regression coefficients, measuring the effect of some particular characteristics of the roughness to the gloss.

Application and results

Several scenarios for the function $\mathcal{C}_i\{.\}$ can be considered and inclusively we can fit dispersion models to the various variance components. Although our choice fell on the following:

$$r^*_{ikj} = \beta_1 d_1 + \ldots + \beta_7 d_7 + b_{ik} + q_k + W_{kj}, \tag{5}$$

where $\boldsymbol{d} = (d_1, \ldots, d_7)$ is a vector of dummy variables for the 8 resin*polishing groups, and

$$g^*_{ik} = \gamma_1 d_1 + \ldots + \gamma_7 d_7 + \alpha_1 b_{ik} + \alpha_2 \sigma_k + \alpha_3 \sigma_{W_k}. \tag{6}$$

We considered typical prior and hyperprior distributions, namely: $\beta_1, \ldots, \beta_7$ and $\gamma_1, \ldots, \gamma_7 \sim \mathcal{N}(0, 1000)$; $b_{ik} \sim \mathcal{N}(0, \sigma_b^2)$; $q_k \sim \mathcal{N}(0, \sigma_q^2)$; $\alpha_1, \alpha_2, \alpha_3 \sim \mathcal{N}(0, 1000)$; $\sigma^{-2}_{W_k} \sim \mathcal{G}(0.5, 0.0005)$; σ_k^{-2}, τ_k^{-2}, σ_b^{-2} and $\sigma_q^{-2} \sim \mathcal{G}(0.001, 0.001)$.

	Resin			
	0		1	
Polishing	log(roughness)	gloss	log(roughness)	gloss
0	v_1: 3.08; (2.80, 3.37)	v_1: 36.49; (32.45, 40.32)	v_5: 1.52; (0.89, 2.15)	v_5: 5.55; (0.08, 11.15)
1	v_2: 0.94; (0.53, 1.33)	v_2: -11.38; (-16.73, -5.96)	v_6: 2.66; (2.16, 3.16)	v_6: -21.81; (-27.21, -16.22)
2	v_3: 1.01; (0.67, 1.34)	v_3: -19.47; (-24.65, -13.80)	v_7: 0.97; (0.41, 1.51)	v_7: -21.02; (-26.20, -15.56)
3	v_4: 1.36; (0.77, 1.99)	v_4: -22.97; (-28.53, -17.58)	v_8: 1.30; (0.53, 2.12)	v_8: -18.39; (-23.73, -12.85)

Results: Posterior mean and the respective Credibility interval (CI). The values represent the difference of each group from v_1 (reference group). For v_1 the values represent the estimated posterior mean.

The best combination to achieve the lowest roughness as possible is $(pol., res.) = (0, 0)$. The best combination to achieve the highest gloss as possible is $(pol., res.) = (0, 1)$ – CI (0.08,11.15) is strictly positive, meaning that it is shinier than the reference group, v_1.