Purpose: To evaluate the current scientific evidence on estimating cumulative risk for biologic complications relating to dental implants and to develop a patient-centered risk assessment tool for establishing aggregate risk. Materials and Methods: A review of the scientific literature on risk indicators relating to dental implants was completed with the goal of identifying and weighting individual risk indicators so aggregate biologic risk could be estimated. Three authors completed independent reviews of the literature, identifying 31 systematic reviews on risk indicators for biologic complications with dental implants, from which 24 potential risk indicators were considered. Due to inconclusive scientific data on risk indicators, a Delphi process was used to gather structured expert opinion to supplement findings from the literature. Eleven Delphi participants with expertise in prosthodontics or periodontics participated in two email exchanges and one face-to-face meeting to comment and debate on the initial identification and weighting of risk indicators, propose the addition or removal of risk indicators, and provide recommended clinical management for each risk indicator. Results: After literature review, three rounds of debate, and additions and removals of various risk indicators, consensus (defined as 95% or more in agreement) was achieved on 20 risk indicators. The Delphi group concluded that the risk indicators of smoking, diabetes, periodontal disease, plaque levels, antiresorptive agents, and cemented restorations should include subcategories to more accurately identify and represent patient-specific risk. Clinical recommendations based on individual and aggregate risk were established by consensus. Conclusion: The literature on risk indicators for biologic complications was conflicting and inconclusive. The Delphi method was used to identify and establish the weighting of individual risk indicators, resulting in a risk assessment tool for estimating aggregate risk.

Keywords: antiresorptive agents, diabetes, peri-implantitis, periodontal disease, risk assessment, smoking

Implant prostheses are often planned, completed, and maintained with a limited understanding of a patient’s cumulative risks for biologic complications. Recent evidence has suggested that individual risk indicators associated with implant success can be identified from patient history, clinical assessment, and the decisions a clinician makes during treatment.1–6 With identification of risk indicators, a more appropriate...
treatment plan, informed consent, and patient-specific maintenance plan could be facilitated.\textsuperscript{17–11} The challenge is in developing a measure of aggregate risk from individual risk indicators. This is especially difficult because the literature on biologic complications with implants is often conflicting\textsuperscript{12,13} and inconclusive.\textsuperscript{14} When a clinical question has an uncertain multifactorial etiology, or when large clinical trials are lacking, a common approach used has been to complete a literature search on the topic followed by a consensus method, such as the Delphi process.\textsuperscript{15–18} The Delphi process is designed to use an iterative process of debate and review to bring experts closer to consensus on a clinical question.\textsuperscript{15,17–20}

A patient-centered risk assessment tool with weighting of individual risk indicators to allow estimation of aggregate risk for biologic complications has not yet been completed, although investigators have recommended that closer scrutiny be placed on patients with multiple risk indicators.\textsuperscript{4,21–25} The outcome of interest is late biologic complications, defined as pathologic bone loss after osseointegration has been previously established, with possible subsequent implant failure.\textsuperscript{26} Late biologic complications include peri-implant disease, implant loss, as well as non-inflammatory processes such as bone remodeling following, for example, a malpositioned implant with little buccal bone. The aim of this study was to complete a literature review and Delphi process to develop a patient-centered risk assessment tool with a weighting of individual risk indicators to allow calculation of cumulative risk for late-term biologic complications related to implants.

MATERIALS AND METHODS

Literature Search
The focused question was whether consensus could be achieved in the weighting of individual risk indicators for biologic complications related to dental implants to allow an estimate of aggregate risk and clinical management recommendations. Three authors (D.C., S.S., G.L.) independently conducted searches in MEDLINE (PubMed) in January 2018 to identify systematic reviews on risk indicators for biologic complications with dental implants. For the initial search, systematic reviews published in the English language and between January 2007 and January 2018 were included, aiming to provide background knowledge for the Delphi I discussion. The search strategy was performed with various combinations of Medical Subject Headings and keywords that included: dental implants, risk factors, risk indicators, biologic complications, peri-implantitis, smoking, diabetes, previous implant loss, maintenance, bisphosphonates, medications, periodontal disease, bruxism, biotype, plaque, and cemented restorations. After a joint discussion, the three authors identified and agreed on including 14 systematic reviews,\textsuperscript{9,12,14,27–37} 17 systematic reviews with meta-analyses,\textsuperscript{8,13,38–52} and 2 review articles\textsuperscript{6,53} that focused on risk indicators for biologic complications with dental implants. Supplemental hand searches were completed to better characterize individual risk indicators, identify potential subscales within each risk indicator, and determine if clinical management recommendations were available. From this initial search, 24 potential risk indicators were identified that formed the basis of a risk factor questionnaire for Delphi I participants. The risk indicators were categorized as patient history, clinical findings, and clinician treatment decisions.

Delphi Process
The Delphi process involved identification of a facilitator, participants, and format (Fig 1).\textsuperscript{17,18} The selection of the Delphi facilitator (D.C.) was based on familiarity with the Delphi process and authorship in the area of risk indicators for biologic complications. Potential Delphi participants were identified regionally and internationally who had expertise in the areas of the 24 initially identified risk indicators, and 11 of the 14 contacted experts agreed. The participants included five prosthodontists, five periodontists, and one dental hygienist. It was agreed that the Delphi process would include three rounds: the first round (Delphi I) by email, the second round (Delphi II) as face-to-face meeting, and the third (Delphi III) by an email exchange. The Delphi group agreed to include structured interactions, predetermined criteria for consensus, private decisions, equal weighting among participants, and the principle of continuous process improvement.\textsuperscript{17,18}

The Delphi I questionnaire asked participants to vote (yes/no) on the initial identification of the 24 risk indicators, propose the addition of new risk indicators, or propose removal of a risk indicator. Participants were also asked to indicate how impactful each risk indicator was based on a relative weighting on a scale from one to six. Participants could also propose the use of subscales for risk indicators because of the influence of dose, severity, or comorbidities. For example, if the expert felt the effect of smoking on biologic complications was dose-dependent, they could scale the number of cigarettes to the selected risk level. In such an example, smoking more than 20 cigarettes a day could be scaled as twice as impactful based on a point score compared with smoking 10 cigarettes a day. Participants were also asked what their recommended clinical management would be. The systematic reviews and key articles were continuously updated and
made available to all participants prior to each Delphi exchange.

At each Delphi exchange, all risk indicators, subscales, point allocation, and clinical management recommendations were voted on with consideration of supporting literature and clinical experience. Consensus was defined as 95% agreement.18 Anonymous individual comments and aggregate voting results were provided to all participants in advance of each Delphi exchange.

RESULTS

Responses to the Delphi I questionnaire resulted in deletion of the risk indicators of heavy consumption of alcohol, low vitamin D, nonsteroidal anti-inflammatory drugs (NSAIDs), and xerostomia (Table 1). The consideration of evaluating risk by edentulous or partially edentulous patients was voted as being outside the purview of this project. The point allocation and subscales for smoking, diabetes, antiresorptive agents, and periodontal disease were modified, and subscales were recommended for plaque levels and cemented restorations. Suggested changes for clinical management were made on all risk indicators proposed except clinician experience.

The face-to-face Delphi II resulted in more change than the Delphi I or Delphi III. The risk indicator of hepatitis was added. The Delphi group voted to further modify the subscales, point allocation, and clinical recommendations for smoking, diabetes, antiresorptive agents, periodontal disease, and plaque levels. The consideration of evaluating synergies among different risk indicators was considered beyond the scope of this project. The category of plaque level readings...
at the initial exam was expanded with a subscale and was considered to include the risk indicator of limited dexterity, which was ultimately not added. Maxillary posterior site replaced type IV bone as a risk indicator. Implant type was debated and dropped. The designation of “red flag” was recommended where alternative treatments to implants should be considered and included: patients taking intravenous (IV) antiresorptive agents for the treatment of cancer, patients with medication-related osteonecrosis of the jaw (MRONJ), a history of radiation above 55 Gy to the head and neck, or untreated aggressive periodontitis. When the group

### Table 1: Percent Agreement After Completion of Delphi I, Delphi II, and Delphi III

<table>
<thead>
<tr>
<th>Risk indicator category</th>
<th>Delphi I</th>
<th>Delphi II</th>
<th>Delphi III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient history</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smoking</td>
<td>76%</td>
<td>100% after subscales</td>
<td></td>
</tr>
<tr>
<td>Diabetes</td>
<td>87%</td>
<td>96% after subscales</td>
<td></td>
</tr>
<tr>
<td>Previous implant loss</td>
<td>80%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>IV anti-resorptive agents</td>
<td>80%</td>
<td>Deferred, added subscales</td>
<td>91%, re-vote to 95%</td>
</tr>
<tr>
<td>Medications/SSRIs/PPIs</td>
<td>86%</td>
<td>100% after revisions</td>
<td></td>
</tr>
<tr>
<td>Alcohol, BMI &gt; 25, Vit D, NSAIDS, cardiovascular disease, corticosteroids</td>
<td>65%</td>
<td>Removed, limited evidence&lt;sup&gt;57,168-173&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Hepatitis</td>
<td>Added as risk indicator</td>
<td>64%, removed</td>
<td></td>
</tr>
<tr>
<td>Head and neck radiation</td>
<td>82%</td>
<td>99% after revisions</td>
<td>100%</td>
</tr>
<tr>
<td>Xerostomia</td>
<td>70%</td>
<td>Removed as risk indicator</td>
<td></td>
</tr>
<tr>
<td>Low motivation maintenance</td>
<td>76%</td>
<td>Removed, overlaps with Plaque Index (PI)</td>
<td></td>
</tr>
<tr>
<td>Limited dexterity, cognition</td>
<td>75%</td>
<td>Removed, overlaps with PI</td>
<td></td>
</tr>
<tr>
<td>Maxillary posterior placement</td>
<td>–</td>
<td>Added, 100%</td>
<td></td>
</tr>
<tr>
<td>Clinical findings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Periodontal disease</td>
<td>81%</td>
<td>100% after adding subscales on severity; treatment status</td>
<td></td>
</tr>
<tr>
<td>Bruxism</td>
<td>75%</td>
<td>96% after revisions</td>
<td></td>
</tr>
<tr>
<td>Plaque Index at exam</td>
<td>86%</td>
<td>99% after subscales</td>
<td></td>
</tr>
<tr>
<td>Having 4 or more implants</td>
<td>59%</td>
<td>59%, reported effect,1,2,127,174–176 related to having more implants</td>
<td>36%, removed</td>
</tr>
<tr>
<td>Inexperienced clinician in surgical or restorative</td>
<td>75%</td>
<td>95%</td>
<td></td>
</tr>
<tr>
<td>Thin tissue biotype</td>
<td>84%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Clinician decisions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 mm attached tissue</td>
<td>74%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Height from implant platform to tissue margin &lt; 3 mm</td>
<td>94%</td>
<td>Deferred; outside consultations</td>
<td>95%</td>
</tr>
<tr>
<td>Bone volume &lt; 2 mm to buccal side of implant</td>
<td>73%</td>
<td>98%</td>
<td></td>
</tr>
<tr>
<td>Type 4 bone</td>
<td>86%</td>
<td>Removed, changed to maxillary posterior</td>
<td></td>
</tr>
<tr>
<td>&lt; 3 mm to adjacent implant</td>
<td>80%</td>
<td>97%; outside consultations</td>
<td></td>
</tr>
<tr>
<td>&lt; 1.5 mm to adjacent tooth</td>
<td>91%</td>
<td>94%; outside consultations</td>
<td>84%, re-vote to 96%</td>
</tr>
<tr>
<td>Placing implant too buccal</td>
<td>84%</td>
<td>Removed, overlaps with bone volume</td>
<td></td>
</tr>
<tr>
<td>Prosthesis that limits access</td>
<td>89%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Cemented and supragingival</td>
<td>59%</td>
<td>100%, after subscales, outside consultations</td>
<td></td>
</tr>
<tr>
<td>Cemented and subgingival</td>
<td>74%</td>
<td>97%, after subscales, outside consultations</td>
<td></td>
</tr>
<tr>
<td>Poor recall compliance</td>
<td>89%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Type of implant (see Table 4 for accommodation for biologic width)</td>
<td>66%</td>
<td>Removed, some evidence&lt;sup&gt;48,99,126,177&lt;/sup&gt;; among major manufacturers, differences are with initial remodeling.&lt;sup&gt;177&lt;/sup&gt; not continuing bone loss</td>
<td></td>
</tr>
<tr>
<td>Platform switching (See Table 4 for accommodation for biologic width)</td>
<td>64%</td>
<td>Removed, but some support if &lt; 3 mm between implants&lt;sup&gt;140&lt;/sup&gt; or closer than 1.5 mm to tooth;&lt;sup&gt;135&lt;/sup&gt; offsets may be of more benefit if &gt; 0.4 mm,&lt;sup&gt;38&lt;/sup&gt; less benefit if thin mucosal tissue&lt;sup&gt;131&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>
lost momentum and could not agree on a risk indicator, the facilitator organized groups of four Delphi participants to further research the literature, query additional content experts nationally and internationally, and to report back to the group. This information from outside experts was incorporated into the Delphi III email questionnaire.

Responses to the Delphi III questionnaire led to removing the risk indicator of hepatitis and risk of patient treatment with four or more implants. The risk indicators of height from implant platform to tissue margin less than 3 mm, platform switching, and cemented restorations were reviewed with opinions from outside experts and modified. Risk indicators with the highest point allocations (6 points) requiring extra precaution were identified: smoking more than 20 cigarettes per day; having glycated hemoglobin levels (HbA1c) higher than 8% at the time of implant placement; patients with treated aggressive periodontal disease, or untreated moderate/severe chronic periodontitis; or a treatment plan that included a prosthesis that limited access for cleaning, resulting in an increase in bacterial load. An aggregate risk scale was proposed with categories of low (< 6 points), intermediate (6 to 10 points), and high risk (> 10 points).

Lack of consensus occurred with risk indicators of hepatitis, having four or more implants, and some of the initially considered medications and systemic conditions (Table 2). The type of implant and use of platform switching also lacked consensus, but were incorporated into the risk indicator of not accommodating for biologic width. The most debated risk indicators included the use of antiresorptive agents, having four or more implants, bruxism, the point allocation for platform switching, and the subcategories for periodontal disease and diabetes.

**DISCUSSION**

The literature on risk indicators for biologic complications with dental implants has been described as
Table 3  Risk Indicators Based on Clinical Findings

<table>
<thead>
<tr>
<th>Risk indicators/subscales</th>
<th>Points</th>
<th>Clinical management considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodontal disease</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Aggressive periodontitis                 | 6      | Red flag; Periodontal treatment needs to be provided and stability achieved prior to implant placement,
| Moderate/severe chronic periodontitis    | 4      | even with patient compliance, risks are elevated in patients with aggressive or chronic periodontal
| Slight chronic periodontitis             | 2      | disease. Adjunctive treatment with triclosan containing toothpaste,6 consider grafting if lacked attached tissue,46 CHX during treatment,157 pocket reduction of natural teeth prior to implants, more recalls |
| Plaque levels at exam (Plaque Index)     |        |                                                                                                     |
| Moderate plaque PI > 20% to 50%          | 2      | Patient education, OHI, more frequent recalls,8 patients with higher Plaque Index at higher risk for unfavorable peri-implant condition97,107 |
| Heavy plaque PI > 50%                   | 4      |                                                                                                     |
| Bruxism                                  | 3      | Bruxers with increased screw loosening and potential for open contacts,148 potential indirect effects including rotational wear and introduction of particulate matter into sulcus, biocorrosion from mating surfaces abrading and removing titanium dioxide,113,181 deformation of implant,190 consider nightguard156 although low compliance191 |
| Implant placed in maxillary posterior    | 2      | Type IV bone least favorable46; therefore, longer waiting period for bone maturation and osseointegration might be suggested; consider splinting if external hex192 |
| Inexperienced clinician                 | 3      | Inexperienced clinician more likely to make mistakes in implant selection, placement, position, and restoration; outcomes not as favorable overall2,58,60,116 |

CHX = chlorhexidine; OHI = oral hygiene instruction.

Table 4  Risk Indicators Based on Clinician Decisions and Post-implant Placement Findings

<table>
<thead>
<tr>
<th>Risk indicators based on clinician decisions/subscales</th>
<th>Points</th>
<th>Clinical management considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft tissue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack 2 mm attached tissue around implant</td>
<td>2</td>
<td>More plaque accumulation, tissue inflammation, recession, and loss of attachment when lacking attached tissue,34 Consider connective tissue grafting before definitive prosthesis if brushing irritates tissue9</td>
</tr>
<tr>
<td>Distance &lt; 3 mm from peri-implant tissue margin to bone crest</td>
<td>2</td>
<td>Tissue thickness less than 3 mm associated with increased bone loss,11,36,130 most often identified in mandible,11 may also be significant risk if &gt; 5 mm between bone crest and tissue104</td>
</tr>
<tr>
<td>Bone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone volume less than 2 mm to buccal side of implant</td>
<td>4</td>
<td>Narrower diameter implant if feasible, bone profiling if acceptable esthetically, grafting, having 2 mm buccal bone after osteotomy helpful to decrease bone loss,136 or grafting buccal bone prior to or at time of implant placement</td>
</tr>
<tr>
<td>Implant position</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closer than 3 mm to adjacent implant</td>
<td>4</td>
<td>More bone and soft tissue loss if implants are less than 3 mm apart,138 platform switching may help offset impact of implants being less than 3 mm apart52,139,140</td>
</tr>
<tr>
<td>Closer than 1.5 mm to adjacent tooth</td>
<td>4</td>
<td>See more bone and soft tissue loss if closer than 1.5 mm between implant and tooth,134 platform switching may be of benefit in allowing closer proximity with less bone loss135</td>
</tr>
<tr>
<td>Treatment plan includes prostheses that limits access for cleaning resulting in an increase in bacterial load</td>
<td>6</td>
<td>High levels of plaque increase odds of peri-implantitis,97 crown contours may influence biologic outcomes,142, 193 consider alternate prostheses if patient access is an issue,141 evaluate in provisional, electric toothbrush,154 water flosser,153 glycine-power airflow,155 increase frequency recalls, triclosan-containing toothpaste,158,194</td>
</tr>
<tr>
<td>Cemented restorations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cemented at or above the gingival margin</td>
<td>2</td>
<td>Cemented restorations increase risk for peri-implantitis,143,144 access for cleaning important,5 may be more problematic if lack 2 mm attached tissue34 or if thin tissue biotype,112 residual cement can act as a foreign body but some cements may also have cytotoxic effects on osteoblasts,146,147 treatment plan screw-retained if practical to avoid cement, retrievable screw-retained since proximal contacts between implants and teeth not stable198</td>
</tr>
<tr>
<td>Cemented and subgingival</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Poor compliance with recommended recall</td>
<td>3</td>
<td>Counseling on the consequences of lack of compliance,7,8 motivational interviewing,178 additional recall attempts,10 costs of recall visits first year included in quoted treatment estimates</td>
</tr>
<tr>
<td>Not accommodating for biologic width with the implant/prosthesis design</td>
<td>2</td>
<td>Accounting for biologic width can be done vertically with a tissue level implant or horizontally with a horizontal offset177; the value of a horizontal offset may be more important when interimplant distance is less than 3 mm,140 when the implant-to-tooth is closer than 1.5 mm,126 if offset is &gt; 0.4 mm36; some implant systems start with a horizontal offset but if used with an intermediate nonengaging abutment, the horizontal offset is lost.</td>
</tr>
</tbody>
</table>

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heterogenous, inconsistent, inconclusive, fraught with potential measurement error, and often lacking details related to clinician factors, such as implant positioning or loading. The study heterogeneity may also reflect variability associated with medical management, clinician expertise, or other unknown factors. As a result, it is not surprising that many of the systematic reviews and meta-analyses considered in the present study included a caveat that their conclusions and clinical recommendations demand caution. This unfortunately leaves the clinician without support for many important decisions regarding treatment planning, patient consent, and a patient-specific maintenance plan.

The Delphi method has been recommended on topics where clinical management is variable, large clinical trials are lacking, and when the outcome studied has an uncertain multifactorial etiology, which is exactly what is seen in the topic of risk assessment with dental implants. The Delphi group voted to add subscales and point allocations to the risk indicators to better represent the impact of dose, disease severity, treatment status, and access for cleaning. By doing so, the Delphi group felt some of the heterogeneity among studies could be reconciled, making actionable clinical recommendations more plausible and less conditional. Below, in sequence and with Tables 2 to 4, is a brief review of each risk indicator with recommended subscales, point allocation, and clinical recommendations for management.

Risk Indicators Based on Patient History

A recent systematic review and meta-analysis that evaluated 107 publications on smoking and implant failure concluded that smoking increased the implant failure rate compared with nonsmokers (6.35% vs 3.18%), and impacted implants in the maxilla more than in the mandible. Additional systematic reviews have reported relative risk for implant failure in smokers compared with nonsmokers to be 2.33, with an odds ratio between 1.72 and 1.96 and the hazard ratio to be 2.6. The Delphi group agreed that smoking is a significant risk indicator for biologic complication and implant failure, and that a subscale to represent the dose-related effect of smoking would better characterize patient-specific risk as well as help explain some of the heterogeneity of the literature on smoking.

Two systematic reviews on the biologic complications of patients with diabetes and dental implants concluded that the risk of peri-implantitis was approximately 50% higher in diabetics than nondiabetics and that patients with diabetes had higher rates of implant failure. In contrast, one systematic review determined a nonsignificant risk ratio when comparing implant failure in patients with or without diabetes. The Delphi group felt the reasons for the inconsistency in findings from systematic reviews included the following: (1) since it is unethical to passively observe patients with poor glycemic control, most studies observe patients who have well-controlled diabetes, for which there is little or no effect on implants; (2) most studies include a dichotomous classification of diabetes as present or not present, rather than a gradation of disease severity, which has been shown to be important. The Delphi group voted to add a subscale and point allocation of disease severity to better characterize patient-specific risk. The Delphi group also recommended more aggressive HbA1c testing since many patients are unaware they have diabetes.

A history of previous implant loss is a risk indicator for future implant loss. A recent systematic review on the survival rate of dental implants placed after an initial failure identified seven studies following 396 patients and determined an 88% success rate for the replacement implant with a mean follow-up of 16 months, with third attempts successful at a 74% survival level. The Delphi group agreed that patients should be urged to consider modifying risk indicators. What was not enumerated in the literature was that the clinician should also consider risk indicators not previously considered, for example, previously undetected risks such as bruxism, clinician-related factors such as inexperience, loading protocol, or prosthetic design factors.

The effect of antiresorptive agents on implant failure rates is uncertain due to a limited number of quality studies and the fact that patients taking antiresorptive agents often have comorbidities as additional risk factors. The Delphi group agreed that the use of IV antiresorptive agents for hypercalcemia resulting from metastatic cancer is an absolute contraindication to implant therapy due to the incidence of osteonecrosis of the jaw (ONJ), but the evidence is of low order. The Delphi group made a distinction between the disease condition being treated and the risk; therefore, a subscale and point allocation identifies the lower risk associated with patients taking oral antiresorptive agents for osteoporosis, moderate risk in patients taking IV antiresorptive agents for osteoporosis, and high risks in patients taking IV antiresorptive agents for cancer (Table 2).

The use of selective serotonin reuptake inhibitors (SSRIs) has been shown to influence bone metabolism and adversely impact biologic outcomes with implants. SSRI users demonstrated an increased incidence of implant failure from 4.6% to 10.6% in one cohort study, but the impact of SSRIs was questioned in a retrospective study where follow-up time, clustering, and dose were thought to influence findings.
The Delphi group acknowledged that patients taking SSRIs for depression may have poorer oral hygiene with higher plaque levels, which could be confounding variables often not accounted for in studies.

Patients are prescribed a proton pump inhibitor (PPI) to decrease gastric acidity. The use of PPIs also results in reduced calcium uptake in the intestine, which may explain the association with increased implant failure. In a rat animal model, PPIs decreased bone-to-implant contact and bone volume. The Delphi group agreed that the association between use of PPI and implant failure is from retrospective studies where dosage and systemic conditions are incompletely identified, but that the additional evidence from animal model studies is supportive of a mechanism of reduced calcium absorption, which explains decreased bone-to-implant contact and bone loss around implants.

A systematic review evaluating implant survival in irradiated oral cancer patients included 38 articles and established that implant survival rates were higher for the mandible (93%) than the maxilla (79%), that the timing of implant placement before or after radiation was not significant, and that there were increased failure rates with implants placed in bone grafts. When the radiation dose was above 55 Gy, the failure rate was significantly greater, consistent with another systematic review. The Delphi group designated patients having received more than 55 Gy as "red flag," where referral to a tertiary center or specialty team should be considered.

### Risk Indicators Based on Clinical Findings

Implants placed in patients with a history of chronic periodontal disease are associated with higher incidence of biologic problems and lower success and survival rates. In a systematic review of implant outcomes in treated periodontitis patients in partially edentulous patients with up to 16-year follow-up, Sousa et al showed 92% to 100% success in the nonperiodontitis group vs 79% to 100% success in the periodontitis group. Dalago et al have estimated that the risk for peri-implant disease is increased 2.2 times when the patient has a history of periodontal disease. Derks et al also reported a higher odds ratio (4.1) for peri-implantitis in patients with periodontitis.

Severe forms of periodontal disease are associated with higher rates of implant loss. In a prospective study, De Boever et al found that patients with generalized aggressive periodontitis have more peri-implant marginal bone loss and a lower implant survival rate. Similarly, Swierkot et al followed patients with generalized aggressive periodontitis for an average of 8.25 years, and reported a five times higher risk of implant failure and a 14 times higher risk of peri-implantitis compared with periodontally healthy individuals. A recently published systematic review concluded that patients with generalized aggressive periodontitis represented a risk ratio of 4.0 compared to patients without periodontitis. Patients with implants and diagnosed with periodontal disease can remain relatively stable, therefore, the Delphi group felt subcategories of periodontal severity, treatment status, and point allocation were important to characterize patient-specific risk.

High plaque levels are a risk indicator, and animal studies have shown that plaque can trigger the development of peri-implantitis. Human studies have also reported a strong correlation between plaque and peri-implantitis. A recent cross-sectional study reported an odds ratio of 9.25 for peri-implantitis in patients with large amounts of plaque. Furthermore, unlike periodontal disease, a "self-limiting" protective process is not seen in peri-implantitis. Upon ligature removal, animal studies have shown spontaneous continuous progression of bone loss. The Delphi group agreed that a subscale of high or moderate Plaque Index more completely represented patient-specific risk. The initially considered risk indicators of an unmotivated patient, patient with limited dexterity, or cognitively impaired patient were better represented by plaque levels at the initial examination.

A thin gingival biotype is related to more buccal bone resorption after tooth extraction than a thick biotype. Curtis et al reported a statistically significant association between the labial gingival biotype and the underlying bone thickness in a cadaver study. Frost et al also identified a tendency for thinner gingival biotype patients to also have a thinner buccal plate. The Delphi group agreed that although there is currently no direct evidence, a thin buccal plate and more buccal bone resorption may occur when a patient presents with a thin gingival biotype.

Patients with bruxism have shown a significant association with biologic complications, although one review stated that bruxism is unlikely to be a biologic complication. In a long-term retrospective study, bruxers had an increased risk (hazard ratio 2.9) for implant failure. In a retrospective study of 2,670 patients with 10,096 implants, the implant failure rate was 13% for bruxers and 4.6% for nonbruxers. A recent systematic review also concluded an odds ratio of 3.83 for implant failures in bruxers vs nonbruxers. Implants with peri-implantitis had significantly higher levels of titanium particles in the crevicular fluid compared with healthy implants, suggesting that material wear and corrosion could occur simultaneously in the oral environment, especially in bruxers. The Delphi group confirmed that there is a link between...
implant failure and bruxism, which underscores the importance of considering an appropriate number of implants, loading regimen, and potential compliance with the use of a nightguard, which has been reported to be approximately 54% in specialty practices.120

The Delphi group agreed that “bone quality” remains an ambiguous and subjective term with low reliability among scoring systems evaluating bone quality.121,122 Additionally, the same osteotomy site often includes areas of higher and lower resistance reflecting different mineralization and density patterns. This makes comparisons between studies evaluating bone quality difficult.48,121 Therefore, the Delphi group recommended the use of maxillary posterior rather than the difficult-to-measure “bone quality” as a risk factor since implants fail with a high frequency in the maxillary posterior,123 presumably due to “bone quality” reasons, including thin cortical bone124 and unfavorable trabeculation patterns. The Delphi group also agreed that as technologies improve, bone quality will be more accurately established by cone beam computed tomography (CBCT).125

Clinician experience significantly impacts surgical58,59,116 and prosthetic126 outcomes. Implant placement by inexperienced surgeons (< 50 implants) has been shown to double the failure rate (5.9% vs 2.4%).58 A hazard ratio of 2.50 was reported for the impact of a less-experienced operator on implant failures.127 Implant prosthetic therapy delivered by a general practitioner, as opposed to a specialist, also exhibited a higher odds ratio for moderate to severe peri-implantitis.126 The Delphi group agreed with a recent systematic review concluding that when considering implant survival, the clinician experience appears to be more impactful than formal training.59

Risk Indicators Based on Clinician Decisions
A recent systematic review concluded that adequate keratinized tissue was related to improved peri-implant tissue health,33 consistent with the view of the European Federation of Periodontology, which proposes that having attached and unmovable keratinized tissue surrounding the implant helps facilitate oral hygiene.5 Similarly, a recently published meta-analysis34 concluded that lacking a wide band of keratinized tissue is associated with more plaque accumulation, tissue inflammation, recession, and loss of attachment.34 Although another review article affirmed that the evidence of non-keratinized mucosa on bone-level changes or implant loss was scarce and inconclusive,128 the Delphi group agreed that recent literature has increasingly cited a positive correlation between the width of keratinized tissue and peri-implant tissue health.35,129

Soft tissue height between the marginal soft tissue and crestal bone may impact bone response.130,131 Thicker peri-implant tissue height minimized the crestal bone loss compared with a thinner (2 mm or less) tissue.130,131 Although current evidence is considered insufficient by some authors,132 a recent systematic review concluded that a thicker initial peri-implant soft tissue could result in less radiographic bone loss in the short term.49 The Delphi group agreed that lacking soft tissue height may adversely impact crestal bone but also noted that tissue thickness of greater than 5 mm in periodontally susceptible patients may also put the patient at increased risk.104

Implant position in relation to available bone volume, adjacent teeth, and adjacent implants can also be important to biologic outcomes.133–136 Monje et al estimated that 40.5% of peri-implantitis diagnoses were in patients where the implant was placed “too-buccal,”133 and that as a result of misplacement, initial bone loss can occur by remodeling with little inflammation.137 Implants should be at least 1.5 mm from adjacent teeth,134 but may need less space with platform switching.135 Having a 3-mm distance or more between implants is considered ideal,138 although some animal139 and human140 studies have shown that a 2-mm distance can be sufficient when used with a horizontal offset, and a recent systematic review concluded that the evidence for a 3-mm distance requirement is unclear.50 An additional guideline is to have 2 mm of bone buccal to the implant,136 which the Delphi group agreed was an important risk indicator.

Prosthesis design influences risk for biologic complications.1,7,141,142 Serino and Ström concluded that a high percentage of patients presenting with peri-implantitis were those with either limited capability or limited access for proper oral hygiene.141 For single-unit implant crowns, a closed emergence angle has been shown to be associated with peri-implantitis in bone-level implants but not tissue-level implants.142 The Delphi group felt that a prosthetic that limits access for cleaning resulting in an increase in bacterial load was problematic to some patients.

Excess cement is a risk indicator for biologic complications.1,143–147 Cement acts as a foreign body, and some cements are also cytotoxic to osteoblasts.146,147 In a retrospective study of 183 patients with 916 implants in function for at least 1 year, a cemented restoration had a 3.6 times increased risk for peri-implantitis compared with a screw-retained restoration.1 The Delphi group agreed that subscales were helpful to differentiate between a cemented margin above or below the gingival margin since the more subgingival the margin, the more difficult it is to remove all excess cement.145

The Delphi group agreed that a maintenance program with appropriate in-office and at-home regimen is essential for a favorable long-term implant treatment outcome.5,7,8,27,148–150 In a 5-year follow-up study,
Costa et al compared patients with and without preventive maintenance, and found that the incidence of peri-implantitis was lower in the group with maintenance (18%) compared to the group without maintenance (43.9%). Rokn et al also reported an incidence of 20% of patients experiencing peri-implantitis if not participating in a regular maintenance program. Importantly, when in a regular maintenance program, a patient is much more likely to remain periodontally stable than if they are not in a maintenance program. The Delphi group agreed that a minimum maintenance recall of 5 to 6 months is recommended.

The Delphi discussions resulted in the recommendation that the points allocated to individual risk indicators be summed to provide an estimate of aggregate risk (sum of Tables 2 to 4) with categories of low (< 6 points), intermediate (6 to 10 points), and high (> 10 points).

### Maintenance Recommendations Based on Aggregate Risk (Sum of Tables 2 to 4)

- **Low risk (< 6 points):** Patients are usually healthy, taking few medications and being treated with one to two implants. Single-tooth replacements represent more than 50% of all implants placed. When the sum of points from the questionnaire is less than 6, regular 6-month recalls, routine cleaning patterns, and routine toothpaste are recommended.

- **Intermediate risk (6 to 10 points):** Patients often have several risk indicators, which may include medications, chronic disease(s), a prosthesis that limits access for cleaning, high plaque levels at presentation, subgingival cemented margins, or other combinations of risk indicators. The modifiable risk indicators should be addressed by referral, counseling, and/or modifications in the maintenance recall prior to implant placement. The biologic response to risk indicators is variable, so oversight and recall every 3 to 4 months during the first year can be helpful. The use of a water flosser if access is an issue, a timer on an electric toothbrush if there is a compliance/cognitive issue, and use of a glycine air polisher have been useful. A nightguard is recommended if the patient is a bruxer, although compliance is often poor. Application of 1% chlorhexidine in the implant prior to abutment connection if abutment(s) are removed and/or if screws are replaced is also helpful to decrease bacterial load. With provisional restorations, it is important to evaluate the patient's ability to access and clean tissues in proximity to the prosthesis. If that patient is a thin tissue biotype, or if there is no attached tissue, consideration of a connective tissue graft is recommended if the patient is unable to comfortably maintain peri-implant tissues.

- **High risk (> 10 points):** These patients often have multiple risk indicators. In addition to the suggestions listed under intermediate risk recommendations, a 3-month recall is recommended. The use of a screw-retained prosthesis becomes more important, especially with bruxers. Screw-retained restoration margins should ideally be 2 mm coronal to marginal bone.

There are limitations to the present study. Some would question a calculation of low-, intermediate-, and high-risk categories based on literature that has been characterized as inconclusive and inconsistent. Additionally, the Delphi process has been criticized for being poorly standardized and inconsistently used. However, the authors would argue that appropriate use of the Delphi method has been successful in addressing areas where literature is heterogeneous and inconclusive. Additionally, estimating aggregate risk for health outcomes is important and has been successfully used to therapeutic benefit, even when the risk assessment algorithm has not been validated.

The authors did not complete a systematic review of the literature but identified systematic reviews as a starting point for the Delphi I questionnaire. This approach is consistent with the use of the Delphi consensus method in the medical and dental literature. Additionally, the authors realize this is not a validated study; rather, it represents a starting point to estimate aggregate risk for biologic complications and represents the authors' interpretation of the literature as debated from the Delphi process. The proposed questionnaire is a tool for clinician planning and patient disclosure, and can potentially help establish a baseline level of risk pretreatment or update potential risk for an existing patient of record who has a change in health history. Patient disclosure and personalizing risk is critical to counterbalance preconceived notions that implants are a low-risk procedure. Risk is often not considered by patients seeking implant treatment, and many of the media messages patients see in the United States reinforce an optimistic outcome with implant treatment.

### CONCLUSIONS

The literature on risk indicators for biologic complications with dental implants has not included efforts to estimate aggregate risk. The use of subscales for the individual risk indicators of smoking, diabetes, antiresorptive agents, periodontal disease, plaque levels, and cemented restorations were recommended to more accurately represent patient-specific risk. The Delphi
process was useful to identify and debate the weighting of individual risk indicators resulting in consensus of a risk assessment tool for estimating aggregate risk.

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