

Mechanical Risk Assessment of Implant–Abutment Connection Geometries Used in Contemporary Dental Implant Systems-Dr Syed Salman Ali (Review white paper)

Executive Summary

This white paper presents an independent, geometry-based mechanical risk assessment of several commonly used bone-level implant–abutment connection designs, focusing on platform (cone) angle and internal hex diameter as primary determinants of bending and fatigue resistance at the implant neck. A simple numerical Mechanical Risk Index (MRI) is proposed, combining (1) a wall-thickness risk score derived from internal hex diameter and (2) a cone-type risk score derived from platform angle and engagement type, to enable comparative case planning across systems.

Available in-vitro and computational evidence consistently shows that internal conical (Morse-type) connections reduce micromotion, preserve screw preload, and lower rates of mechanical complications compared with flat butt-joint internal hex designs, particularly under cyclic off-axis loading.^{[1][2][^3]} At the same time, increasing the internal connection diameter or reducing the remaining wall thickness at the cervical region decreases fatigue life, especially in narrow-diameter implants under non-axial loading.^{[4][5][^6]}

Within the set of connections analyzed here, deep, low-angle internal cones with small internal hexes (e.g., ROOTT, MegaGen AnyRidge) exhibit the lowest mechanical risk scores, followed by modern conical systems with slightly larger cone angles or internal diameters (e.g., Straumann BLX, Nobel Biocare conical connection, Neodent Grand Morse, MegaGen BlueDiamond).^{[7][8][9][10][11][12][13][14][15][16]} High-angle or essentially flat internal hex platforms (some Korean and Israeli generic systems) show the highest relative mechanical risk in this framework because they combine thinner walls with butt-joint behavior, leading to greater screw-dominated loading and higher risk of fatigue-related complications under demanding conditions.^{[17][2][^1]}

Background and Rationale

Mechanical complications in implant prosthodontics—screw loosening, abutment or implant fracture, and deformation of the implant–abutment interface—are closely related to how loads are transferred across the connection.^{[1][2]}

Key design variables include connection type (external vs internal; conical vs butt-joint), cone angle, connection depth, and the residual cross-section of implant material at the cervical region.

Multiple comparative studies have demonstrated that internal conical connections generally exhibit reduced microgap formation and improved maintenance of screw preload under static and dynamic loading compared with internal hex or external hex designs.^{[3][18]}^[^1]

Finite-element analyses further show that internal cones distribute stresses more uniformly into the implant walls and surrounding bone, lowering peak stresses in the abutment screw and at the first implant thread.^{[19][20]}

At the same time, fatigue tests and simulations indicate that narrowing the implant diameter or enlarging the internal connection diameter at the neck can substantially reduce fatigue life and increase the likelihood of fracture, especially for bone-level implants subjected to non-axial occlusal forces.^{[4][21]}^[^6] These findings motivate a simplified engineering-oriented framework that combines connection geometry and section modulus into a single relative risk indicator that clinicians can use across manufacturers.

Literature Evidence on Connection Geometry and Fatigue Behavior

Influence of Connection Type

A comprehensive review of implant–abutment connection designs concluded that conical abutments show fewer mechanical complications, such as screw loosening and fracture, and display higher torque preservation compared with butt-joint internal hex and external hex designs.^[^1]

The same review reported that internal hexagon and especially internal conical (Morse taper) connections exhibited less microleakage under dynamic loading conditions than external designs, reflecting improved interface stability.

In an in-vitro comparison of external hex, internal hex, and cone-in-cone connections using rotating bending fatigue tests, external hex implants displayed the highest fatigue resistance; however, this was attributed primarily to their larger remaining metal cross-section at the neck rather than inherent superiority of the external connection concept.^[^22]

Subsequent work modifying internal conical designs within the same implant system has demonstrated that optimizing the internal geometry—while keeping outer dimensions constant—can significantly improve fatigue behavior, confirming the sensitivity of fatigue resistance to connection shape.^[^23]

Effect of Internal Geometry, Platform Diameter, and Section Modulus

An experimental study of two-piece titanium implants under non-axial loading found that both connection type and platform diameter influenced fatigue resistance and stress distribution, with wider platforms generally increasing fatigue life of the prosthetic screw and narrower diameters showing earlier fatigue failure.^[6]

A more recent investigation of narrow-diameter implants assessed the effect of internal connection parameters on fatigue limit and noted that systematic variation of the internal geometry significantly altered fatigue resistance.^[4]

Another study on butt-joint implant-supported prostheses demonstrated that increasing the implant platform and body diameter significantly improved fatigue life of the prosthetic screw, highlighting the role of section modulus at the neck.^[5]

Together, these data indicate that both the size of the internal connection (which reduces wall thickness) and the type of interface (conical vs flat) are critical for mechanical performance.

Bone-Level vs Tissue-Level Considerations

Finite-element modeling comparing bone-level and tissue-level connections under vertical and oblique loading found that bone-level designs experienced larger microgap formation at the implant–abutment interface and were more prone to fatigue failure, particularly at diameters below 3.5 mm in the posterior mandible.^[20]

This suggests that bone-level connections with large internal geometries in narrow fixtures warrant special caution when high bending loads are expected.

Systems and Geometries Included in the Analysis

The present assessment focuses on the following bone-level implant systems and their internal connection geometries (hex diameter and platform angle) as summarized from manufacturer technical documentation, catalogues, and system overviews:

- **ROOTT:** Internal hex diameter ≈ 2.05 mm with a 10° internal cone; single platform design.^{[10][11]}
- **Korean Mini:** Internal hex ≈ 2.10 mm with a 22° platform bevel (butt-joint dominant behavior).
- **Korean Regular:** Internal hex ≈ 2.50 mm with a 22° platform bevel.
- **Israel Wide Systems:** Internal hex ≈ 2.43 mm with an essentially flat 90° platform.
- **Israel Systems:** Internal hex ≈ 2.43 mm with a 90° butt-joint configuration.
- **Neodent Grand Morse (GM):** Internal index 3.0 mm with a deep 16° conical connection; single platform across diameters.^{[8][24][9]}

- **Nobel Biocare NP:** Narrow-platform internal conical connection with platform switching and approximately 24° conical geometry.^{[25][26]}
- **Nobel Biocare Regular (CC):** Regular-platform internal conical connection of similar angle with a tri-channel or trioval indexing design.^{[27][26][^16]}
- **Straumann BLX:** Internal conical connection (TorcFit) described as a narrow-angle cone with deep engagement and internal indexing.^{[7][28]}
- **Straumann BLT:** Tapered bone-level implant with internal conical connection; the platform angle used in this analysis reflects the bevel angle at the implant shoulder based on available technical drawings.^[^7]
- **MegaGen AnyRidge:** Universal internal connection combining a 5° Morse taper with a 2.3 mm internal hex across all diameters ("Magic Five").^{[13][29][14][15]}
- **MegaGen BlueDiamond (X-FIT):** Internal X-FIT connection with a 30° internal cone and octa-based keystone architecture; internal connection diameter $\approx$ 3.1 mm depending on platform.^{[30][31][^12]}

Where manufacturer data were incomplete, geometric parameters were approximated from published diagrams and technical schematics, using consistent criteria across systems.

Construction of the Mechanical Risk Index

Conceptual Basis

The Mechanical Risk Index (MRI) is designed as a relative indicator of mechanical vulnerability to bending and fatigue at the implant neck, assuming comparable outer implant diameters and materials.

It combines two dimensionless subscores:

1. **Wall-thickness risk score (1–5)**, derived primarily from internal hex diameter as a proxy for remaining wall thickness and section modulus at the cervical region.
2. **Cone-type risk score (1–5)**, derived from platform angle and whether the interface behaves as a friction-locking internal cone or a butt-joint platform.

This approach is grounded in evidence that reduction of the metallic cross-section at the neck decreases fatigue life, and that conical connections with frictional engagement improve load transfer and minimize micromotion compared with flat interfaces.^{[1][4][5][6][^18]}

Scoring Rules

The following heuristic scoring rules were applied:

- **Wall-thickness risk (1–5)** based on internal hex diameter (approximate ranges):
 - ≤ 2.3 mm → score 1 (very thick walls, higher section modulus).
 - 2.31–2.6 mm → score 2.
 - 2.61–3.0 mm → score 3.
 - 3.01–3.4 mm → score 4.
 - 3.4 mm → score 5 (thinnest walls, lower section modulus).
- **Cone-type risk (1–5)** based on platform angle and interface type:
 - 5–15° internal cone (Morse-type) → score 1 (maximal frictional engagement, lower micromotion).^{[1][18]}
 - 16–25° internal cone → score 2 (good conical behavior, somewhat reduced frictional locking).
 - 26–35° internal cone → score 3.
 - 36–60° bevel or shallow cone → score 4.
 - 90° or butt-joint platform → score 5 (no meaningful conical engagement; screw-dominated load path).^{[2][3]}

The **Mechanical Risk Index (MRI)** is then defined simply as:

$$\text{MRI} = \text{Wall-thickness risk} + \text{Cone-type risk}$$

This linear combination is intentionally simple and conservative; it is meant for relative comparison rather than absolute prediction of fatigue life.

Future work could refine weighting of these components or incorporate additional variables (implant diameter, alloy, thread design), but the present framework already aligns qualitatively with published fatigue and deformation data across connection types.^{[4][5][23][6]}

Results: Relative Mechanical Risk Ranking

Calculated Scores

Applying the scoring rules to the systems described above yields the following table:

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System	Hex diameter (mm)	Platform angle (°)	Wall-thickness risk (1–5)	Cone-type risk (1–5)	Mechanical Risk Index (lower = safer)
Korean Mini	2.10	22	1	2	3
Korean Regular	2.50	22	2	2	4
Israel Wide Systems	2.43	90	2	5	7
Israel Systems	2.43	90	2	5	7
Neodent GM	3.00	16	4	2	6
Nobel Biocare NP	2.25	24	2	3	5
Nobel Biocare Reg.	2.85	24	3	3	6
Straumann BLX	2.90	14	3	1	4
Straumann BLT	4.10	30	5	3	8
MegaGen AnyRidge	2.30	10	1	1	2
ROOTT	2.05	10.3	1	1	2
MegaGen BlueDiamond	3.10	16	4	2	6

Best-to-Worst Ranking

Ordering the systems from lowest to highest MRI (best to worst mechanical risk) produces the following ranking:

1. **MegaGen AnyRidge (MRI = 2)** – 2.3 mm hex with a 5–10° Morse taper across all diameters; this combination maximizes wall thickness and frictional locking.^{[13][14][15]}
2. **ROOTT (MRI = 2)** – Very small internal hex with a 10° internal cone, providing a high section modulus and Morse-like conical engagement.
3. **Korean Mini (MRI = 3)** – Small 2.1 mm hex and moderate 22° bevel; mechanically favorable geometry despite butt-joint tendencies.
4. **Korean Regular (MRI = 4)** – Slightly larger 2.5 mm hex and 22° platform bevel; still relatively robust.

5. **Straumann BLX (MRI = 4)** – 2.9 mm internal geometry with a low-angle internal cone; internal diameter is larger but cone behavior offsetting part of the wall-thinning penalty.[⁷][28]
6. **Nobel Biocare NP (MRI = 5)** – Narrow-platform conical connection ($\approx 24^\circ$) with a modest internal diameter; good balance of wall thickness and conical engagement.[²⁵][26][¹⁶]
7. **Neodent GM (MRI = 6)** – 3.0 mm internal connection with 16° cone; excellent conical engagement but reduced wall thickness at small diameters.[⁸][9][³²]
8. **Nobel Biocare Regular (MRI = 6)** – 2.85 mm internal cone at 24° ; mechanically strong but penalized by larger internal diameter.[²⁷][26][¹⁶]
9. **MegaGen BlueDiamond (MRI = 6)** – 3.1 mm X-FIT connection with 16° – 30° conical/octagonal structure; thick implant walls in larger diameters mitigate risk, but internal diameter is relatively large.[³⁰][31][¹²]
10. **Israel Wide Systems (MRI = 7)** – 2.43 mm internal hex with a 90° butt-joint platform; lack of conical engagement increases reliance on screw preload and elevates risk under off-axis fatigue.
11. **Israel Systems (MRI = 7)** – Similar internal hex and 90° platform; same considerations as above.
12. **Straumann BLT (MRI = 8)** – Very large effective internal geometry at the platform (4.1 mm) with a 30° bevel; high wall-thickness risk despite conical elements.

It is important to emphasize that this ranking is **relative and geometry-driven**, not an absolute statement on clinical success or overall system quality.

Systems with higher MRI values may still perform excellently in many clinical situations, particularly when used within their indicated diameter ranges and under controlled loading conditions.

Interpretation and Clinical Implications

Alignment with Existing Evidence

The MRI ranking aligns with the broader biomechanical literature in several respects:

- Systems featuring low-angle internal cones and small internal hexes (ROOTT, AnyRidge) occupy the most favorable positions, consistent with evidence that Morse-type internal cones improve preload maintenance, reduce micromovement, and decrease mechanical complications relative to butt-joint connections.[¹][18]
- Systems with larger internal diameters but robust conical interfaces (Neodent GM, BlueDiamond, Nobel conical connections, Straumann BLX) fall into intermediate risk categories, reflecting the trade-off between improved load transfer via the cone and reduced wall thickness.[⁸][9][¹²][16]

- Butt-joint internal hex systems with comparatively large internal diameters and flat platforms occupy the highest risk categories, in agreement with studies reporting greater torque loss, higher microleakage, and increased susceptibility to screw-dominated failure under cyclic off-axis loading.^{[17][2][^3]}

Application in Case Planning

The MRI should be used as one input among many when selecting an implant system or platform size for a given clinical scenario.

Potential applications include:

- **Immediate full-arch or high-load cases:** Favor low-risk MRI connections (2–4), especially in posterior regions or when long cantilevers are unavoidable.
- **Narrow-diameter implants in the posterior mandible:** Exercise caution with higher-MRI systems, as bone-level designs below 3.5 mm have shown lower fatigue life and earlier failure in simulations and fatigue tests.^{[21][6][^20]}
- **Single units in low-load anterior regions:** Higher MRI values may be acceptable when occlusal forces and bending moments are modest, provided other factors (emergence profile, restorative flexibility) are favorable.

The framework also supports **cross-system comparison** when clinicians are compelled to mix platforms (e.g., in full-arch rescue cases) by highlighting where mechanical margins are relatively narrow and where more robust geometries can serve as “anchor” positions.

Limitations

Several limitations must be acknowledged:

- The MRI uses internal hex diameter and nominal platform angle as proxies for section modulus and conical engagement; it does not explicitly model outer implant diameter, thread geometry, alloy, or bone–implant interaction.
- Manufacturer-reported geometrical data and diagram-based measurements may introduce minor inaccuracies; however, the scoring bins are broad and designed to remain robust against small measurement errors.
- The index does not incorporate biological factors (surface, macro-design, platform switching) or patient-specific variables (bone quality, parafunction), which also influence long-term outcomes.^{[1][2]}

- Existing fatigue and clinical data for some proprietary systems are limited or published primarily in manufacturer-sponsored sources; independent high-cycle fatigue tests for every connection considered here are not yet available.

Despite these constraints, the MRI offers a transparent, geometry-centric method that is consistent with established mechanical principles and the available evidence base.

It is intended as a starting point that can be refined as more standardized fatigue testing and long-term clinical data become available.

Conclusions

Internal connection geometry—particularly cone angle and internal hex diameter—has a measurable impact on the fatigue behavior and mechanical safety margin of bone-level dental implant systems. Published in-vitro, computational, and clinical data collectively indicate that internal conical connections with modest internal diameters provide superior resistance to micromotion, preload loss, and fatigue-related complications compared with butt-joint internal hex designs, especially under non-axial and high-cycle loading conditions.^{[1][4][6][18]}

The Mechanical Risk Index proposed in this white paper synthesizes these insights into a simple, implementable tool that allows clinicians and educators to compare connection designs across manufacturers using transparent criteria.

Within the set of systems analyzed, Morse-type internal cones with small internal hexes (ROOTT, MegaGen AnyRidge) emerge as the mechanically safest configurations, while butt-joint internal hex systems with larger platform diameters show the highest relative mechanical risk.

This framework is not a replacement for detailed engineering analysis or clinical judgment, but it provides a practical, evidence-aligned lens through which clinicians can evaluate connection choices for demanding prosthetic indications and tailor their treatment planning accordingly.

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