Wear behaviour of direct composite restorations in tooth wear patients: a 5-year clinical study

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ABSTRACT

Objective: This study aimed to investigate the wear behaviour of direct composite restorations after 5 years and associated patient factors.

Methods: 38 patients (6 females, 32 males; 35.2 ± 7.6y) from the Radboud Tooth Wear Project with generalized moderate to severe tooth wear were treated with direct composite restorations on all teeth. Ethical approval was sought and granted before the study was undertaken. Intraoral 3D scans were recorded at 1 month (baseline) and 5 years (recall) after treatment. The amount of height loss was measured at six index teeth (first molars and upper central incisors). Patient factors (age, vertical dimension of occlusion increase, bite force, aetiology score, jaw position and bearing/ non-bearing cusps) were included in the analysis. Multilevel multiple regression with bootstrapping was used to analyse the influence of these factors on wear behaviour of restorations. Observer reliability was tested by paired t-tests and Band-Altman plots (p<0.05).

Results: After 5 years, the mean height loss was 0.23± 0.19 mm for incisors and 0.43± 0.24 mm for molars (p<0.001). Patient factors did not show any significant influence on height loss of the composite restorations, while bearing cusps showed significant more wear compared to non-bearing cusps (p<0.001). The observer reliability tests confirmed the repeatability (correlation of 0.809, DME 0.103).

Conclusions: Wear of composite restorations is a significant and relevant factor over time in patients treated with severe tooth wear. Within the limitations of this clinical study, patient factors were found not to have a significant effect on wear behaviour of direct composite restorations.

1. Introduction

Severe tooth wear is defined as tooth wear with substantial loss of tooth structure, dentin exposure, and significant loss (≥ 1/3) of the clinical crown [1,2]. At the moment the progression of tooth wear leads to functional or esthetical problems, a restorative treatment has to be prescribed. According to the 2017 consensus paper a minimally invasive treatment option is recommended [1]. Direct composite restorations have shown good mid-to-long-term results with an annual failure rate at 2.3% after 5.5 years in severe tooth wear patients [3,4]. Using direct composite restorations an acceptable failure rate was obtained, nevertheless significant wear facets were clearly detected on the occlusal surfaces. In patients without tooth wear, wear of ‘normal’ composite resin restorations has been overcome with the improvement of the material properties [5]. Recently, the wear behaviour of two different types of direct composite restorations was investigated in a 5-year clinical study in severe tooth wear patients, where a micro-hybrid composite and a nanocomposite showed different wear behaviour under certain clinical conditions [6]. This led to the assumption that wear of composite restorations in this specific group with a high-risk profile (e.g. bruxism, erosive challenges) may be a relevant risk factor in the survival of these restorations.

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The cause of wear of restorations is complex and can be described as a multifactorial process, also involving a multiplex interplay of many host factors [7], in which the influence of the patient factors could be a main factor. Besides age, gender, tooth and jaw position, also factors such as increase of vertical dimension of occlusion (VDO), bite force and etiological factors (mechanical or chemically related) may be of importance in the wear process [6,8].

Therefore, this clinical study aimed to investigate the wear behaviour of composite resin restorations in relation to patient factors such as age, gender, VDO increase, biting force, etiological factors, jaw position and bearing condition. We hypothesized that 1) wear of composite restoration on posterior and anterior teeth would be similar, 2) mechanical challenges would lead to more wear of composite restorations over time compared to chemical challenges, and 3) a larger increase of VDO and higher bite force would lead to more wear.

2. Methods

This explorative study, based on prospective data, was carried out as part of the Radboud Tooth Wear Project (RTWP). To answer the research question on wear behaviour of composite restorations in relation to patient factors, we carried out an analysis of data collected by the RTWP [3,8,9].

2.1. Participants

Patients had been referred by their general dental practitioners to the Department of Dentistry of the Radboud university medical center in Nijmegen, the Netherlands. Inclusion took place between April 2012 and July 2015. Ethical approval from the Hospital Medical Ethical Board was attained before the two research-arms were commenced (trial numbers: NL30346.091.10 and NL31371.091.10). This clinical trial was designed in accordance with the Declaration of Helsinki (1964). All patients who were asked to participate agreed and signed a consent form prior to entry into the study. The study was registered local trial register (PaNaMa#113794).

The following inclusion- and exclusion criteria were used in the RTWP: 1) Patients aged 18 years and older were included. 2) All participants were required to have a moderate or severe tooth wear (Tooth Wear Index-score ≥2 [10]). 3) Full dental arches, with no more than a single missing tooth in the posterior area. 4) At least they had to be relatively ‘healthy’: defined as the absence of serious general health problems (e.g. hematologic disorders, cancer, immunosuppression or using adrenergic drugs, etc.) with contraindications of dental treatment. Patients were excluded from the study when, their mouth opening was less than 3.5 cm, they had temporomandibular pain or dysfunction, periodontal problems (periodontitis, pockets > 4 mm), endodontic problems or active dental caries. Patients were not excluded based on the assumed etiological factor (e.g. bruxism or gastro-oesophageal reflux).

In total 122 patients have been restored in two prospective clinical trials, in which patients received different full-mouth direct and indirect resin restorations [5,11]. To focus on the wear behaviour of composite restorations (and to reduce the number of other variables) all patients (n = 59) restored with a specific composite material were selected (ClearfilAP-X, Kuraray, Osaka, Japan) for this study. Additional inclusion criterion was that intra-oral 3D scans of 1 month after treatment and of which all necessary scans were available. Finally, 38 patients were eligible to this study as they presented the same materials combination and of which all necessary scans were available.

2.2. Data collection before restorative intervention

All participants were asked about their age and gender at the intake. The dentition was documented using clinical examination, photographs and intraoral 3D scans (LAVA COS / True Def, 3M, USA), which was conducted following the manufacturer’s instructions. The patients were at a sitting position during intra-oral scanning (Optragate, Ivoclar Vivadent, Liechtenstein). Teeth were rinsed, air-dried and lightly dusted with high-resolution scanning spray (3M, USA). After scanning, the scans were stored in the web-based platform (Case Manager, 3M, USA).

Clinical presentation of tooth wear at intake was scored using 3D-scans and intra oral images by one researcher on patient-level using an individualized index. This index was based on already existing indices and focused on 5 morphological features of tooth wear lesions, according toflammoudiet al (2019) and can be found in Table 1 [12,13]. The features of mechanical tooth wear include 1) A similar degree of wear in all occluding sextants, and 2) The imprint of mandibular anterior teeth on palatal surfaces of maxillary anterior teeth. The features of chemical tooth wear include 1) Presence of ‘raised restorations’, 2) Loss of convexities on the palatal surface of maxillary teeth, and 3) Preserved enamel ‘cuff’ in the gingival palatal crevice of maxillary anterior teeth. Patients received a score for both mechanical wear aetiopathy (score 0 to 2 depending on the numbers of features presented), and chemical wear aetiology with scores from 0 to 3.

Maximum voluntary bite force was measured using a bite force transducer [14]. Both sides of the transducer tips were covered with a 6.5 mm thick rubber layer in order to protect teeth. The measuring bite fork was 18 mm thick, and it was covered with a disposable plastic protective shield when used in the mouth. The bite force measuring device was calibrated with loads varying from 0 to 1050 N by means of a compression test machine at our department. Bite force was measured at two locations: between the first molars on the right and between the first molars on the left side [15]. Patients were encouraged to bite on the transducer as hard as possible for a few seconds. The measurements on each side were performed three times in a row. The mean bite force of all six measurements was used for statistical analysis.

2.3. Establishing the new VDO

The increased Vertical Dimension of Occlusion (VDO) needed to obtain sufficient interdental space for the restorations was estimated by two operators (NO and CK) on a consensus basis and based on previously published literature [3,8]. To determine the increase, the height loss of those teeth with the largest amount of wear (commonly the first molar) was estimated from the models that were mounted in an articulator. The possibility to lengthen upper and lower anterior teeth was also established. It was assessed clinically by an intra-oral mock-up on the maxilla from canine to canine, in order to obtain consent from the patient for the expected aesthetic appearance. Deficient existing composite restorations and all amalgam restorations were replaced by composite restorations [3,8].

2.4. Restorative procedure

All operators were dentists experienced in adhesive dentistry from our Department of Dentistry (Radboud university medical center, Nijmegen, the Netherlands) and participated in multiple calibration sessions for the clinical procedures. Restorations were placed without preparation of teeth, when possible. In cases of sharp occlusal edges, a minimally invasive preparation was performed using a course grit diamond chamfer bur. Rubberdam or cotton rolls and suction devices were used for moisture control. Appropriate matrix systems and wedges were used to build up the teeth, at the discretion of the operator. For bonding, a 3-step etch-and-rinse adhesive was applied according to the manufacturer’s instructions, using 37% phosphoric acid (DMG, Hamburg, Germany), Clearfil SA Primer, and Clearfil Photo Bond (Kuraray). A micro-hybrid composite (Clearfil AP-X, Kuraray) was used for posterior restorations and palatal/lingual veneer restorations on anterior teeth. Restorations were placed according to the DSO-technique (Direct Shaping by Occlusion, including biting in occlusion on soft composite before polymerization) [16]. In maxillary and mandibular anterior
Table 1
A simplified tooth wear etiological evaluation system with five most commonly used mechanical/chemical aetiology phenotypes. Patients received a score for both mechanical wear aetiology (score 0 to 2 depending on the numbers of features presented), and chemical wear aetiology with scores from 0 to 3.

<table>
<thead>
<tr>
<th>Features</th>
<th>Level of evaluation</th>
<th>Aimed tooth with FDI dental notation (gray: non-study tooth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical features</td>
<td>1. A similar degree of occlusal/incisal wear in both arches</td>
<td>Sextant</td>
</tr>
<tr>
<td></td>
<td>2. Wear facets on palatal side of maxillary anterior teeth corresponding with mandibular anterior teeth</td>
<td>Tooth</td>
</tr>
<tr>
<td>Chemical features</td>
<td>1. Raised’ restorations (no restorations score 1)</td>
<td>Tooth</td>
</tr>
<tr>
<td></td>
<td>2. Loss of convexities on palatal side of maxillary teeth</td>
<td>Tooth</td>
</tr>
<tr>
<td></td>
<td>3. Enamel ‘cuff’ in gingival crevice</td>
<td>Tooth</td>
</tr>
</tbody>
</table>

Fig. 1. a – Patient with severe tooth wear treated with direct composite restorations. After 5 years of service clear wear facets were visible especially on the molar teeth. Fig 1b – Also on the intra-oral 3D scans, the progression of wear of the restorations was measured and quantified.
teeth, buccal direct veneer restorations were placed using IPS Empress Direct nano-hybrid composite (Ivoclar Vivadent, Schaan, Liechtenstein) with the same bonding system as described above. The overall aim was to attain an acceptable aesthetic outcome and a fully supported occlusion (with even centric stops in the MIP), with the ideal of a canine guided occlusal scheme and shared anteriorocclusal contacts during mandibular protrusion.

2.5. Follow-up and scoring

Recall appointments were scheduled at 1 month and 5 years after treatment. Restorations were checked on clinical acceptability and the dentition was documented using intra-oral examination, intra-oral photographs and intra-oral 3D scans (Fig 1).

2.5.1. Increase in VDO

The applied increase of the vertical dimension of occlusion (VDO) was digitally measured at the location of the first molars by analysing the intra-oral 3D-scans of the dentition in maximum occlusion of before and after treatment using a 3D mesh processing software (MeshLab 2020, www.meshlab.net) [17]. On both scans, the distance between the lowest point on the buccal sulcus of the upper and lower first molars were measured. The difference between the distances measured before and after treatment was regarded as the applied increase in VDO.

2.5.2. Measurement of height loss on restorations

A 3D Wear Analysis (3DWA) protocol using 3D measurement software has been developed to measure wear in vivo using an intra-oral 3D scanner on patients [18]. From a study of O’Toole it was shown that analysing rates of wear on index teeth can be a resource-saving substitute for analysing rates of wear on the entire dentition [19,20]; therefore we have chosen to measure height loss of composite restorations on six index teeth: all first molars and both upper central incisors (Fig. 2a).

All measurements were performed on tooth level (e.g. tooth #46, scans of baseline and recall, Fig. 2b-f) by manually isolating each tooth from the full arch scan (Fig. 2b). By using Geomagic Qualify (3D Systems, USA), two scans were aligned by ‘Best Fit Alignment’ function based on the whole tooth surface (Deviation Elimination: 1) to create a ‘3D comparison’. ‘3D comparison’ is a heatmap with a spectrum to visualize differences between the scans, where the baseline scan was selected as ‘reference’ and the recall scan as ‘test’. The cold colour indicated the decrease and the warm colour indicated the increase. In the ‘3D comparison’ in Fig. 2c, there were some height-increased parts (yellow colour areas), which is not logical. To correct this ‘3D comparison’, the locations showing wear facets (with blue colour) were manually deselected (Fig. 2d). A new ‘Best Fit Alignment’ was performed based on a new ‘modified reference areas’ and the quality of the best fit was double checked by ‘3D comparison’ and ‘Cross-sections’ (perpendicular to the surface in buccal-palatal/lingual direction) (Fig. 2e). In the zoomed-in heatmap of ‘3D comparison’, the darkest blue area indicated the largest amount of wear and quantified height loss was measured by ‘creating annotations’ (Fig. 2f 1). ‘2D Dimensions’ was used on the location where the largest loss of material was expected and the heatmap could not work (Fig. 2f 2).

For maxillary central incisors, material height loss was quantified at the incisal edge and palatal area; for first molars, the occlusal surfaces on

![Fig. 2. Visual representation of the steps for superimposition and quantitative wear measurement. Schematic diagram of the index teeth with green colour (a) and a flowchart of quantification procedure of the amount of wear (b - f). Manually isolation of each tooth scan (b); a ‘Best Fit Alignment’ based on the whole tooth surface and checked by the ‘3D comparison’ (c); manual deselection of locations showing wear facets (d); a new ‘Best Fit Alignment’ based on the new modified reference areas and it was checked by the ‘3D comparison’ and ‘Cross-sections’ (e); quantification of height loss by the heatmap (f 1) and ‘2D Dimensions’ (f 2).](image-url)
mesio-buccal, disto-buccal, mesio-lingual and disto-lingual cusps were measured. The maximum height loss per location was expressed in millimetres (mm).

2.5.3. Inter-observer reliability

Inter-observer reliability was tested by re-measuring recall data after 5 years post-treatment. All patients in this study were measured twice by two observers independently to test the inter-observer reliability.

2.6. Statistical analysis

The inter-observer reliability on height loss measurement was analysed with a paired t-test. Subsequently, the correlation between both measurements, the duplicate measurement error (DME), the mean difference (diff), 95% CI, and p values were calculated. The relation between patient factors and height loss was analysed with multilevel multiple regression models with a random intercept for a patient to allow for the presence of several height losses within one patient. This was done separately for incisors and molars. In both cases the residuals were skewed, therefore, the procedure was augmented with a 1000-fold bootstrapping process to get unbiased 95% confidence intervals and p-values. All analyses were done with R version 3.6.2.

3. Results

3.1. Observer reliability test

The height loss summary statistics for observer reliability tests are shown in Table 2 and Fig. 3. The observer reliability test by paired t-test showed a fairly high correlation result (0.809), and a small duplicate measurement error (DME) and a mean difference between two observers was found, but there was a significant structural difference ((0.015...0.042), p < 0.001). However, based on the DME result, the random error of the height loss measurement by two observers was small, therefore, the measurement (height loss) difference caused by the structure difference is relatively small.

3.2. Overview of the study population and height loss

From the 122 patients restoratively treated, 38 patients (710 measurements of maximum height loss) were eligible to be included in this explorative study. The descriptive information for this study population is shown in Table 3. The overviews of height loss measurements after 5 years are presented in Fig 4a+b. After 5 years, the mean height loss of incisors (0.23± 0.19 mm) was significantly less than for molars (0.43± 0.24 mm), with a mean difference of 0.21 mm ((0.173...0.248), p ≤ 0.001).

For incisors the progression of wear after 5 years could not be related to specific patient factors such as the effect of biting force, etiological factor score (number of mechanical/chemical features), increase to specific patient factors such as the effect of biting force, etiological signs was not related to an increased number of failures. On the contrary, the presence of mechanical signs was related to a decreased number of failures.

This effect, which is to be interpreted as an extra height loss of 0.026 mm for each mechanical factor present, is not statistically significant. But the asymmetrical 95% CI suggests that more chemical factors being present are associated with an increase of wear. In contrast with this, the effect of mechanical features is very close to 0, with a very high p-value and a symmetrical 95% CI, giving no indication on a relation being present. The other factors did not have a meaningful influence on height loss.

4. Discussion

The purpose of this explorative study based on prospective data, was to investigate the wear behaviour of direct composite restorations prescribed in moderate to severe tooth wear patients. Moreover, the relation of patient factors on the wear behaviour was investigated. In this study, 38 patients were studied, and the height loss of the composite restorations over 5 years was quantitatively measured at six index teeth. It was found that wear of composite restorations was significant, that posterior restorations showed significantly more wear than anterior restorations and that patient factors showed not to be related to wear progression of the composite restorations.

The first hypothesis must be rejected as it was clearly shown that posterior composite restorations showed significant more wear than anterior restorations. The rationale could be the higher loads and friction in these areas due to functional activities (attritive and abrasive actions) is much higher than in the anterior area, resulting in more wear. Also, the second hypothesis on the effect of aetiology (mechanical versus chemical features) has to be rejected. The assumption that mechanical clinical features at intake would be indication as risk factor for the progression of wear was not proven. The presence of mechanical clinical features at intake could therefore not be identified as a risk factor for the progression of wear of the composite restorations. A similar outcome was found in clinical survival study in which the presence of mechanical signs was not related to an increased number of failures. On the contrary, the presence of chemical features was found to be ‘protective’ [13]. This was not found in the present study. Since the wear process is a multifactorial process, it may be concluded that it will be difficult to accurately discriminate the main origin of wear process. Still, the third hypothesis on the effect of VDO and bite force was rejected. No relationship was found between the applied VDO and level of bite force with the progression of wear on the composite restorations.

It was previously shown that using index teeth to score wear over time showed a similar pattern compared to a full-arch analysis [20]. Scoring index teeth greatly shortened the time required for the measurement procedure for each participant and allowed for the inclusion of many participants in this study. Therefore, in total 38 patients and more than 700 measurements of maximum height loss could be included, including two maxillary central incisors and four first molars. The number of patients analysed in this study may be relatively low to relate patients’ factors to progression of wear on restorations, but these 38 was the maximum of patients available in the RadboudTooth Wear Project treated with this specific type of composite restoration and of which intra-oral 3D scans of intake and of the 5-year recall moment were present. As our study was not designed to answer one specific yes-no question no sample size calculation is presented. The present study did target to deliver a statistically significant result given a “certain effect”, as there is no such a priori effect. Yes-no answers are not given by this study. We do present p-values, but mainly for historical reasons. The true outcomes are the 95% confidence intervals for the relationship between factors and tooth wear we estimated and presented in Tables 4 and 5. Wide 95% confidence intervals for various variables were found. That leaves room for sizeable effects being present, although no statistically significant effect was found. If one assumes that a sizeable effect does exist, this is a lack of power, but whether that assumption is tenable is open for question. Using the results of this study, the scientific community can move forward and consider starting a new study into this topic, being better informed on the precision that can be expected from...

Table 2.

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<th>Comparison</th>
<th>Correlation</th>
<th>DME</th>
<th>Diff</th>
<th>95% CI</th>
<th>p</th>
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<tbody>
<tr>
<td>Two observers</td>
<td>0.809</td>
<td>0.103</td>
<td>0.029</td>
<td>[0.015...0.042]</td>
<td>&lt;0.001</td>
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such a study.

3D scans were used to record all teeth after treatment 1 month (intake) and 5 years (recall), and height loss of direct composite restorations was quantitatively measured using a validated protocol [18]. Alignment techniques may greatly affect the accuracy of alignment [22]. Therefore, a ‘modified reference-based alignment’ method was used, which fully uses all possible reference areas, including buccal, palatal/lingual and occlusal surfaces as alignment references to achieve an accurate alignment. Furthermore, before measuring the amount of wear, specific locations with clear wear facets were excluded from a second alignment procedure. This procedure provided reliable and accurate interobserver agreement. The inter-observer performance showed a fairly strong correlation (0.809). The duplicate measurement error (DME) showed a very small random error in the two measurements. A significant structural difference was found in the two measurements (0.015...0.042, p < 0.001), but the duplicate measurement error (DME) by two observers was small and this causes the relatively small differences to be associated with a low p-value.

It was found that bearing cusps in first molars showed significantly more height loss than non-bearing cusps on the direct composite restorations. Compared to non-bearing cusps, bearing cusps showed 0.156 mm more height loss over 5 years. As bearing cusps are prone to more fatigue, it may be logic explanation for this result. A similar trend was found in another study showing that the height loss on non-bearing cusps was less on the bearing cusps in the molars treated with the

<table>
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<th>Descriptive information</th>
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<tr>
<td>Age (y)</td>
<td>35.2 ± 7.6 (min: 19.9, max: 52.8)</td>
</tr>
<tr>
<td>Gender</td>
<td>6 females, 32 males</td>
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<tr>
<td>VDO increase(mm)</td>
<td>1.60 ± 0.74 (min: 0.41, max: 3.70)</td>
</tr>
<tr>
<td>Biting force (10^2 N)</td>
<td>4.00 ± 1.69 (min: 1.05, max: 7.60)</td>
</tr>
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Fig. 3. Bland-Altman plot presenting the two observer performance of the wear (height loss) measurements.

Table 3
The descriptive information of the study population.

![Fig. 4. The overviews of height loss measurements after 5 years. The mean and standard deviation of height loss (mm) in both maxillary central incisors (incisor, 0.23 ± 0.19 mm) and all first molars (molar, 0.43 ± 0.24 mm) (a); the mean and standard deviation of height loss (mm) of molars on maxillary bearing cusps vs. maxillary non-bearing cusps (0.48 ± 0.23 mm vs. 0.39 ± 0.19 mm) and mandibular bearing cusps vs. mandibular non-bearing cusps (0.53 ± 0.27 mm vs. 0.31 ± 0.22 mm) (b).](image-url)
same direct composite restorations (Clearfil AP-X) [6]. Moreover, comparable results were found when comparing the effect of jaw position on the progression of wear.

No significant influence of VDO increase on the wear behaviour of direct composite restorations was observed. The VDO increase is necessary to restore the lost vertical dimension and to provide space to insert restorations. From the results it may be concluded that the amount of increase of VDO is not related to more wear over time. Even it has been shown in another study that thicker composite restorations placed in patients with severe tooth wear resulted in better survival compared to thinner applied restorations [8]. Similarly, as the progression of wear is not directly related to the increase of VDO, application of relatively thicker restorations in the reconstruction of these patients would be preferred.

Finally, the patient factor ‘age’ did not have a significant influence on wear behaviour of direct composite restoration. The group of patients in this study (6 females, 32 males corresponding to 64.2% males) had a relatively low mean age of 35 ±7.6 years. In another study, similar age and gender distribution were reported [23], but the number of patients was relatively small, so the power may not be sufficient to identify potential effects of age and gender. Based on the significant difference in male/female patient percentage in this study, gender was not included in the statistical analysis, while it is interesting to investigate the possible influence of gender in future work.

5. Conclusion

Wear of composite restorations is a significant and relevant factor over time in patients treated with severe tooth wear. Within the limitations of this clinical study, patient factors were not found to have a significant effect on wear behaviour of direct composite restorations.

Clinical significance

From these mid-to-long-term clinical survival and wear behaviour studies direct composite restorations are still a promising option for tooth wear patients who have demands for restoration treatment.

Credit authorship contribution statement

Ke Ning contributed to conception, design, data acquisition, analysis, and interpretation, drafted and critically revised the manuscript; Ewald Bronkhorst, contributed to data analysis and interpretation, critically revised the manuscript; Luuk Crins contributed to etiological (mechanical/chemical) evaluation, critically revised the manuscript; Wiecher van der Meer and Tatiana Pereira-Cenci critically revised the manuscript; Fang Yang, Sander Leeuwenburgh, Bas Loomans contributed to conception, design, data acquisition, analysis, and interpretation, critically revised the manuscript. All authors gave final approval and agree to be accountable for all aspects of the work.

Declaration of Competing Interest

The authors declare no potential conflicts of interest with respect to the authorship and publication of this article.

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Supplementary materials

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